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Discussion & Replies

Discussion of "Physio-Chemical Properties, Consolidation, and Stabilization of Tropical Peat Soil Using Traditional Soil Additives – A State of the Art Literature Review" by Afnan Ahmad[a], Muslich Hartadi Sutanto[a], Mohammed Ali Mohammed Al-Bared[a], Indra Sati Hamonangan Harahap[a], Seyed Vahid Alavi Nezhad Khalil Abad[a], Mudassir Ali Khan[a]

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ABSTRACT

This discussion article provides commenting on the sections of the review paper by Ahmad et al. (the authors) concerning consistency limits determinations for peats and peaty soils, drawing on the writer's experiences regarding the usefulness of liquid limit (LL) and plastic limit (PL) testing/results for these soils in explaining their geotechnical behaviors/properties. From the writer's experience, despite being regularly specified in geotechnical engineering practice and used in research work, the conventional consistency limits tests generally do not produce physically meaningful results when testing peat soils, especially for more fibrous peats. Hence, the writer does not agree with the authors' recommendations on consistency limits testing of peats; namely, they recommended that an utmost effort is needed to improve the quality and standard of the thread rolling test and the fall-cone test for consistency limits determinations of highly organic soils such as peat. Rather than grappling with various known inherent shortcomings of consistency limits testing for peats and other highly organic soils, a suggested way forward for assessing the likely geoengineering behavior/properties of these materials points to the routine measurement of a more useful suite of index tests; namely, their natural water content, organic content, fiber content, and humification (decomposition) level. In this discussion, the above aspects are explored in detail, including greater elaboration of the writer's earlier research work in this area, which was touched on in the authors' paper.

1. Background – Inappropriateness of Consistency Limits Determinations for Peats and other Highly Organic Soils

In the papers by O'Kelly (2015a, 2016), some fundamental issues regarding the consistency limits concepts, from the viewpoint of testing peat and peaty soils, are described, specifically: 1) the relevance of consistency limits concepts and testing for these soil types; and 2) their weakness in meaningfully characterizing the geoengineering behavior of the sampled (original) peat materials. Based on the results of investigations using the standard fall-cone LL and thread-rolling PL methods presented in O'Kelly (2015a), as well as earlier experimental work reported in the papers by O'Kelly and Zhang (2013), Pichan and O'Kelly (2013) and O'Kelly and Sivakumar (2014) for testing of various peat materials, it was concluded that the conventional consistency limits tests are generally not appropriate for investigating peats, since:

1. The deduced plastic range (i.e., plasticity index, PI = LL – PL) for the prepared peat test material is speculative; that is, test material prepared by maceration/pulverization and then sieving (on the 0.425 mm sieve size) of the fibrous

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peat invariably has no practical correspondence to the sampled peat material;
2. The liquidity index values, calculated based on the experimental consistency limits and measured natural water content, are generally not reliable indicators of the sampled material's consistency (O'Kelly, 2015a, 2016).

These conclusions follow from the findings that, as demonstrated experimentally in O'Kelly (2015a), the measured LL and PL values are strongly dependent on the test-specimen preparation method employed, with greater mechanical breakdown of the fibrous peat solids during specimen preparation resulting in lower measured consistency limit values and also a reduced PI (O'Kelly, 2015a, 2016). Air-drying and (or) oven drying of the peat materials in the course of the test material preparation would also result in significantly lower measured consistency limit values and much reduced PI, which, again, are not representative of the behavior and properties of the sampled peat material (O'Kelly, 2018).

Further, from conventional understanding, the outcome of standard thread-rolling PL testing of pseudo-fibrous peats reported in the papers by O'Kelly and Zhang (2013), Pichan and O'Kelly (2013) and O'Kelly and Sivakumar (2014) indicated that these soils were non-plastic (i.e., regardless of their water content on testing, uniform soil threads could not be rolled out on a glass plate to approx. 3-mm in dia. without them crumbling/breaking). However, at the investigated water contents, the bulk test materials clearly exhibited plasticity, in that they could be (re-)molded relatively easy in the form of a ball by hand pressure. Moreover, O'Kelly (2015a) demonstrated that for macerated fibrous peat, and also for the factions of this material passing the 1.18 and 0.425 mm sieve sizes (with fiber contents (ASTM D1997–20, 2020) of FC = 70%, 49% and 28%, respectively), the bulk test materials clearly exhibited plastic behavior (in that they could be easily remolded by hand pressure) for water contents below their measured 'PL' values. Note the FC is determined as the dry mass of fibrous material retained on the 0.150-mm sieve size after wet sieving, expressed as a percentage of the total dry sample mass (ASTM D1997–20, 2020). So, according to this definition, and as demonstrated in the above example, even the sub-0.425-mm fraction of the fibrous peat material (tested for consistency limits determinations) contained fibers, ranging between 0.150 and 0.425 mm in nominal size.

In other words, as described by O'Kelly (2015a), the experimental 'PL' values deduced from conventional PL testing of variously prepared fibrous peat sub-samples were notional, and they did not represent (equate to) the brittle–ductile state transition for the bulk test materials, since a moist soil mass of each test material was easily (re-)molded in the form of a ball by hand pressure for water contents below its measured 'PL' value. Without presenting any new experimental evidence of their own, the authors restated the latter observations (originally reported in the paper by O'Kelly (2015a)), though without providing appropriate citation to the original experimental research work. The same experimental observations were also reported in the earlier paper by O'Kelly (2014) for investigation of amorphous organic clay (with N = 57%, where N is the loss-in-dry-mass on ignition at 440°) derived from the water-treatment processes employed in the production of potable water. Overall, the findings presented in the papers by O'Kelly (2014, 2015a) concur with those of Hobbs (1986), who reported that "the plasticity properties of peat, where obtainable, throw little useful light on its character and consequently there is little point in completing plastic limit determinations on peat soils" (p. 41 of Hobbs (1986)). They are also in general agreement with those of Skempton and Petley (1970), whom reported that the PL cannot be readily determined for peat, even for peat test material with high humification, and, furthermore, the thread-rolling PL test was undoubtedly subject to operator-dependent variations. The latter observation, while true for testing of all fine-grained soils (e.g., Sherwood (1970) and Sivakumar et al. (2015)), is especially relevant for testing of peats and other highly organic soils.

Additionally, O'Kelly (2015a) examined the significance of the soil thread's starting and crumbling diameters in performing the PL test, investigating macerated fibrous peat material, and considering starting thread diameters of between approx. 6 and 20 mm initially, with crumbling of the rolled-out peat threads (having different water contents) occurring for diameters of between 3 and 20 mm. (Note, for standard PL testing (e.g., ASTM D4318-17e1 (2017)), the starting and crumbling thread diameters are specified as approx. 6 and 3.2 mm, respectively). For the investigated peat material, a relative increase in the measured 'PL' water content of only 6.6% occurred for increasing the thread-diameter requirement for the failure/crumbling condition from 3 to 18 mm. Based on these experimental findings, O'Kelly (2015a) tentatively concluded that the reinforcement and scale effects related to peat fibers still remaining in the macerated test-specimen material were relatively minor for rolling out of the peat threads to 3-mm in diameter, but rather the distinctive nature of the macerated peat solids (peat matrix) is the more significant factor. Regardless of the soil thread's starting and crumbling diameters examined for the investigated macerated fibrous peat material, O'Kelly (2015a) found that the measured 'PL's bore no correspondence to the water content at the brittle–ductile state transition observed for the bulk test material.

O'Kelly (2015a) also demonstrated a 'stress history'-type effect for measured consistency limits of preloaded peat material that relates to the compressible nature of the constituent porous, flexible, organic solids of the peat matrix. In this study, preloading of investigated sapric peat material (i.e., FC < 33%) was found to produce lower measured 'LL' and resulted in the material prepared for PL testing being classified as non-plastic; that is, regardless of water content, uniform threads of the prepared peat test material could not be rolled out to approx. 3-mm in dia. without them crumbling/breaking beforehand. O'Kelly (2015a) explained the described 'stress history'-type effect in terms of the two-level structure of micro- and macro-pores in the peat material (Berry and Poskitt, 1972). Besides peat, O'Kelly (2016) drew attention to the fact that the LL test method has also been questioned for other fibrous organic soil-like materials, such as the paper mill sludge material investigated by Moo-Young and Zimmie (1996). In other words, Moo-Young and Zimmie (1996) reported that the paper fibers and tissues present in the sludge material caused problems when cutting the standard groove in the paste specimen for performing the Casagrande (percussion-cup) LL test. According to O'Kelly (2014), it can be argued that the LL and PL conditions were originally defined for fine-grained mineral (inorganic) soils, for which they have specific physical meaning, in defining the water contents corresponding to the viscous-liquid to plastic, and the plastic-to-brittle state transitions, respectively. Furthermore, in light of the above experimental evidence and observations, O'Kelly (2014) concluded that the consistency limits concepts should not be applied/ extended to peats nor for other highly organic soils. In other words, unlike remolded fine-grained mineral (inorganic) soils, the actuality of an individual (distinct) soil particle strictly does not apply for peats that are not completely humified (O'Kelly, 2015a), with connectivity between the constituent fibers in fibrous peat materials provided by cellular connections and fiber entanglement (O'Kelly, 2014, 2015b).

2. Geotechnical Engineering Characterization of Peat: the Way Forward?

An observation by O'Kelly (2017) was that for many instances in the geotechnical engineering literature, tested peats are often poorly described (often only their water contents, consistency limits and/or *N* values are given), which makes comparisons between reported geomechanical properties for different peat materials investigated more difficult. As evident from Section 1, consistency limits testing is typically not a reliable means of assessing the likely geoengineering behavior/properties of the sampled (bulk) peat materials and also not for other highly organic soils in general. As a suggested way forward, and rather than employing standard or modified LL and PL testing methods, it was the major recommendation of the papers by O'Kelly (2015a, 2016) that a more useful suite of index tests in the case of (fibrous) peats is the natural water content, organic content (e.g., given by the *N* value), fiber content (ASTM D1997–20, 2020), and the material's level of humification. Humification level is generally assessed according to the von Post humification scale of H1 to H10, representing freshly deposited plant fibers (no decomposition of peat material) and completely decomposed peat material (plant structure non-discernible), respectively (see Landva and Pheeney (1980). According to Edil and Wang (2000), this suite of tests should be routinely performed (instead of consistency limits tests) on organic soils for geotechnical engineering purposes. Note, for this suite of tests, organic content is favored over the specific gravity of the soil solids (G_s), firstly because, as described below, these two parameters closely correlate to one another, and, secondly, the organic content (*N*) is more readily and accurately measured, as compared to the specific gravity parameter, when testing peats and other types of organic soils (O'Kelly, 2019).

Therefore, for assessments of the geoengineering behavior/ properties of peats and other highly organic soils, it is recommended that the emphasis of research and practice efforts should be on routine measurement of this suite of index parameters, and to move away from consistency limits testing. This holistic approach was taken, for instance, in experimental studies performed on fibric and hemic *Sphagnum* peats (O'Kelly and Pichan, 2014; Zhang and O'Kelly, 2015), sapric *Phragmites* peat, and for other highly organic fine-grained soils investigated in the paper by Li et al. (2021). Note, it is mentioned here for completeness that another consensus has developed in Dutch organic soil practice, whereby it is recognized that the mainstays of correlations with strength and compressibility parameters are the water content and bulk density (see den Haan and Feddema (2013)).

While there are nuances, and also some potential issues, in applying the standard laboratory test methods for water content, organic content, fiber content and level of humification determinations in investigating peats and other highly organic soils, these index tests provide physically meaningful parameter values (as compared to the 'LL' and 'PL' results obtained from conventional consistency limits tests performed on these materials). For instance, the question can arise as to what oven-drying temperature range should be employed to obtain accurate water content measurements for these soils, on account of possible charring/oxidation of the constituent organic solids occurring for higher oven temperatures (e.g., see O'Kelly (2004) and O'Kelly and Sivakumar (2014)). Based on the increasing body of experimental evidence, the general consensus supports an oven - drying temperature range of 105 – 110°C as acceptable for performing routine water content determinations on peats and other highly organic soils (Skempton and Petley, 1970; O'Kelly and Sivakumar, 2014; Li et al., 2021). Over the decades, many correlations have emerged between water content, organic content, fiber content and (or) level of humification, on the one hand, and useful geotechnical design parameters, on the other, for peat deposits. For instance, organic content (*N*) is correlated with the specific gravity of the peat solids (e.g., see Li et al. (2020a, 2020b)), so having measured the natural water content and organic content, estimates of the bulk density and void ratio (among other basic engineering parameters) can be computed for the in-situ/sampled peat and peaty soils. Another example is that the compression index (C_c) and secondary compression index (C_a) parameters, both use in settlement predictions, correlate to the initial water content and the organic content, respectively (e.g., see Li et al. (2020b)).

In addition to the suite of index tests described above, Farrell (2012) and O'Kelly (2015a, 2015b, 2016, 2017) recommended that for classification of peat soils, the type of parent vegetation should always be reported, either by using terms such as 'moss peat' or 'grass peat' or, preferably, by referring to the predominant plant type(s) present — for example, *Sphagnum* peat or sedge peat. As described in the papers by O'Kelly (2017, 2022) and Foteu Madio and Dykes (2022), there is a dearth of reported work on the links between the geoengineering properties and predominant botanical constituents of investigated peat materials, with differences in botanical composition likely somewhat responsible for measured differences in the geotechnical behaviors/properties of various peat materials (O'Kelly, 2017). Another useful parameter, particularly if, for example, concrete design is a consideration, is the pH of the peat, with its magnitude related to the peat morphology (i.e., to the peatland's formation, vegetation and development) (Hobbs, 1986; O'Kelly, 2016). Additionally, recent advances in digital imaging methods across multiple scales provide numerous opportunities for clearer identification of the peat morphology and the structure of the peat fabric, allowing material descriptions and classification that are more appropriate to the investigated peat deposits, as well as providing a better understanding of the structure of the peat material and its likely geoengineering behavior/properties (O'Kelly, 2016).

3. Other Commenting on the Authors' Review Paper

This section addresses two minor points regarding the authors' review paper. The first point concerns the Fig. 2 presented in their paper, while the second relates to Section 2.1.2 (reviewing of standard LL test methods) on p. 4 of their paper. There is an error in the mentioned figure, in that the 'Liquid Limit' boundary, i.e., the transition between the liquid state and the plastic state, is incorrectly positioned (in this figure), such that the 'Plasticity Index' is also incorrectly defined in this figure. In other words, contrary to what is presented in Figure 2 of the authors' paper, the plasticity index and the plastic state (range) are synonymous.

On the second point, as part of their reviewing of standard LL test methods in Section 2.1.2 'Liquid Limit' on p.4 of their paper, the authors state that "O'Kelly et al. (2018) recommended the standard fall-cone device with 30° – 80 g specification after carefully reviewing various techniques employed to consistency limits determination". For clarity from the readers' perspective, this recommendation in O'Kelly et al. (2018) was presented in the context of LL determinations for fine-grained soils, and not, *per se*, for LL testing of peats and other highly organic soils. As described above and also stated in O'Kelly et al. (2018), "greater mechanical breakdown of the peat solids during sample preparation produces lower LL, PL and PI values, especially for less humified material (O'Kelly, 2015a), such that the measured plastic ranges are arbitrary and unlikely to sensibly correlate with mechanical behavior (Hobbs, 1986; O'Kelly and Zhang, 2013; O'Kelly, 2015a, 2016)" (p. 847 of O'Kelly et al. (2018)). For updated state-of-the-art literature reviews of consistency limits determinations (of mineral fine-grained soils), the reader is referred to the papers by O'Kelly (2021), Soltani and O'Kelly (2021) and O'Kelly et al. (2022).

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