

Shear Strength Parameters of Cement Stabilized Amorphous Peat of Various Water Additive Ratios at Different Natural Moisture Contents under Consolidated Undrained Triaxial Test

A Rahmi, SNL Taib, F Sahdi, MJ Mapplati, MK Ghani

Abstract: Peat is a problematic soil which has a low shear strength characteristic. Addition of cement can improve the properties and strength of peat soil. This paper presents the findings of the shear characteristic of cement stabilized amorphous peat under consolidated undrained (CU) triaxial test. Three different natural moisture contents of peat which are 1210%, 803% and 380%, were stabilized using cement with water to additive (W/A) ratio of 2.0 and 3.0. CU triaxial test was conducted to the specimens after cured for 90 days. The shear parameters and characteristics were investigated towards the change of W/A ratio of the samples with different moisture contents. The result shows that the stabilized peat specimens exhibited ductile behavior and were sensitive to the over consolidation. The total and effective cohesion (c_{cu} , c') of the stabilized peat were found to be greater at W/A ratio of 2.0 compared to W/A ratio of 3.0, and greater at lower initial moisture content specimens. The total and effective friction angles (ϕ_{cu} , ϕ') are ranged from 14° to 27° and 36° to 47° consecutively and found to be increased upon the increase of W/A ratio except for the specimens with moisture content 1210% and 803% in term of total friction angle.

Keywords: cement-stabilized peat, consolidated-undrained triaxial, peat, shear parameters, water to additive ratio.

I. INTRODUCTION

Peat is considered as a problematic soil due to the weak characteristic to support built structures, including the high moisture content, low shear strength, low bearing capacity, high compressibility, etc. Cement stabilization is one of the solutions to solve the geotechnical problems. Many studies had proved that the peat shear strength can be improved by adding cement ([1], [2]). However, there is still a lack of study of cement-stabilized peat strength shear characteristic. This paper presents the shear characteristics and parameters of cement stabilized amorphous peat obtained from consolidated undrained (CU) triaxial test. From the previous studies, the behavior of saturated peat can be observed according to the principle of the effective stress as in the inorganic soils [3]. Fibrous peat has a low cohesion, high friction angle, and greater undrained strength parameters compared to those of inorganic soils caused by the effect of the tension in fibers ([3]–[6]).

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Long [7], and Mesri and Aljouni [8] found the friction angles of fibrous peat are ranged from 40° to 60° . For the cement-stabilized fibrous peat, Hwa [6] found that the specimen with lower moisture content achieved higher strength. The strength increased as the confining pressure increase for both untreated and treated specimens [6]. The cement-stabilized peat stress-strain behavior under consolidated undrained test depends on the effective confining pressure given [4].

Several studies had been carried out to investigate the fibrous peat strength parameters, thus, further investigation of the behavior and strength parameters of the other types of peat is needed. In this study, consolidated undrained triaxial test was conducted to study cement-stabilized amorphous peat of different initial moisture content with different water to additive (W/A) ratio.

II. MATERIAL AND METHOD

Peat sample was taken from Kampung Meranek, Sarawak, Malaysia from 0.5-1 m depth below the surface. Peat sample that transported to the laboratory, was kept in a sealed container. Disturbed amorphous peat samples were sieved through 6.63 sieve. Soil investigations were conducted to get the soil properties of the peat.

Samples were air-dried until it reached the desired moisture content in order to make the sample of varied moisture contents (1210%, 803%, and 380%). In this research, the moisture contents varied in the gap of $\pm 400\%$ to investigate the differences of the behavior of the peat with different moisture contents. To reach the desired moisture content, peat cannot be dried by oven and added water afterwards. It is because once peat is dried, losing its moisture content, and added water afterwards, it will not have the same moisture content as before [9]. Thus, the peat samples must be air-dried.

For each sample of different natural moisture contents, cement was added with the water additive (W/A) ratio of 2.0 and 3.0. All of the samples were air-cured for 90 days before tested for consolidated undrained triaxial test. Peat with the initial moisture content of 1210%, 803%, and 308% later are referred as peat A, B, C consecutively.

Triaxial test carried out in consolidated undrained (CU) condition based on ASTM 4767 guidelines. The test was run in three phases, saturation, consolidation, and shearing phases. The saturation ratio (B) above 0.95 is considered saturated. During the consolidation phase, three initial effective stresses used were 50, 100, and 200 kPa. Constant rate of strain in shearing phase was maintained at 0.13% per minute until 40% axial strain was reached ($\epsilon_a = 40\%$).



III. RESULT AND DISCUSSION

A. Soil Properties

Table- I shows the physical properties of the untreated peat sample. The fiber content and degree of decomposition results show that the peat sample can be classified as an amorphous peat based on ASTM D4427 [10]. Peat has a high initial water content, high liquid limit, and high organic content. The peat is highly acidic with pH 3.31.

Table- I: Physical properties of Kampung Meranek peat

Properties	Values
Degree of decomposition	H7-H8
Moisture content (%)	1210.497
Specific gravity	1.408
Liquid limit (%)	458
Linear shrinkage (%)	27.338
Organic content (%)	95.793
Fiber content (%)	32.333
pH	3.31

B. Consolidated undrained triaxial test result

Table- II shows the specimen labelling for the samples used in this research. Table- III shows the summary of axial strain and deviator stress at failure, and undrained shear strength S_u from the specimens tested. The axial strains at failure range from 6% to 16 % for stabilized specimens. The peak deviator stress shows increment upon the increase of the effective confining pressure except for stabilized peat C specimens with W/A ratio 2.0. This might be caused by undesirable disturbance while preparing the specimen, thus affected the deformation behavior in the test result. The peat C specimens with W/A ratio 2.0 at confining pressure 200 kPa is taken as an anomaly. Peak deviator stresses for specimens with W/A ratio 2.0 are higher compared to W/A ratio 3.0 for almost all of the specimens.

Table- II: Specimen labelling

Specimen label	Initial moisture content (%)	W/A ratio
CU-A-2.0	1210	2
CU-A-3.0	1210	3
CU-B-Un	803	-
CU-B-2.0	803	2
CU-B-3.0	803	3
CU-C-Un	380	-
CU-C-2.0	380	2
CU-C-3.0	380	3

*Un=Untreated

Table- III: Summary of CU Triaxial results

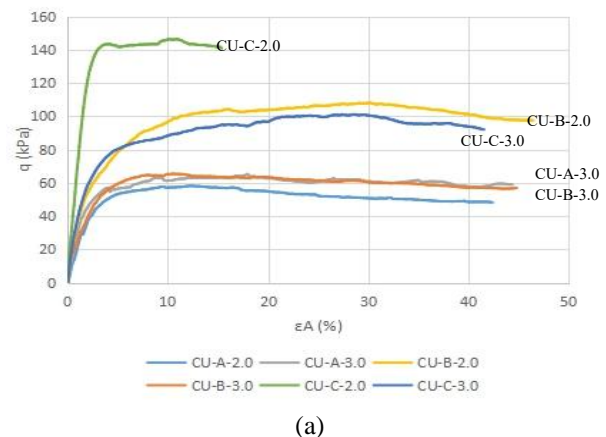
Specimen	Initial moisture content (%)	Effective confining pressure (kPa)	Axial strain (%)	Peak deviator stress (kPa)	Undrained shear strength, S_u (kPa)
CU-A-2.0	1210	50	12.188	58.23	29.115
		100	11.452	149.276	74.638

CU-A-3.0	1210	200	11.877	310.607	155.304
		50	13.09	63.228	31.614
		100	16.002	134.43	67.213
CU-B-Un	803	200	13.023	263.04	131.519
		5	15.586	11.594	5.797
		10	30.784	13.68	6.84
CU-B-2.0	803	15	42.455	22.401	11.201
		50	15.881	104.282	52.141
		100	12.801	173.652	86.826
CU-B-3.0	803	200	14.657	372.374	186.187
		50	10.495	65.423	32.712
		100	12.509	155.43	77.715
CU-C-Un	380	200	7.361	237.159	118.58
		5	3.521	13.364	6.682
		10	15.115	31.937	15.968
CU-C-2.0	380	15	19.356	50.463	25.231
		50	10.952	146.602	73.301
		100	14.058	179.823	89.914
CU-C-3.0	380	200	10.577	112.189	56.095
		50	16.049	95.186	47.593
		100	6.769	180.215	90.108
		200	12.293	268.728	134.364

C. Stress, Excess Pore Pressure-Strain Relationship

Fig. 1(a) shows the stress-strain graph of the shear phase at confining pressure of 50 kPa. Ductile behavior is observed from the sloping strains for all specimens. Peat C specimens with W/A ratio 2.0 achieved the highest shear strength of all. For peat A specimen, W/A ratio 3.0 performed better than 2.0. Meanwhile, for peat B and C specimens, W/A ratio 2.0 performed better than 3.0. The deviator stress remains constant after the peak strength as also found by Dhowian and Edil [4].

Fig. 1(b) shows the change in pore pressure and strain relationship. There are two different patterns of graph observed. For peat A and B specimens at W/A ratio 3.0, the pore pressure change keeps increasing along with the strains. This pattern resembles a typical normally consolidated clay change in pore pressure under applied stress explained by Bishop & Henkel [11]. Meanwhile, for the rest of the specimens, the pore pressure change is decreasing after reaching the peak, which resembles a typical over consolidated clay.



(a)

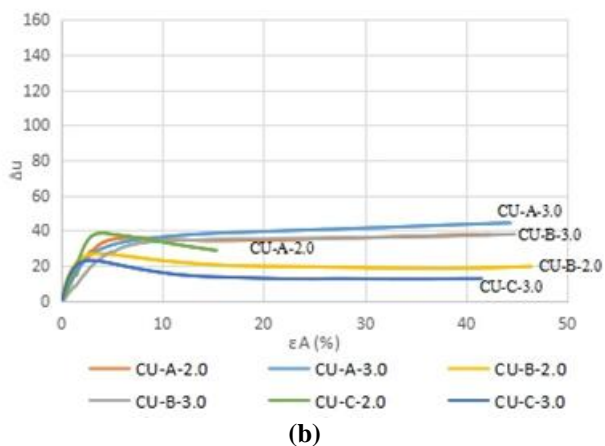
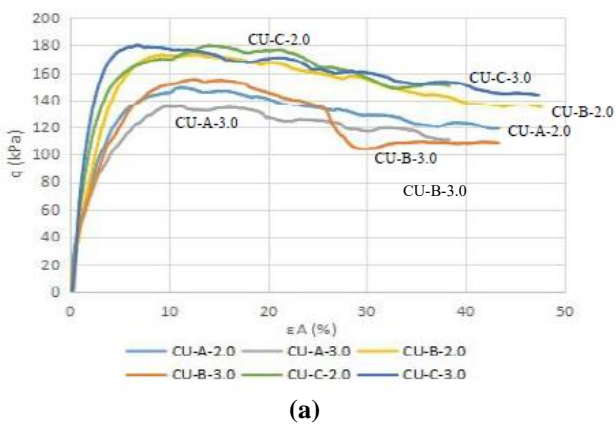


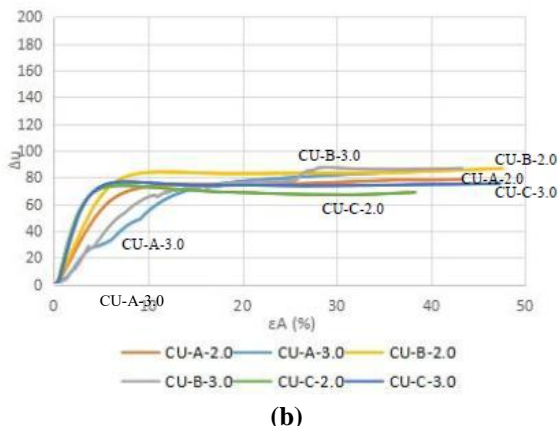
Fig. 1 Specimens with 50 kPa of confining pressure
(a) stress-strain relationship; (b) pore pressure change vs strain

Fig. 2(a) shows the stress-strain graph of the shear phase at confining pressure of 100 kPa. Similar to the previous graph, the ductile behavior is observed for all specimens. The shear strength achieved by all of the specimens seem close in value. Peat A and B specimens with W/A ratio of 2.0 performed better than 3.0, while peat C specimens performed almost the same for both W/A ratio.

From the pore pressure change graph (Fig. 2(b)), peat A and B with W/A ratio 3.0 show a normally consolidated soil behavior just like the previous graphs of pore pressure change at 50 kPa confining pressure. Meanwhile, the rest of the specimens show an over consolidated behavior.



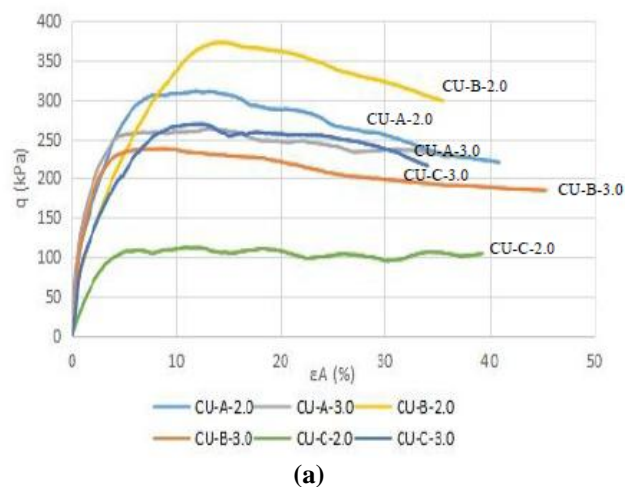
(a)



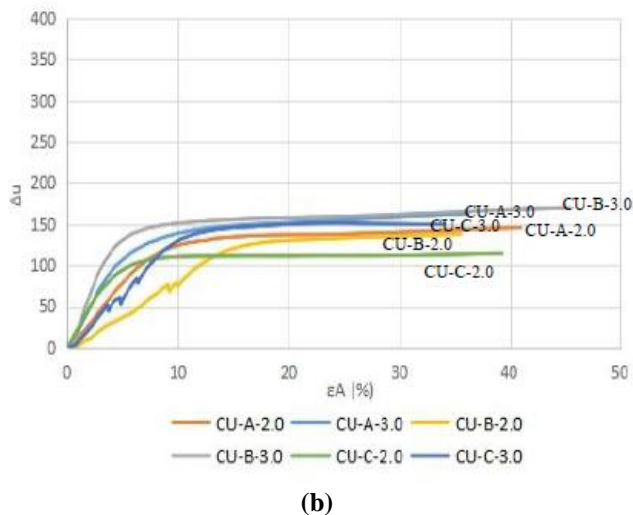
(b)

Fig. 2 Specimens with 100 kPa of confining pressure
(a) stress-strain relationship; (b) pore pressure change vs strain

Fig. 3(a) is as much the same as the two previous graphs. For every specimen, W/A ratio 2.0 performed better than W/A ratio 3.0. From the Fig. 3(b), every specimen shows a normally consolidated behavior.



(a)



(b)

Fig. 3 Specimens with 200 kPa of confining pressure
(a) stress-strain relationship; (b) pore pressure change vs strain

From the graphs, it can be observed that the shear behavior is sensitive to over consolidation as mentioned by Cola and Cortellazo [12]. Cola and Cortellazo [12] also concluded that the pore pressure is affected by the over consolidation level shown by the lower pore pressure of over consolidated specimens compared to normally consolidated ones which also found in the graphs in this study.

D. Shear Strength Parameters

Shear strength parameters obtained by plotting the p' and q value from triaxial data. The cohesion of stabilized specimens is greater compared to the untreated specimens. It means that stabilization successfully contributes to the increase of the peat strength, even though the number is still quite small in peat A and B. It might be caused by the excessive moisture content and the cement added as stabilizer does not yet reach the threshold of the cement amount needed to stabilize the peat.

The cohesion (c') values of the stabilized specimens increase over the decrease of the initial moisture content. The highest cohesion value obtained by stabilized peat C (w 380%), followed by stabilized peat B (w 803%), and the last is stabilized peat A (w 1210%). Lower W/A ratio gave greater cohesion for both drained (effective failure envelope) and undrained conditions (total failure envelope) (c' , c_{cu}), which mean that more cement add more strength. The lower cohesion obtained from the undrained condition compared to those of the drained condition shows that the stabilized soil strength under the undrained condition is not fully developed.

Peat has a high friction angle. The high friction angle likely obtained because of the fiber presence inside the peat which does not represent the real strength of the peat because the fiber might be decomposed or broken off at some point. The friction angle (ϕ') of the stabilized specimens is lower than original specimens, which ranges from 36.648° to 47.321° . It might be caused by the replacement of some of the fiber with cement. For the same specimen with the same initial moisture content, higher W/A ratio achieved higher friction angle (ϕ'). The friction angle of undrained condition (ϕ_{cu}) gave a lower value compared to the effective friction angle (ϕ') and in contrary, lower W/A ratio gave a higher ϕ_{cu} , except for peat C specimens. Overall, stabilized peat specimens with higher initial moisture content gave higher friction angle. The strength parameters values are summarized in Table- IV.

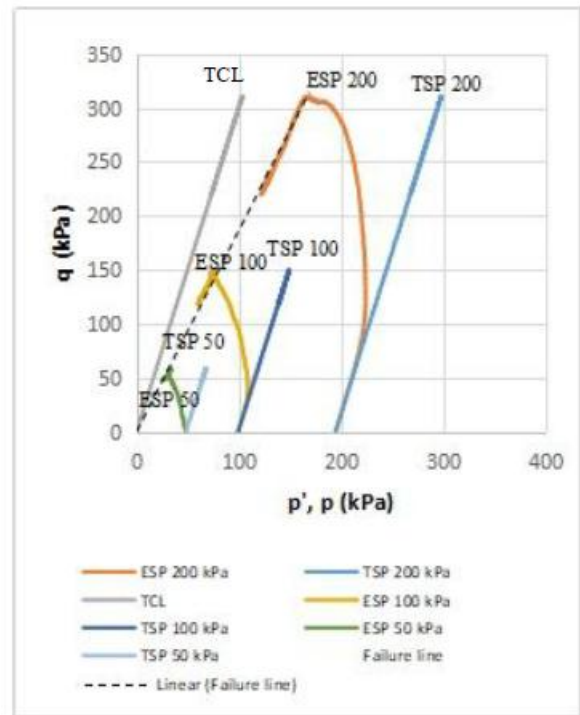
Table- IV: Summary of the strength parameters

Specimen	Initial moisture content (%)	Effective failure envelope		Total failure envelope	
		c' (kPa)	ϕ' ($^\circ$)	c_{cu} (kPa)	ϕ_{cu} ($^\circ$)
CU-A-2.0	1210	1.751	44.687	0	27.222
CU-A-3.0	1210	0.008	47.321	0	23.34
CU-B-Un	803	0	78.783	1.5	20.797
CU-B-2.0	803	5.126	43.576	4	26.739
CU-B-3.0	803	0.975	45.124	3	21.455
CU-C-Un	380	0	59.322	0	30.955
CU-C-2.0	380	60.82	36.648	42	14.381
CU-C-3.0	380	11.072	42.578	13	27.222

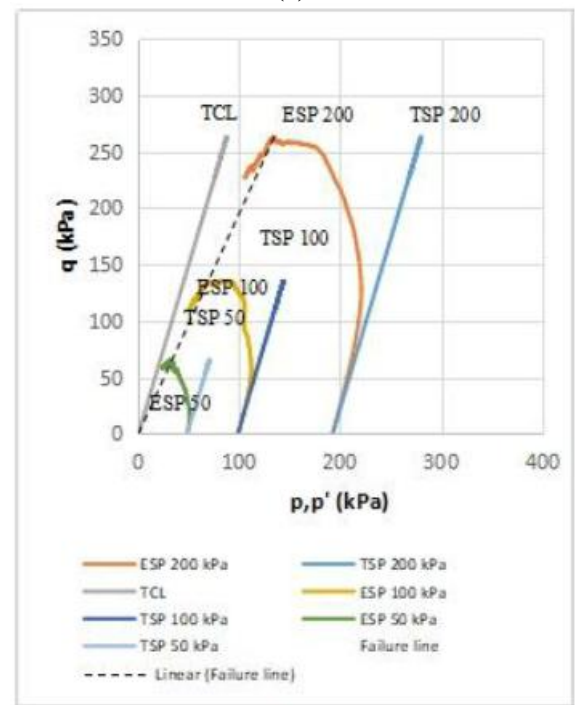
E. Shear path

Shear path of the tested specimens is shown in Fig. 4, Fig. 5, Fig. 6. The shear path connecting the stress points and shows the characteristic and behavior of the soil. Total stress path (TSP), effective stress path (ESP), and the tension cut-off line (TCL) are presented in the graphs.

Fig. 4 shows the stress path of stabilized peat A specimens with W/A 2.0 and 3.0. The shape of the stress path shows the shape of the typical normally consolidated behavior [13]. The dotted line shows the failure line of the specimens tested in three different confining pressures.



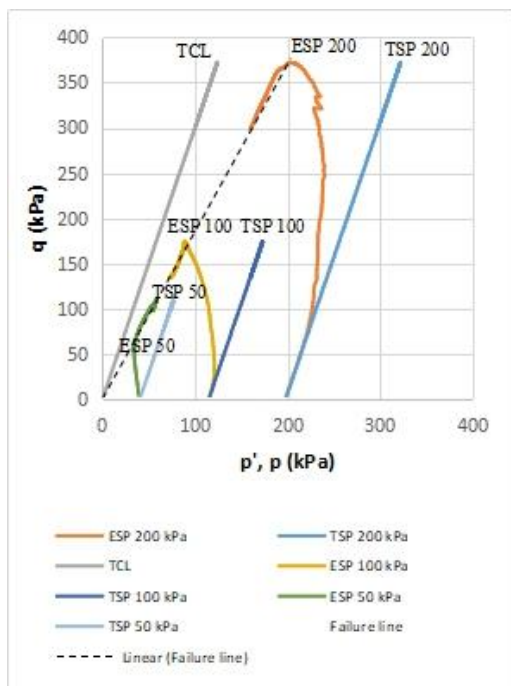
(a)



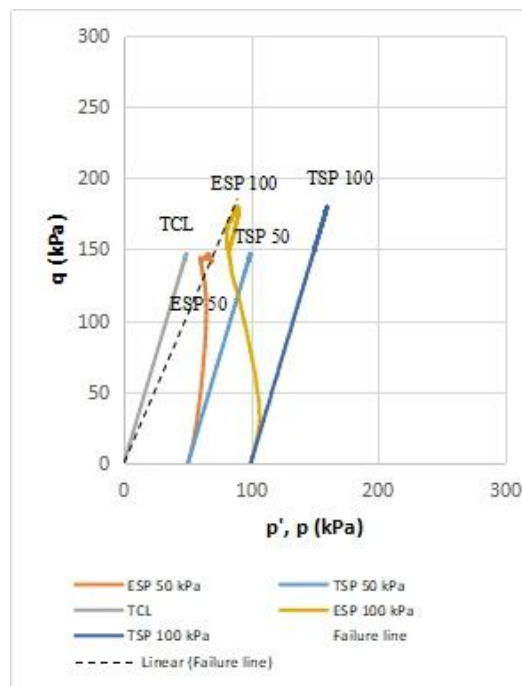
(b)

Fig. 4 Shear path of stabilized peat A specimens; (a) with W/A ratio 2.0; (b) with W/A ratio 3.0

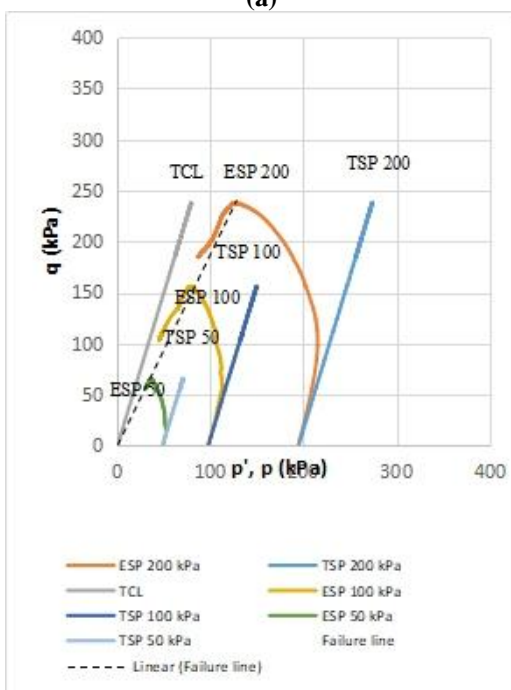
Fig. 5 shows the stress path of stabilized peat B specimens with W/A 2.0 and 3.0. The graph of stabilized peat B specimens with W/A 2.0 at confining pressure of 50 kPa shows the typical of the over consolidated behavior. Meanwhile, the rest shows the shape of the typical normally consolidated behavior.



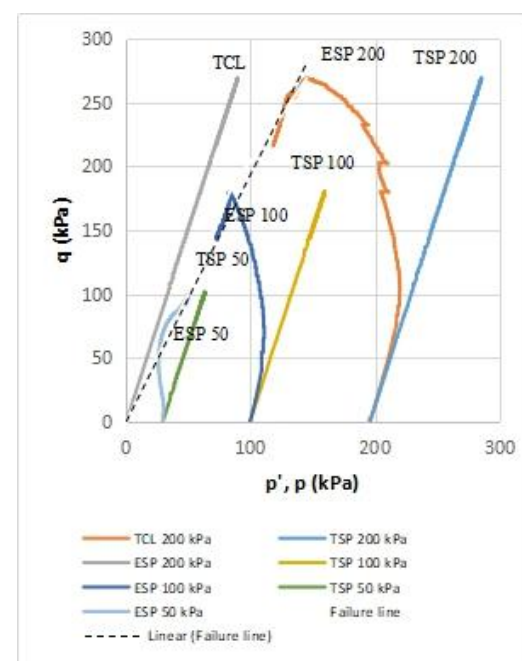
(a)



(a)



(b)



(b)

Fig. 5 Shear path of stabilized peat B specimens; (a) with W/A ratio 2.0; (b) with W/A ratio 3.0

Fig. 6 Shear path of stabilized peat C specimens; (a) with W/A ratio 2.0; (b) with W/A ratio 3.0

In Fig. 6, peat C specimens of W/A ratio 2.0 with confining pressure of 200 kPa is omitted because of the anomaly of its stress value. The remaining is showing the over consolidated behavior. The difference between the behavior of the specimens, whether it is normally consolidated or over consolidated, might be caused by the stress received by specimens during sample preparation and stabilization process. As mentioned before, the over-consolidated behavior of the specimens might be the sensitive characteristic of the peat specimens towards stress or loading.

IV. CONCLUSION

Kampung Meranek amorphous peat has a high friction angle as obtained from the CU Triaxial test. This characteristic resembles the characteristic of fibrous peat as reported by previous researchers ([3]–[6]). The decrease of friction angle in stabilized specimens compared to the untreated specimens might be caused by replacement of fiber with the cement. The friction angles (ϕ') found to be increased upon the increase of W/A ratio. However, in term of total friction angle (ϕ), it is increased upon the decrease of W/A ratio, except for peat C.

The contrary trend between total and effective friction angles shows that the moisture content plays a big role in peat friction angle which should be investigated further. The total and effective cohesion (c_{cu} , c') was found to be greater at W/A ratio of 2.0 compared to W/A ratio of 3.0, and greater at lower initial moisture content specimen. Therefore, more cement addition gives more cohesion to the peat soil. The optimum addition of the cement in peat soil in accordance to the peat moisture content should be further investigated. The stabilized peat also found to be sensitive toward over consolidation.

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