DETERMINATION OF THE POST-CYCLIC YIELD STRENGTH AND INITIAL STIFFNESS OF TWO PEAT SOILS

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ABSTRACT: The post-cyclic yield shear strength and initial stiffness of a peat soil after subjecting to cyclic loading is a major topic in this study. Due to the effects of cyclic loading, post-cyclic shear strength decreases lower than its initial strength. A series laboratory static and cyclic triaxial test followed by post-cyclic monotonic tests carried out to determine the yielding parameters. Tests were carried out on the undisturbed samples taken from Parit Nipah, Johor and Lumadan, Sabah within west and east Malaysia peat soils. Post-cyclic loading test conducted with effective stress 100 kPa with frequency 1.0Hz. The initial stiffness is the initial tangential modulus with yield shear strength was half of the deviator stress in which two tangential lines intersect. The post cyclic yield shear strength of undisturbed peat soil is considerably lower compared to static at the axial strain of only 1.4% and 1.5%. The Parit Nipah and Lumadan peat are classified as Hemic.

Keywords: Post-cyclic, Peat, Yield shear strength, Initial stiffness

1. INTRODUCTION

Peats occur as extremely soft, wet and unconsolidated surficial deposits. Peats are geotechnically problematic due to their high compressibility and low shear strength [1]. In a moderate load increment, it may lead to large volume changes that shows high compressibility. Deep peats exhibit high compressibility, medium to low permeability, low strength and volume instability [2]. Peats are also characterized by high initial void ratio, organic content and water holding capacity [3].

Since the main component is an organic matter, peats are very spongy, highly compressible and combustible in characteristics [4]. These characteristics make the peats to pose its own distinctive geotechnical properties as compared to other inorganic soils like clay and sandy soils which are made up of only soil particles [3]. Peats which are formed from the accumulation of organic materials over thousands of years, are characterised by its high water content, compressibility and low shear stiffness and shear strength [5]. However, the overburden pressure of peats are very low [6].

Nonetheless, the effective shear strength of peat soils are essentially a frictional material and that it behaves closely in accordance with the principles of effective stress. Past researchers conclusively explained that standard tests that consolidates undrained triaxial test with the measurement of pore water pressure does not required over 50% axial strain to fail [6]. The undrained shear strength (su) refers to the strength of soil in situations where the excess pore water pressures developed during shearing cannot dissipate and failure takes place [7]. Post-cyclic behaviour of soil is generally considered to depend on the maximum strain developed during cyclic loading [8]. Post-cyclic as tests carried out on the sample by allowing the cyclic pore pressure to develop during cyclic loading to either dissipate or without dissipation [9]. While the samples are then subjected to post-cyclic monotonic loading without dissipation of cyclic pore pressure. Post-cyclic monotonic shear strengths were evaluated after various numbers of cycles of dynamic loading [10].

The studies of post-cyclic behaviour of soils includes the loss of static undrained shear strength and strain softening of soils under cyclic loads [11]. There is a considerable reduction in the undrained strength after cyclic loading [12]. There were effects from the number of loading cycles on the test respectively involved. Similar trends were observed for the test, and it shows that there were increases with continuing loading cycles from 1 to 100 cycles [9]-[13] findings.

The initial stiffness is the initial tangential modulus, which is in turn the slope of the curve of deviator stress versus axial strain at the axial strain of 0%. To get the yield shear strength, two tangential lines were plotted [14]. The yield shear strength was half of the deviator stress at an axial strain, in which those two tangential lines intersect [15]. The shear strength and stiffness at small deformation were called as yield shear strength and initial stiffness while, the shear strength and stiffness at large deformation were called as undrained shear strength and secant modulus, respectively.

Figure 1 shows the illustration of method for determination of yield shear strength (S_y) and initial stiffness (E_i) suggested by Wang (2011). The initial stiffness is the initial tangential modulus, which is in turn the slope of the curve of deviator stress versus

axial strain at the axial strain of 0%. Two tangential lines were plotted to get the yield shear strength. The yield of shear strength was half of the deviator stress at an axial strain and intersect with two tangential lines [15]. This research work deals with a study on the post cyclic behaviour of peat soils analyzed using dynamic and static methods. The application of effective stresses and frequencies are critically reviewed using triaxial tests.
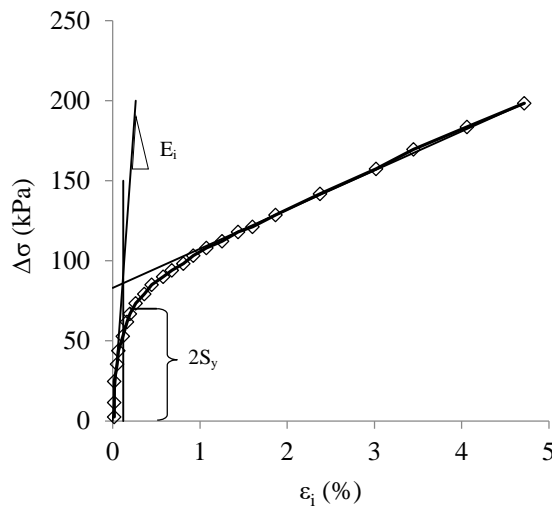

Fig. 1 Determination of yield shear strength and initial stiffness (Wang, 2011).

A series of triaxial tests were carried out to investigate the influence of dynamic loading on shear strength. The post-cyclic yield shear strength and initial stiffness of peat soil after subjecting to cyclic loading is presented in this research. The procedure used to determine the stress-strain threshold is proposed using the reduction of post-cyclic strength after 100 cycles of loading.

2. MATERIAL AND EXPERIMENTAL METHOD

This paper had conducted investigation on the post-cyclic shear strength of peat soil. All tests have been conducted using undisturbed peat soil specimen. The sampling location was located in Parit Nipah, Johor and Lumadan, Beaufort, Sabah. Ground water table was found at the depth of less than 1 meter during the sampling.

The soil was excavated to a depth of 0.5 m below the ground surface and numbers of tube sampler with the size of 50mm diameter and 100mm height were pushed slowly into the soil. The undisturbed peat soils were waxed both at the end of the tubes and sealed with the aluminium and plastics to prevent the loss or gain of moisture. Jolting during transport was avoided. The samples were kept in the laboratory under constant temperature in the air conditioned room. Dynamic triaxial apparatus or popularly

known as Dynamic Triaxial Testing System (ELDYN) was used in the determination of shear strength of peat soil using an electronic controlled system. Sample preparation for the post-cyclic triaxial test is similar to the monotonic test.

The specimens was mounted on the base of the pedestal sealed with a rubber membrane and ends with filter paper and porous stone at each end. All samples were consolidated 100 kPa effective confining stress and cyclic tests were performed under 1.0 Hz frequency in order to determine the shear strength. The index properties tests conducted on undisturbed specimens.

Monotonic loading was seriate applied at a 0.10mm/minute loading rate, and lasted till the soil specimens exhibited an axial strain of 20%. The specimens were subjected to 100 cycles. After cyclic loading, the specimens were immediately subjected to post-cyclic loading or known similar to standard consolidated undrained triaxial monotonic loading to failure. Peat sample was obtained from Malaysia peat deposit area. Under reserved land area and far from agricultural activity.

As seen in Table 1, the index properties of Parit Nipah fairly significant that natural moisture content is about 593% higher than Lumadan peat about 455.51%. The natural water content of peat in Malaysia ranges from 200 % to 700 % and with organic content in the range of 50 % to 95 % [1]. Therefore, the recorded values for Parit Nipah and Lumadan fulfil this statement. Specific gravity recorded 1.3 for Parit Nipah and Lumadan recorded 1.37 were within the range as reported by [1]. In addition to basic characterization tests, the Parit Nipah and Lumadan peat identified as Hemic.

Table 1 Index properties of peat soil

Properties	Lumadan	Parit Nipah
Moisture content, %	455.51	593
Liquid limit w_l, %	211	243
Specific Gravity, G_s	1.37	1.3
pH test	4.3	4.0
Organic Content, %	95.51	95.6
Fiber Content, %	66	38.5
Von Post Scale	H7	H5

3. DETERMINATION OF YIELD STRENGTH AND INNITIAL STIFFNESS

In order to evaluate the post-cyclic yield strength and initial stiffness, an extensive series of static and cyclic tests were carried out on large 50 mm diameter cylindrical specimens of peat soil materials using consolidated undrained triaxle tests and followed by post-cyclic shear test after cyclic loading. This paper

presented the behaviour of peat soil subjected cyclic loading and effect to post-cyclic shear strength while compared to static results. The shear strength and stiffness at small deformation were called as yield shear strength and initial stiffness, respectively and the shear strength and stiffness at large deformation were called as undrained shear strength and secant modulus [14]. This research carried out to study the shear strength and stiffness at small deformation. Static results are compared to the post-cyclic shear strength and stiffness. The reduction of shear strength and stiffness measured and there are significant behaviour when peat imposed with cyclic loading.

Figure 2 shows the consolidated undrained static results for both sample. Parit Nipah peat has maximum shear strength at 92.04 kPa and higher than Lumadan peat where about 58.44 kPa. The variations of index properties of both sample resulting in different shear strength property. The West Malaysia peat moisture content varied in the ranges 676.30% to 735.45% [16] while, 710.44% [17], 460% [18]. Undoubted, tropical peat has high water content and most of peat deposit are in moderately decomposed condition. However, the shear strength of intact peat is made up of interparticle friction as well as tension in the peat fibres [19].
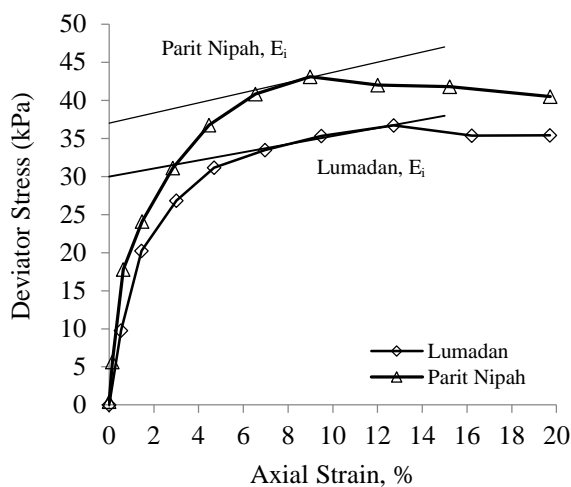

Fig. 2 Consolidated undrained static results

This study focuses on the shear strength and initial stiffness of peat soil in post-cyclic behaviour. Figure 3 shows the results of consolidated undrained post-cyclic for both sample. This test carried out after 100 numbers of cycles in dynamic stage. This test similar to static test arrangement. From the results, it can be seen clearly that, the shear strength of peat significantly decreased when subjected to cyclic loading. This statement in line with [16] where, the shear strength of peat soil decreased after 100 number of cyclic loading in post-cyclic compared to the monotonic tests and post-cyclic peak shear strength decreased substantially with frequencies applied.

Table 2 indicates the initial stiffness and shear strength (Sy) results for static and post-cyclic test conducted. In post-cyclic, Lumadan peat shear strength 21.55 kPa, decreased compared to static about 29.37 kPa. This reduction of shear strength Lumadan peat fairly lost in shear strength about 26.63% from the initial strength. Parit Nipah peat in certain patterns keep popping up in same behaviour. Those relationship offers decreases in shear strength after subjected to cyclic loading. Initial shear strength of Parit Nipah peat 46.02 kPa, decreased to 60.13% and remaining shear strength about 18.35 kPa. The static undrained shear strength decreased significantly after 15 loading cycles and softening behaviour occurred when the specimen exhibited ± 1.5% axial strain [10]. The initial stiffness (E_i) of both samples expressly decrement in post-cyclic compared to static results. The reduction of initial stiffness of Lumadan and Parit Nipah peat about 60.80% and 31.92%, respectively. The initial stiffness slope tangential get passes through the curve of deviator stress and pointed 10.45 for Lumadan peat and 10.73 for Parit Nipah.

Tangential slope for both sample almost closed where the curves derived from deviator stress in post-cyclic notched same patterns. The decrement of initial stiffness due to cyclic loading. On the other hand, if peat soil has experienced cyclic loading, the deformation of soil structure and alteration of void will resulted in decreasing in yield shear strength.

The existence of yield strength, where softening starts, is determined from post-cyclic tests. The level of post-cyclic yield strain occurred in ±0.62% of axial strain for Parit Nipah peat and ±0.58% for the undisturbed peat soils. The shear deformations increase rapidly in post-cyclic, exceeding the curves after 9%. The reduction properties of initial stiffness and yield shear strength due to soil softening during cyclic loading. Softening behaviour occurred after 12 cycles, in this study the softening behaviour outgrow at 100 number of cycles [10].
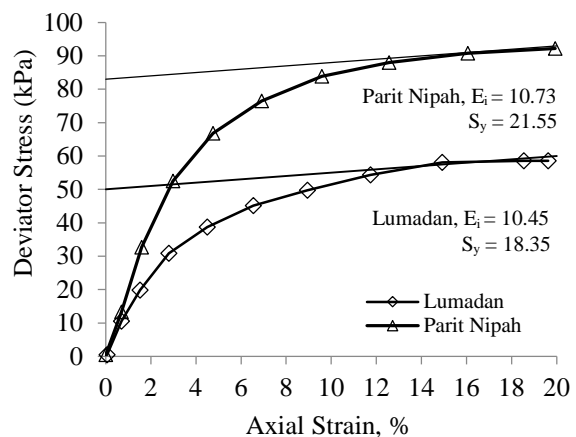

Fig. 3 Consolidated undrained post-cyclic results

Table 2 Initial stiffness and shear strength results for static and post-cyclic

Test	Location	Initial stiffness (E_i)	Shear strength (S_y)
Static	Lumadan	26.66	29.37
	Parit Nipah	15.76	46.02
Post-cyclic	Lumadan	10.45	21.55
	Parit Nipah	10.73	18.35
Reduction (%)	Lumadan	60.80	26.63
	Parit Nipah	31.92	60.13

Yield shear strength decreases by the number of cyclic loadings, and exceeds a failure limit in 100 cycles with 9% and 12% of an axial strain for Lumadan and Parit Nipah peat. Allowing the deviator stress developed an increase during post-cyclic loading, initial stiffness decrease significantly and more pronounced in knee point at the axial strain of only 1.4% and 1.5% intersect in turn the slope of the curve of deviator stress until the end of the test.

4. EFFECTS TO YIELD STRENGTH

In this research, there is relevance behavioural effects through the cyclic loading parameters. To further evaluate the post-cyclic shear strength degradation due to restructuring effects from cyclic loading, the undrained yield shear strength (Su) and secant modulus, Esec for stiffness studied. The post-cyclic undrained shear strength determined from stress-strain behaviour as illustrated in Figures 3. The determination of undrained yield shear strength parameters was measured to be half of the deviator stress at critical state. This state which have discussed [14], the undrained yield shear strength at which there is no change in deviator stress with continued axial strain. While, the secant modulus is the ratio of deviator stress to axial strain, at which the deviator stress is equal to one half of deviator stress at critical state [20].

Figure 4 presents the undrained shear strength, Su (kPa) and frequency, 1 Hz applied at effective stress, $\sigma' = 100$ kPa for Parit Nipah and Lumadan peat. It has been observed that, the undrained shear strength upon reaching maximum axial strain at 20%, the undrained shear strength decreased against frequencies that applied. The undrained shear strength of the post-cyclic peat soil for Parit Nipah is higher compared to Lumadan. These variation of undrained shear strength results observably in line with the findings where, index properties of each

sample from different locations are varied. The shear strength degradation in post-cyclic mainly causes by cyclic loading history which is related to the degradation in Young's modulus, E represents stiffness of both peat soils, where the computed elastic parameter appears then to be a deceleration in the growth of Young's modulus that leads to deficiency of stiffness and degradable of elastic behaviour in the range of this research's peat soil. This is clearly showed that, the cyclic loading cause's reduction in cohesion of peat soil in line with degradation of stiffness.
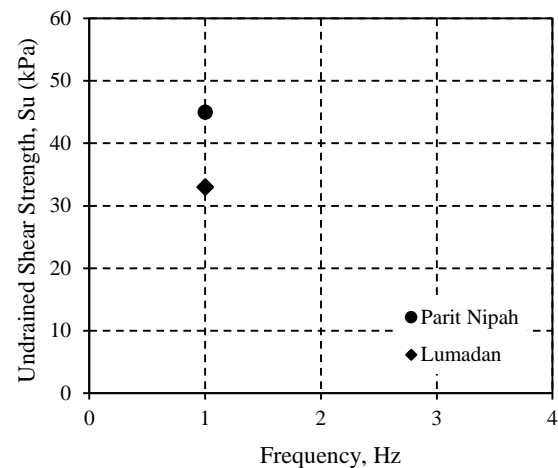

Fig. 4 Undrained shear strength, Su (kPa) and Frequencies, Hz Applied at Effective Stress, $\sigma' = 100$ kPa

This phenomenon occurs due to the dilative behaviour during cyclic loading. The secant modulus or stiffness (E_{sec}) for all specimens reflects decrement. Shear strength decreased more with than secant modulus. The post-cyclic yield shear strength of undisturbed peat soil is considerably lower compared to static while cyclic loading are imposed to specimens after 100 numbers of cycles.

The reduction of shear stress and shear stress ratio is significant when the peat soil specimen imposed with number of cycle, N = 100 cycles that enough to change the structure of peat soil and reaches a certain yield strain level under the same stress amplitude.

The reduction in shear strength and shear stress ratio considerably higher depending on the toughness of frequency and effective stress applied that formed amplitude and strain acts. In general, peat soil subjected to cyclic loading exhibit reduction in shear strength with the cyclic shear stress history.

The cyclic triaxial loading test which simulates a various dynamic loading from traffic loading, wave, earthquake and machineries are related to the fibrous condition of peat soil itself. A comparison of the stress-strain behaviour during the post-cyclic tests with the stress-strain behaviour during the monotonic tests has been plotted and it has been observed that,

the post-cyclic stress-strain behaviour of consolidated undrained peat soil from all samples shows the diminution behaviour compared to its initial behaviour in static test with axial strain increasing as the specimens heads towards the hardening and softening analogous under post-cyclic monotonic loading.

Shear strength decreased and notched lower strength than its initial strength. Author also observed the decrease in pore pressure during post-cyclic loading has induced highly strength reduction and dilate upon loading to failure. The pore pressure generation seems to depend on the different loading frequencies and rely on amplitude levels that generated in cyclic loading stage.

The secant modulus, Esec of post-cyclic monotonic test shows a significant. There are enlargement and expansion occurs in stress-strain behaviour curves that leads to the sharpness of gradient and automatically increase the secant modulus in post-cyclic. The causes of the declined in secant modulus, the effect of fibre content on the cyclic strain and amplitude imposed on the sample are discussed to explain the role of index properties towards post-cyclic stress-strain behaviour. For the fibre content, it is realized that in undrained shear strength, Su(pc)/Su(c) does not change considerably.

The trend remained same as the decreases pattern in stress-strain behaviour and the root causes are related to the amplitude and maximum strain effects.

5. CONCLUSION

In summary, the main contributions to research in the determination of the post-cyclic yield shear strength and initial stiffness of Lumadan and Parit Nipah peat soil can be included as follows:

1. The post cyclic yield shear strength of undisturbed peat soil is considerably lower compared to static while cyclic loading are imposed to specimens after 100 numbers of cycles.
2. The initial stiffness of post cyclic of peat soil is governed by the softening behaviour that occurred when the specimen exhibited ± 1.5% axial strain.
3. The level of post-cyclic yield strain occurred in ±0.62% of axial strain for Parit Nipah peat and ±0.58% for the undisturbed peat soils.
4. Cyclic loading causes deformation of soil structure and alteration of void will resulted in decreasing of yield shear strength.

6. ACKNOWLEDGEMENT

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