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

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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 ($c_t$, $c'$) and the total and effective friction angles ($\phi_t$, $\phi'$) 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 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]).

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 ±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 ($\varepsilon_a = 40\%$).
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 peak 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         |

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                         | 30                                 | 12.188          | 58.23                     | 29.115                                |
|          |                              | 100                                | 11.452          | 149.276                   | 74.638                                |

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.
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.

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.

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 ($\phi'$) 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 ($\phi'$). The friction angle of undrained condition ($\phi_{cu}$) gave a lower value compared to the effective friction angle ($\phi'$) and in contrary, lower W/A ratio gave a higher $\phi_{cu}$, 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.

| Specimen | Initial moisture content (%) | Effective failure envelope | Total failure envelope |
|----------|-----------------------------|---------------------------|-----------------------|
|          | $c'$ (kPa)                  | $\phi'$ (°)               | $c_{cu}$ (kPa)        | $\phi_{cu}$ (°)  |
| 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  |

**Table-IV: Summary of the strength parameters**

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.

**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.
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 ($\phi'$) found to be increased upon the increase of W/A ratio. However, in term of total friction angle ($\phi$), 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<sub>ef</sub>, 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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