INVESTIGATION INTO SHEAR STRENGTH OF PEAT

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ABSTRACT
Results of CU triaxial compression tests on remolded peat specimens retrieved from a site located in Rivière-du-Loup in Quebec, Canada are presented. The remolded specimens showed different anisotropic behavior with increasing axial strain, indicating the fibers tend to align their faces perpendicular to the direction of loading. Microstructural reconstruction of the fibers is diminishing at the end of elasticity. The anisotropic behaviour induced by specimen preparation is totally different from that by shear deformation. The pore pressure parameter 'a', and the failure mode of the remolded peat specimens exhibit great dependency on the initial mean effective confining stress, ranging between twist and bulging failure. A more reasonable procedure to estimate the shear strength of fibrous peat, incorporating the fiber reinforcement is described. It involves following the almost linear portion of effective stress path, which corresponds to the linear strain-hardening portion of the stress-strain curve. This will obtain the deviator stress by intersecting the tension cut-off line. The shear strength parameters, with an apparent angle of shearing resistance of 34º and considerable amount of effective cohesion of 4.5 kPa, thus, can be obtained. Further studies are recommended to find a better understanding of the efficiency of this method in safety evaluation of infrastructures built on fibrous peat.

RÉSUMÉ
Résultats des tests de compression triaxiale CU sur des échantillons de tourbe remoulés récupérés d'un site situé à Rivière-du-Loup au Québec, Canada. Les échantillons remoulés ont montré un comportement anisotrope différent avec une déformation axiale croissante, indiquant que les fibres ont tendance à aligner leurs faces perpendiculairement à la direction de chargement. La reconstruction microstructurale des fibres diminue en fin d'élasticité. Le comportement anisotrope induit par la préparation des échantillons est totalement différent de celui de la déformation par cisaillement. Le paramètre de pression interstitielle, «a», et le mode de défaillance des échantillons de tourbe remoulés présentent une grande dépendance à l'égard de la contrainte de confinement effective moyenne initiale, variant entre la torsion et la défaillance du bombement. Une procédure plus raisonnable pour estimer la résistance au cisaillement de la tourbe fibreuse, incorporant le renforcement des fibres est décrite. Il s'agit de suivre la portion presque linéaire du chemin de contrainte efficace, ce qui correspond à la portion de durcissement linéaire de la courbe contrainte-déformation. Ceci permettra d'obtenir la contrainte déviatrice en coupant la ligne de coupure de tension. Les paramètres de résistance au cisaillement, avec un angle effectif de résistance au cisaillement de 34 ° et une quantité considérable de cohésion efficace de 4,5 kPa, peuvent ainsi être obtenus. Des études complémentaires sont recommandées pour mieux comprendre l'efficacité de cette méthode dans l'évaluation de la sécurité des infrastructures construites en tourbe fibreuse.

1 INTRODUCTION

Peat deposits are complex natural formation, mainly consisting of organic residues derived from incomplete decomposition of dead plant constitutes under conditions of excessive moisture and water submerged (MacFarlane 1969). Peat is known as problematic soil in geotechnical engineering practice because of its extremely high compressibility, low shear strength and high potential biodegradation.

On account of the inherent anisotropic structure and relatively high tensile strength provided by the predominantly horizontally oriented plant fibers, peat soils exhibit distinct mechanical and engineering behavior. Fortunately, the fundamental mechanisms control the peat soil is similar to that of most inorganic soils. Attempts regarding determination of the shear strength of peat have been made to by not a few research workers (Hanrahan 1954; Adam 1965; Yamaguchi et al. 1985; Hendry et al. 2012; O'kelly et al. 2013).

However, the real behaviors in terms of failure conditions of peat are not well represented yet. This can be explained by the general in-situ conditions (i.e., difficulty in traffic and accessibility) and experimental challenges (limited traditional testing method) encountered on the investigation of peat material (Huat et al. 2014).

Fibrous peat specimens for the consolidated undrained triaxial compression tests studied in this paper were ordered by a third party, who retrieved it from a field site located in Rivière-du-Loup in Quebec, Canada.

Results of laboratory tests are expected to show the anisotropic behaviors of Canadian fibrous peat and

estimate the shear strength incorporating strength component derived from fiber reinforcement effect and frictional interface between the fibers and other structures that compose the peat soil.
Also, at the long-term level, the shear strength is expected to be applied in an effective stress analysis for the construction of transportation infrastructure.

2 BACKGROUND

Study on the engineering behaviors of peat has been conducted for several decades (Adams, 1961,1965; Hanrahan 1954; Macfarlane 1965; Landva and Pheeney 1980; Yamaguchi et al., 1985c; Hendry et al., 2012, 2014). There are divergent opinions with respect to the investigation on the nature, shear strength, and testing methods of peat materials. Thereby difficulties remain for engineers working with peat, particularly regarding shear strength determination. This primarily is attributed to the existence of the fibers, resulting in the ability of peat to linearly strain harden when subjecting to the axial loading. An appropriate stress level is hard to be achieved from the strength tests, much less in analyzing the mechanisms at the failure.
However, laboratory strength testing methods are the same as those used for inorganic soils in geotechnical engineering practice (Farrell and Hebib 1998). As for the shear strength of peat, it is observed the shear resistance keeps increasing at high axial strains to the extent that failure may not be achieved (Adams 1961; Yamaguchi et al. 1985; Hendry et al. 2012; O'kelly 2014). Thus, this results in the fact that fibrous peats under compression exhibits extremely high effective strength parameter(s) in the range of 40º to 60º compared to less than 35 º for mineral soils (Landva and La Rochelle 1983; Mesri and Ajlouni 2007).
As per these high apparent angles of shearing resistance, efforts have been made to separately interpret the fiber reinforcement effect and the frictional strength derived from the interface (Landva and La Rochelle 1983; Hendry et al. 2012;). Specifically, Landva and La Rochelle (1983) presented a technique to estimate the apparent increase in lateral resistance and its effect on the shearing behavior of fibrous peat. Hendry et al. (2012) proposed a procedure to estimate the interparticle frictional strength of fibrous peat.
A combination of fiber tension and frictional strength of peat is also interpreted at different levels in some published papers. For example, Den Hann and Kruse (2007) described a graphical procedure to estimate the filed-equivalent triaxial shear strength of fibrous peat by ignoring the dilative effect after phase transformation point at the compression stage. However, the mobilized fiber tension is well under-estimated with this method, which turns to be a conservative approach.
Further, peat is assumed to be normally consolidated, which is not consistent with its real state in the field. Since the low effective stresses exist in the field, most peat materials are over-consolidated to some degree, then relatively high cohesion should not be disregarded. This would also result in under-estimation of shear strength for peat.

Therefore, inspired by these previous studies, a further study resulting with a more reasonable interpretation of shear strength for peat is required.

3 TEST MATERIAL

The peat samples studied in this paper is order from a third party, who retrieved it from Rivière-du-Loup, a city with extensive peatland concentration on the south shore of the Saint Lawrence River in Quebec. Part of the trans-Canada Highway is constructed in this area, crossing a large expanse of peat soil.
Peat samples, as highly disturbed materials, were collected by flat shovels. The peat soil has a fibrous consistency, mainly consisting of sphagnum moss plant residues in light brown, shown in Fig 1.
The natural water content of prepared remolded and compressed sample was determined by oven-drying at the temperature of 105 ºC over a period of 24 h, which is expressed a percentage of dry mass with an average of 276%. This magnitude is a bit higher than that for native sample due to the additional distilled water in the process of crumbling. The organic content, indirectly determined by the loss of ignition in a muffle furnace at 440 ºC, is very high and reaches average of 93% (ASTM D2974). Fiber content of 68%, which was expressed the oven-dried mass of retained material as a percentage of dry mass at 105 ºC (ASTM D1997). However, on account of the fibrous nature, Atterberg limits can not be determined. The acidity of peat water was measured by battery operated pH meter giving value of 5.9 (ASTM D2976).
According to the von Post peat classification system (Hobbs 1986), with low degree of humification (H_3), low natural water content (B_2), high content of fine fibers (F_3), low amount of coarse fibers (R_1), low content of wood remnants (W_1), and high portion of shrub (N_3), the peat is classified as $H_3B_2F_3R_1W_1N_3$.

Figure 1. Peat soil used in this paper

4 LABORATORY TESTING METHODOLOGY

4.1 Specimen preparation

The remolded peat specimens were prepared from the remnants free of long woods or large roots. Peat soil was crumbled with addition of distilled water for thorough remolding before placing into a 50 mm diameter tube up to 170 ± 5 mm and then stirred with a steel tube by hand for 30 rounds to ensure the uniform distribution of fibers prior to subjecting to a vertical stress of 50 kPa. It usually took 15 ~ 24 hours to get the curve of settlement-versus-time flattened, in which the settlement response was right into the secondary compression stage. Specifically, settlement increases very rapidly under compression, and at elapsed time beyond 1.7 hours, approximately reaches the steady state. The vertical strain at the end of compression was 36% ± 5%. After that, the specimens were extruded from the pipe and trimmed by a very sharp razor knife to a length of 100 ± 1 mm for triaxial compression testing.

The density of the remolded specimens was in the range from 1.04 to 1.08 g/cm^3, and initial water content varied between 274% and 279%. In general, the remolded peat specimens were smooth on the surface without any defects after extrusion from the tube.

4.2 Consolidated undrained triaxial compression tests

CU triaxial compression tests were conducted according to ASTM D4767. Saturation of the remolded peat specimens was accomplished by applying a back pressure of 250 kPa and a cell pressure of slightly greater than back pressure both to an accuracy of 1 kPa. Full saturation was confirmed with pore pressure parameter, B, greater than 0.98 for all samples. The specimens were subsequently consolidated to the desired value of effective confining stress in the range 60 to 100 kPa, with a volume change device to an accuracy of 0.1 ml.

All the specimens were consolidated through the drainage passage at the top against the applied back pressure. During the consolidation stage, the pore pressure response remained elevated after several days but did level off. Therefore, the end of primary consolidation was assumed to be reached and the specimens were subsequently subjected to a displacement-controlled undrained shearing at a rate of 0.15 mm/min.

The pore pressure at the bottom of the specimen was measured using a pressure transducer to an accuracy of 1 kPa. Axial load was measured using S-shape load cell with a capacity of 453.6 kN to an accuracy of 0.1 kN, and the axial displacement was measured by an external linear variable differential transformer (LVDT) to a sensitivity of 0.01 mm, placing at the top of the triaxial cell. A total of three remolded peat specimens were tested in this paper.

5 RESULTS

For investigating the mechanical and engineering behavior of remolded peat specimens, the results of triaxial tests were presented in Figures 2, 3, and 4 in terms of stress-strain relationship, pore pressure response, and effective stress paths, respectively.

As shown in Fig. 2, the remolded peat specimens under compression exhibited linear elastic responses varying between 0.19% and 0.33% axial strain, while there was a rapid increase in the deviator stress. Also, there were gradual transitions from linear elastic responses to strain hardening response for all specimens. This behavior was previously reported by Hendry et al. (2012) in the CU triaxial test results on remolded peat specimens.

The portions of the stress path in q-p' stress space corresponding to the linear elastic behavior are almost straight lines at a slope of 3:1, which is the same as drained behavior. However, since the drainage valve has been closed, a drained response is not possible for the specimens to occur in response to shearing, then implying the over-consolidated stress state of the specimens before testing. This 'drained response' can be attributed to the reorientation of uniformly distributed fibers to a preferred orientation - that is perpendicular to the direction of the applied major principal stress.

Following the initial elastic response, the interaction between peat matrix and fibers results in the increase of q during the transition period. After yielding of this interaction, the increase in q is assumed only due to the fiber reinforcement. However, the tension is assumed to be partially mobilized by the fibers before reaching the tension cut-off line. Also, as shown in Fig. 2, the phase transformation points on the effective stress path occurred at greater shear deformation as the increasing effective confining stress. This can be explained in terms of the general increased interparticle friction between the fibers and peat matrix within the specimens as well.

Plot of variation of pore pressure (Δu) with axial strain is shown in Fig. 3. The rate of increase in Δu exhibits great dependence on the effective confining stress, specifically, the higher the effective confining stress, the greater is the rate of increase of Δu. The values of Δu continue to increase before reaching the tension cut-off line in q-p' space. There are great differences between the applied cell pressure and the values of Δu at the end of the tests, which also implies that the tension is partially mobilized by the fibers.

It is worth pointing out that the difference of the measured pore pressure at higher strains between the specimen of p_0' of 100 kPa and 80 kPa is way less than that between 80 kPa and 60 kPa. This behavior indicates that after p_0' exceeding 80 kPa, increasing p_0' has a little impact on the fiber reorientation and accompanying mobilized tension by these fibers.

After large shear-induced volume change, the specimens showed different shapes of failure, varying from twisted to bulging failure, which depended upon the magnitude of effective confining effective pressure, shown in Figures 5, 6 and 7. Specifically, with relatively low confinement, the specimen was twisted along the height. While as the confining stress increased, the lateral bulging response changed into general bulging behavior. Due to the limited number of testing, the validity of this result requires further study in the future. This can also be attributed to both the effect of end restraint and the nature of high compressibility of fibrous peat. The fibrous specimen was necked after triaxial consolidation and easily to be twisted under low confinement.

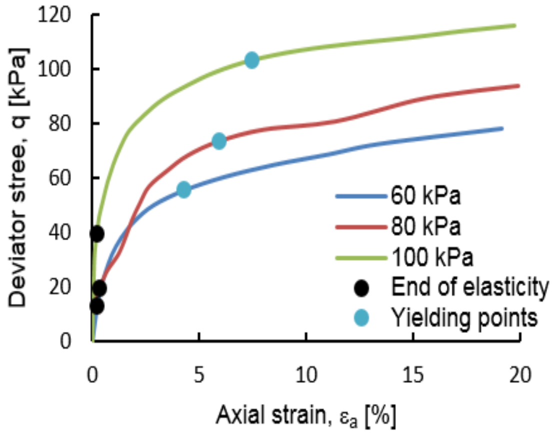

Fig. 2. Deviator stress, q, versus axial strain, ε_a

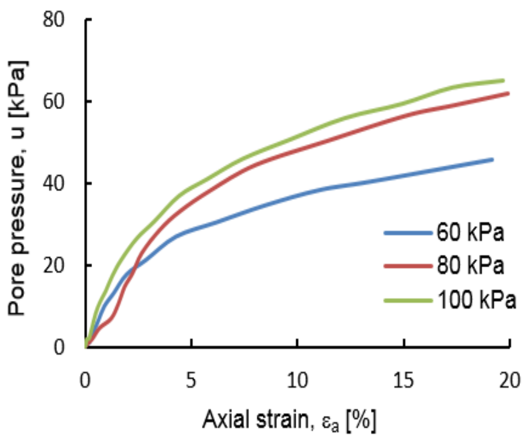

Fig. 3. Change in pore pressure, Δu, versus axial strain, ε_a

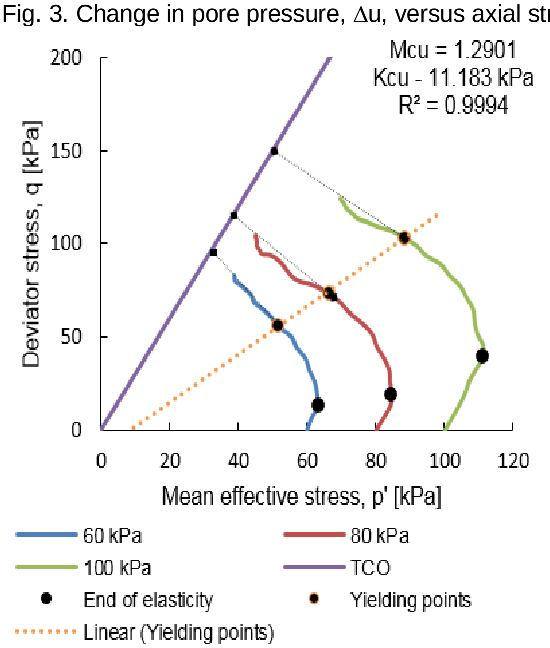

Fig. 4. Deviator stress, q, versus effective mean stress, p'

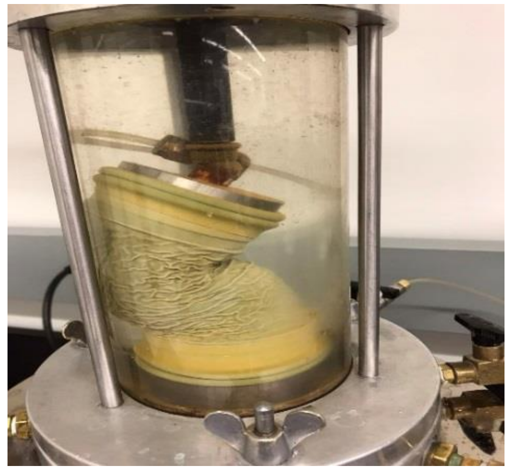

Figure 5. Twisted failure at $\sigma_3' = 60$ kPa

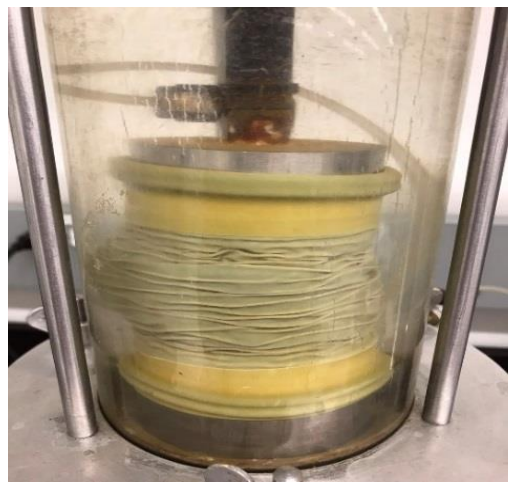

Figure 6. Lateral bulging at $\sigma_3' = 80$ kPa

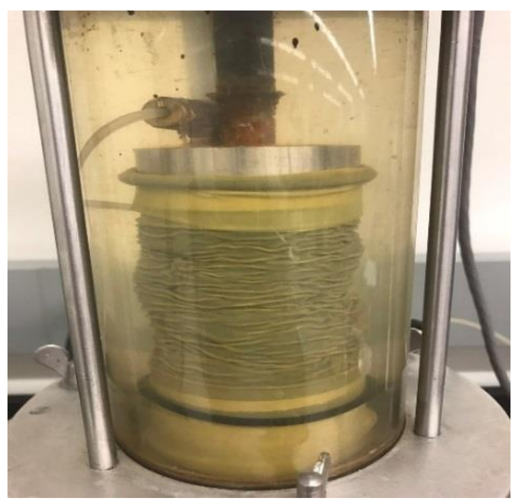

Figure 7. General bulging at $\sigma_3' = 100$ kPa

6 DISCUSSION

6.1 Anisotropic pore pressure response of fibrous peat

Anisotropic response can be reflected by the deviation of the undrained effective stress path trace from the vertical line, namely the slope of the undrained ESP traces. The undrained effective stress paths in q-p' for the remolded peat specimens can be examined based on the anisotropic behaviour in terms of the pore pressure parameter 'a'.

However, the anisotropic pore pressure response for remolded peat specimens in the linear elastic region is totally different from that of further axial compression shown in q-p' space. Specifically, in the linear elastic region, the slopes of the undrained ESP trace are all positive, varying from 0.24 to 0.28, which is similar to drained response. As noted, the possibility of drained condition has been eliminated, then this "drained behavior" can be attributed to the initial over-consolidated stress state of the remolded peat specimens.

The undrained Young's modulus in the vertical direction is greater than that in the horizontal direction. However, the slopes of the undrained ESP trace switch to the opposite side at the end of elasticity. This phenomenon indicates that the microstructural anisotropy induced by specimen preparation, with most of fibers-oriented incline to the horizontal plane, is different from that by natural deposition and shear deformation. Also, it demonstrates the previously mentioned fact of diminishing the re-orientation of fibers at the end of elasticity.

Following the initial elastic behaviour, the values of 'a' show a simultaneous increase tendency with increasing initial mean effective stress as the specimens undergo further axial compression, shown in Fig. 8. It is probably due to both the increased frictional resistance between fibers and peat matrix and the mobilized fiber tension with expansive strain, in particular, after phase transformation point. Hendry et al. (2012) also reported this behavior from triaxial tests on remolded peat and peat fibers specimens in previous studies and explained that the increased tendency of 'a' value indicated the re-alignment of peat fibers in the direction of expansive strain and an accompanying increase in the mobilization of fiber tension.

For now, due to the limited time and available apparatus to use, the number of remolded peat specimens tested is not enough to determine a specific relationship between pore pressure parameter a and cross-anisotropic behavior, indicating further study is still required.

The pore pressure parameter, 'a', at failure shows great increasing trend with the increased P0', reaching between 0.8 and 0.9. It indicates that these prepared remolded specimens are at over-consolidated state. This finding can also confirm the observation in effective stress path of the linear elastic region, which behaves in a similar pattern as a drained condition.

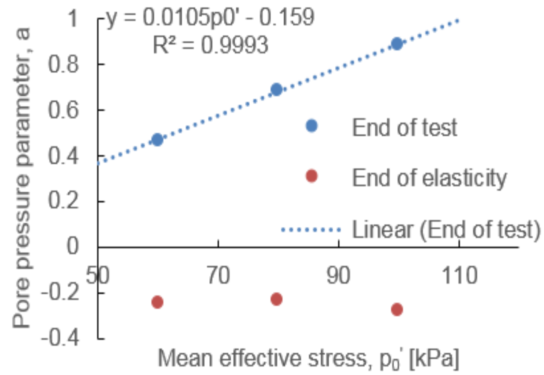

Fig. 8. Variation of pore pressure parameter, a with initial mean effective stress, p_0', for remolded peat specimens

6.2 Anisotropic elastic stiffness of fibrous peat

According to the definition of the undrained Young's modulus in the vertical direction, E_v (Graham and Houlsby 1983), Fig. 9 shows the values of E_v for remolded peat specimens versus normalized initial mean effective stress using atmospheric pressure. The experimental data are fitted with exponential curve with a theoretical intercept of 1.0. The E_v values for the remolded peat specimens are expected to increase with increasing initial mean effective stress, which indicates its impact on the undrained Young's modulus. However, the initial Young's modulus for the specimen with p_0' of 80 kPa is found to be less than that obtained for the p_0' of 60 kPa. This abnormal tendency might be attributed to fact that the fibers in the specimen with p_0' of 80 kPa were not distributed as much uniform as that with p_0' of 60 kPa. Therefore, it took much longer period of time for the fibers to re-align, this can be confirmed by the behavior that the measured pore pressure for the specimen with p_0' of 80 kPa at lower axial strain is also lower than that p_0' of 60 kPa.

Here, the E_v values from the experimental results, ranging from 29.6 to 57.6 MPa corresponding to p_0' value of 60 kPa and 100 kPa, respectively, are much higher than that with same p_0' values from other studies (Edil et al.1978; Hendry et al., 2012; 2014). This may be attributed to more uniform distribution of fibers within the specimens instead of the preferred horizontal orientation, resulting with accompanying the increased frictional resistance in the interface between the fibers and other structures. High values of modulus also reflect that the increase in q is an immediate result of increase in axial strain.

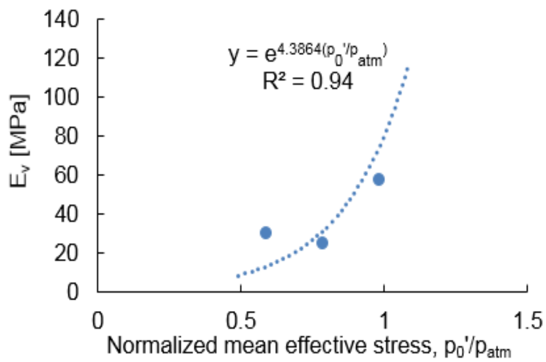

Fig. 9. The initial Young's modulus in the vertical direction, E_v, versus normalized mean effective stress, p_0'/p_{atm}

6.3 Shear strength of fibrous peat

As shown in the Fig. 2, q versus ε_a, beyond the initial elastic response, there are gradual transitions from the linear elastic to linear strain-hardening for all remolded peat specimens. Hendry et al. (2012) also reported this similar behavior on remolded peat specimens. In present study, it is assumed that the shear strength of these fibrous specimens is primarily associated with frictional interactions in the transition, and the subsequent linear increase in q during strain-hardening is a result of additional shear resistance derived from fiber tension.
Using the procedure proposed by Hendry et al. (2012) to estimate the interparticle frictional strength, gives a frictional strength (ϕ_{fs}') of 32º, which compares favourably with value of (ϕ_{fs}') of 31º from direct shear tests conducted in his paper. However, this application will result in a slightly conservative approach in an effective stress analysis to operate in the filed without consideration of fiber reinforcement effects.
The fiber reinforcement results in the mobilization of shear strength in excess of the frictional shear strength of peat (Landva and La Rochelle 1983; Farrell and Hebib 1998). Observing that the increase in q with increasing p_0' after phase transformation point in p'-q space is almost linear, which corresponds to the linear portion of strain hardening response in this present study, therefore, it is assumed that the mobilization of tension by the fibers is also linear until reaching the tension cut-off line. Based on the graphical methods from Den Haan and Kruse (2007) and Hendry et al. (2012), thus, the shear strength of fibrous peat in compression can be estimated by following the increased tendency and projecting forward this ongoing linear portion of the ESP trace to intersect the tension cut-off line. The related q_{ff} value obtained represents the deviator stress associated with not only the interphase frictional strength but also the most effective fiber tension that can be mobilized in compression manner. This concept as per considering the fiber reinforcement, which appears to be more accountable, is directly illustrated in the Fig.4.
Fig. 10 shows the values of q_{ff} for the remolded peat specimens plotted against values of p_0' with a fitted shear strength line (SSL). Values of 1.38 and 9.33 obtained for the slope and intercept correspond to an apparent angle of shearing resistance (ϕ_{ff}') of 34º and effective cohesion of 4.5 kPa, respectively. These represent more reasonable undrained shear strength parameters of peat with consideration of both interparticle frictional strength and mobilized fiber tension in response to compression loading. Also, the cohesion is considered in this strength envelope.

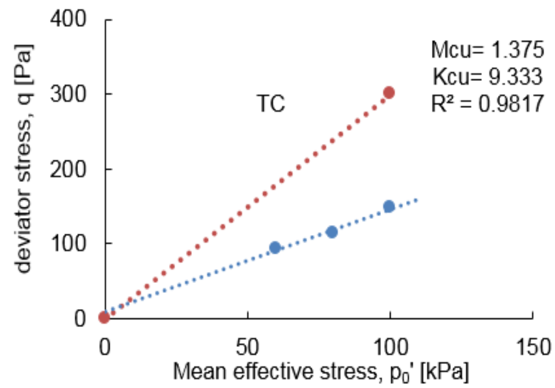

Fig. 10. Undrained shear strength line for the remolded peat specimens.

7 CONCLUSION

According to the results of the consolidated undrained triaxial compression tests on a series of remolded peat specimens, the microstructural anisotropy induced by specimen preparation is totally different from that by shear deformation, resulting with different anisotropic pore pressure response. As of yet, the pore pressure parameter 'a', at the end of test for the remolded peat specimens is believed to be strongly dependent upon the initial effective confining stress. The greater is the effective confining stress, the higher is the pore pressure parameter 'a'. This is due to the more frictional resistance between peat matrix as well as fibers and higher corresponding mobilized fiber tension. However, on account of the increased tendency of pore pressure parameter, 'a' and the limited number of tests, the degree of cross-anisotropy for the remolded peat specimens can not be fully characterized and further study is required in the following.
There are great differences between the applied cell pressure and the values of Δu at the end of the tests, which also imply that the tension is only partially mobilized within the fibers. Therefore, the values of Δu continue to increase before reaching the tension cut-off line in q-p' space. The relatively low pore pressure parameter, 'a', at failure can confirm the assumption that the remolded peat specimens are over-consolidated.
The Young's modulus of peat specimen can be largely elevated by more uniformed distribution of fibers obtained from specimen preparation phase, which effectively increases the fictional resistance between peat matrix and fibers.
The experimental facts also confirm that the randomly distributed fibers will ultimately align their faces perpendicular to the direction of the applied major principal stress. And the microstructural reconstruction is finished at the end of elasticity.

A more accountable graphical method, incorporating both the considerable amount of fiber reinforcement and frictional strength component derived from interface, is described to estimate the undrained shear strength of peat based on consolidated undrained triaxial compression test results. This procedure is constructed on bases of the previous work from Den Haan (2007) and Hendry et al. (2012), involves following the tendency of the almost linear portion of the ESP trace, corresponding to the strain-hardening portion in the stress-strain curve, and projecting forwards to intersect the tension cut-off line to obtain its q values. The values of q, when plotted against the initial mean effective confining stress p_0', give an apparent friction angel (ϕ_{ff}') of 34º and effective cohesion of 4.5 kPa, representative of the undrained shear strength of fibrous peat in response to compression loading.

It is recommended that further studies to evaluate the safety and stability of infrastructures built upon fibrous peat based on the undrained shear strength parameters determined in this paper.

8 ACKNOWLEDGEMENTS

The authors acknowledge the contribution from the Canadian National Railways for both the project and support. This research is made by the funding from Natural Sciences and Engineering Research Council (NSERC) Discovery Grant and China Scholarship Council (CSC) Grant.

9 REFERENCE

Adams, J.L 1961. Laboratory compression test on peat. In proceedings of the 7th Muskeg Research Conference, Ottawa, Ont. ACSSM Technical Memorandum 71, pp. 36-54.

Adams, J. I. 1965. The engineering behaviour of a Canadian Muskeg. In Proceedings of 6th ICSMFE (Vol. 1, pp. 3-7).

ASTM. 1988. Standard test methods consolidated-undisturbed triaxial compression test on cohesive soils. D4767, West Conshohocken, PA.

ASTM. 1991. Standard test method for laboratory determination of the fiber content of peat samples by dry mass. D1997, Wes Conshohocken, PA.

ASTM. 2007. Standard test methods for moisture, ash, and organic matter of peat and other organic soils. D2974, West Conshohocken, PA.

Den Haan, E. J., and G. A. M. Kruse. 2007 Characterisation and engineering properties of Dutch peats. Characterisation and engineering properties of natural soils 3: 2101-2133.

Edil. T.B., and Wang, X. 2000. Shear strength and K_0 of peats and organic soils. In Geotechnics of high-water content materials, ASTM special publication STP 1374. American Society for Testing and Materials West Conshohocken, Pa.

Farrell, E.R., and Hebib, S. 1998. The determination of the geotechnical parameters of organic soils. In proceedings of International Symposium on Problematic Soils, IS-TOHOKU. pp. 33-36.

Hanrahan, E.T., Dune, J.M., and Sodha, V.G. 1967. Shear strength of peat. In Proceeding of the Geotechnical Congress, Oslo, Norway. Vol.1, pp. 193-198.

Hanrahan, E.T. 1954. An investigation of some physical properties of peat. Geotechnique, 4(3): 108-123.

Hendry, M.T., Sharma, J.S., Martin, C.D., and Barbour, S.L. 2012. Effect of fibre content and structure on anisotropic elastic stiffness and shear strength of peat. Canadian Geotechnical Journal, 49(4), 403-415.

Hendry, M.T., Barbour, S.L., and Martin, C.D. 2014. Evaluation the effect of fiber reinforcement on the anisotropic undrained stiffness and strength of peat. Journal of Geotechnical and Geo-environmental Engineering, 140(9), 04014054.

Hobbs, N.B., 1986. Mire morphology and the properties and behaviour of some British and foreign peats. Quarterly Journal of Engineering Geology and Hydrogeology, 19(1), pp.7-80.

Huat, B.B., Prasad, A., Asadi, A. and Kazemian, S., 2014. Geotechnics of organic soils and peat. CRC press

Landva, A. O., & Pheeney, P. E. 1980. Peat fabric and structure. Canadian Geotechnical Journal, 17(3), 416-435.

Landva, A.O., and La Rochlle, P. 1983. Compressibility and shear characteristics of Radforth peats. In Testing of peats and organic soils. ASTM Special Technical Publication 820. American Society for Testing and Materials., West Conshohocken, Pa. pp. 157-191.

MacFarlane, I.C. 1969. Muskeg Engineering Handbook.

Mesri, G., and Ajouni, M. 2007. Engineering properties of fibrous peats. Journal of Geotechnical and Geo-environmental Engineering, 133(7): 850-866. Doi:10.1061/(ASCE) 1090-0241(2007)133:7(850)

O'Kelly, B. C., & Orr, T. L. 2014. Briefing: Effective-stress strength of peat in triaxial compression. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 167(5), 417-420.

Wood, D. M., and Graham, J. 1990. Anisotropic elasticity and yielding of a natural plastic clay. International Journal of Plasticity, 6(4), 377-388.

Yamaguchi, H., Ohira, Y., Kogure, K., and Mori, S. 1985c. Undrained shear characteristics of normally consolidated peat under triaxial compression and extension conditions. Soils and Foundations, 25(3), 1-18.