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Characterisation of peat using full flow penetrometers

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ABSTRACT: This paper examines the utility of full flow penetrometers such as the T-bar and Ball penetrometers as characterisation tools for peat. Penetration tests were conducted at three peat sites together with in-situ vane tests and a number of laboratory triaxial tests. The T-bar and Ball are shown to yield a narrower range of N factors relating penetration resistances to undrained shear strength than the N_{kt} factor of the CPTU. The T-bar and Ball are found to overcome many of the difficulties associated with the CPTU in soft peat. In disagreement with analytical solutions, T-bar resistances tended to be higher than comparative tests using the Ball. It is suggested that this is due to the structural anisotropy of peat and is a feature of other soils where this phenomenon is observed. N factors based on excess pore water pressures for the CPTU ($N_{\Delta u}$) and Ball ($N_{\Delta uBall}$) seem to be less scattered than those based on penetration resistances. The pore pressure parameter from the Ball penetrometer test (B_{Ball}) is shown to be a useful parameter to identify the relative humification within a peat deposit.

1 INTRODUCTION

The characterisation of peat for engineering projects has traditionally been based on numerous in-situ vane tests and determination of VonPost humification profiles (Von Post and Granlund, 1926). In order to make site investigations more efficient, various researchers and practitioners have used piezocone (CPTU) tests to gain continuous profiles of peat strength with correlation to in-situ vane tests or laboratory triaxial tests.

The results of CPTU tests in peat are problematic with results tending to be scattered due to the interaction with fibres (see Figure 1). In extremely soft peat, resistance can be less than the load cell accuracy, resulting in zero resistance being measured. While more accurate load cells would be useful, they are expensive and their range of use is limited.

Landva (1986) studied the deformation pattern of model cones penetrating peat in the laboratory and found it to be one of varying compression and tearing which does not resemble any real mode of deformation under structures on peatland, concluding that the cone penetration test "was of little engineering use". Uncertainty about the deformation around the cone and the level of corrections to be applied to results has led researchers to investigate with larger full flow penetrometers such as the T-bar and ball penetrometer (see figure 2). These penetrometers have several advantages over the standard cone (Randolph, 2004);

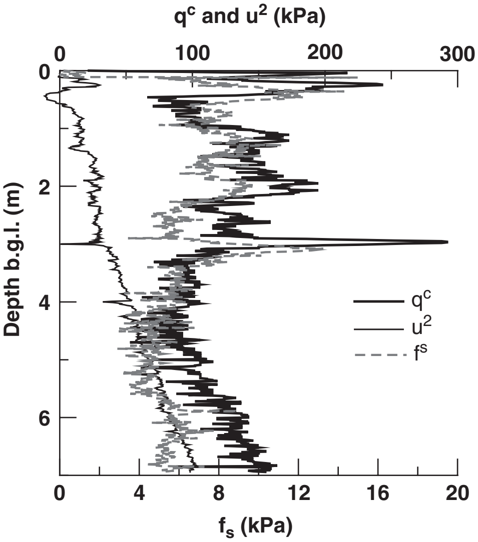

Figure 1. Typical CPTU from commercial project in peat.

(1) The measured resistance requires minimal correction to provide corrected resistance compared to possibly significant adjustment to the cone resistance.
(2) Improved accuracy is obtained in soft soils due to the larger projected area – 100 cm^2 compared to the 10 cm^2 of the cone. This results in improved resolution and reduced sensitivity to any load cell drift.

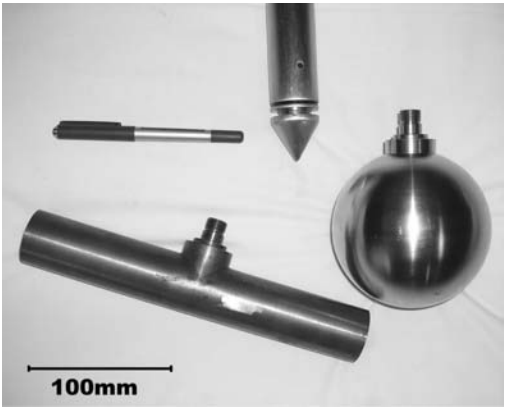

Figure 2. Cone Penetrometer and full flow probes.

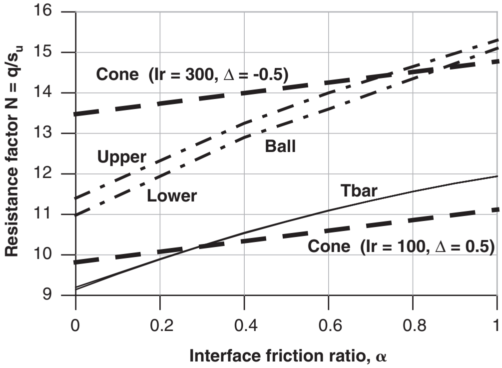

Figure 3. Range of Cone Factors (adapted from Randolph, 2004).

(3) Plasticity solutions based on simplified assumptions of soil behaviour exist which relate the net resistance to the shear strength of the soil.

Long & Gudjonsson (2004) conducted T-bar penetrometer tests in several Irish soft soils, including peat, yielding less scattered uniform resistances compared to the CPTU and a high degree of repeatability. Long (2005) has shown that the pore pressure parameter (B_q) derived from CPTU tests holds promise as a profiling tool for peat humification.

The objective of this paper is to examine the ability of full flow penetrometers to overcome the problems of the CPTU in peat and to assess the repeatability of the results. Tests were conducted at 3 locations in Ireland with both blanket bog and raised bog peat. A number of in-situ vane tests and laboratory triaxial compression tests were carried out and the correlation between penetrometer tests and analytical solutions examined. The B_q parameter as a profiling tool for peat humification is investigated.

2 BACKGROUND TO FULL FLOW PENETROMETERS

The undrained shear strength (s_u) of soil is normally determined by dividing the net cone resistance (q_{net}) by a cone factor (N_{kt}) using Equation 1. Net cone resistance is determined by correcting the measured cone resistance (q_c) for unequal pore pressure effects using Equation 2 and the overburden vertical stress (σ_{v0}).

$$s_u = \frac{q_{net}}{N_{kt}} = \frac{(q_t - \sigma_{vo})}{N_{kt}} \qquad (1)$$

$$q_t = q_c + (1 - a)u_2 \qquad (2)$$

where q_t = corrected cone resistance; a = net area ratio and u_2 = measured pore water pressure (Lunne et al., 1997). For soft soils, where the tip resistances are already low, these corrections can be a large percentage of the measured resistance. Long & Gudjonsson (2004) showed these corrections to be as high as 17% of the measured resistance in soft Irish clays. Theoretical analysis of the CPTU test (Teh & Houlsby, 1991) has highlighted that the value of N_{kt} will be influenced by the soil stiffness (or rigidity index, I_r) and in-situ stress ratio (Δ). This has meant that the results of CPTU tests need to be interpreted with cone factors from empirical correlations which can vary widely (Lunne et al., 1997).

Full flow penetrometers were developed in an attempt to overcome some of these problems, by replacing the cone with a geometry for which closely bracketed theoretical plasticity solutions exist. Theoretical upper and lower bound solutions (see Figure 3) have been computed for both the T-bar and Ball (Randolph & Houlsby, 1984; Martin & Randolph, 2006; Randolph et al., 2000) which have a smaller range than those computed for the cone (Randolph, 2004). This would seem to make it more possible to measure a continuous profile of soil strength without the need for empirical relationships. Researchers at the Norwegian Geotechnical Institute (NGI) and the Center for Offshore and Foundation Systems (COFS) in Australia have carried out extensive research into the use of the T-bar probe and found that it is limited by the very high strain rates in the shear zone, and the combined effects of anisotropy and gradual strain-softening of the soil as the T-bar passes a given horizon (Randolph & Anderson, 2005). This has meant that empirical relationships are still required, but the range of N factors relating measured resistance to undrained shear strength (s_u) is slightly narrower for the T-bar than the standard CPTU (Lunne et al., 2005).

3 TEST PROCEDURES & DATA ANALYSIS

3.1 *In-situ testing*

3.1.1 *Cone penetration tests (CPTU)*

The piezocone CPTU tests were conducted using a standard cone dimension of 35.7 mm and a projected area of 10 cm^2. Pore pressure measurements were taken from behind the cone (u_2 position). Penetration was carried out at 2 cm/sec and readings recorded at intervals of 0.01 m. Corrections were carried out according to the recommendations of Lunne at al. (1997) and undrained shear strength was computed using Equations 1 and 2. The undrained shear strength was also computed from the excess pore water pressures using Equation 3:

$$s_u = \frac{\Delta_u}{N_{\Delta u}} = \frac{u_2 - u_0}{N_{\Delta u}} \tag{3}$$

where (u_0) is the ambient in-situ pore water pressure.

The pore pressure parameter (B_q) is determined using Equation 4.

$$B_q = \frac{u_2 - u_0}{q_t - \sigma_{v0}} \tag{4}$$

3.1.2 *T-bar & ball tests*

T-bar tests were conducted by unscrewing the cone just below the load cell and replacing it with the T-bar. The T-bar used in this study is identical to the T-bar used by NGI and COFS being 250 mm long and 40 mm in diameter with a lightly sandblasted surface. Tests were conducted in the same manner as CPTU tests although no pore water pressure measurements were taken.

The Ball used in this study has a diameter of 113 mm and smooth spherical surface and is capable of making pore water pressure readings through two 3.5 mm diameter porous elements at opposite sides of the Ball, a third the way up from the tip (see Figure 4). In order to ensure saturation of the porous regions, the Ball was connected to the shaft in a similar manner to the T-bar before being immersed in a de-airing tank filled with glycerine. When all air was removed from the Ball, a specially altered latex glove was placed over the porous regions before penetration commenced.

Penetration of the T-bar and Ball was conducted in the same manner as CPTU tests at a rate of 2 cm/sec and measurements at intervals of 0.01 m. Net resistances for the T-bar and Ball were calculated using Equation 5 (Randolph, 2004):

$$q_{Tbar} = q_{Ball} = q_C - [\sigma_{v0} - (1-\alpha)u_0]\frac{A_s}{A_p} \tag{5}$$

Where A_s/A_p is the ratio of shaft area to the bearing area of the probe, which in this case is 0.1 for both probes. The undrained shear strength were determined for the T-bar using Equation 6 and for the Ball using both Equations 7 and 8.

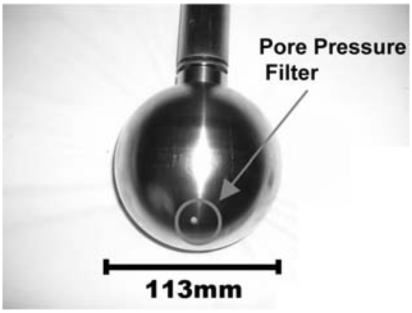

Figure 4. Ball Penetrometer.

$$s_u = \frac{q_{Tbar}}{N_{Tbar}} \tag{6}$$

$$s_u = \frac{q_{Ball}}{N_{Ball}} \tag{7}$$

$$s_u = \frac{\Delta u}{N_{\Delta uBall}} = \frac{u_{Ball} - u_0}{N_{\Delta uBall}} \tag{8}$$

The pore pressure parameter for the Ball (B_{Ball}) is calculated using Equation 9.

$$B_{Ball} = \frac{u_{Ball} - u_0}{q_{Ball}} \tag{9}$$

3.1.3 *In-situ vane tests*

In-situ vane tests were carried at the Limerick and Loughrea sites in this study using two types of shear vane apparatus. Vane tests at Limerick were conducted using the Geonor H10 field vane apparatus which is the most common type of vane apparatus used in Ireland, United Kingdom and Scandinavia. The vane head used was 55 mm × 110 mm in size and the vane rods were contained within a casing to cancel any error due to rod friction. During the test, the operator held the torque head and an average rotation of 1°/sec was applied manually.

Vane tests conducted at Loughrea used the Geotech electrical field vane apparatus using a 140 mm × 280 mm vane head. This vane apparatus allows for very well controlled testing conditions. The vane apparatus is mounted on a special stand to minimise movements during the test with rotation of the vane controlled by a motor in turn controlled by a computer. Tests were conducted at a rate of 10°/min. Rod friction was corrected for automatically by a 15° slip-coupling on the vane head. The undrained shear strengths (s_u) were determined using Equation 7.

$$s_u = \frac{T}{k} \tag{10}$$

where T = measured torque and k = vane constant.

3.2 *Laboratory testing*

3.2.1 *Triaxial tests*

A number of Isotropically Consolidated Undrained Compression (CIUC) tests were undertaken to determine the undrained shear strength (s_u) of peat in the laboratory. Samples were obtained using the SGI peat sampler (Carlsten, 1988) which consists of a sharp serrated edge connected to a PVC drainage pipe that obtains samples of approximately 9.6 cm diameter. In order to minimise sample disturbance, the sample retainer was removed and the sampler was excavated to retrieve samples.

Test procedures adopted were similar to those adopted at the Norwegian Geotechnical Institute (NGI), described by Berre (1982). Samples were tested at either the 96 mm size or trimmed to 70 mm with a height to diameter ratio of at least 1.6. In order to minimise friction between the sample and end pattens, petroleum jelly was smeared on the periphery of the end platen in contact with the sample. Thin membranes with a thickness of 0.25 mm were used to minimise the correction for membrane stiffness. Initially, the sample was subject to a cell pressure of $0.5\sigma_{vo}$ and left overnight. B-checks were carried out by increasing the back pressure in small increments of about 20 kPa until it reached 120 kPa. B values were always greater than 0.95 and saturation of samples was not required. Samples were then consolidated isotropically to the apparent in-situ effective vertical stress (σ'_{vo}) using a differential transducer between the back and cell pressure controllers to maintain the low stresses involved which were typically less than 5 kPa. It is likely that consolidation stresses could have increased by up to 3 kPa for short periods due to the controllers adjusting. At the end of consolidation which occurred within 24 hrs, samples were sheared at a strain rate of 10% axial strain per day. After tests were completed, samples were visually inspected to ascertain if peak strength was accurate of the whole sample or due to slight imperfections. The bi-linear correction of the deviator stress due to membrane stiffness developed by Greeuw et al. (2001) was applied to the results.

4 SITES

4.1 *General*

Testing of the various penetrometers was conducted at both a raised and blanket bog site. The raised bog site is located near Limerick and the blanket bog site is located on the outskirts of Loughrea, Co. Galway. An additional T-bar test was conducted on a raised bog site on the outskirts of Tuam, Co. Galway for correlation with laboratory strength data.

Raised bogs are different from blanket bogs in a number of ways but the key difference is in the way they formed. Raised bogs owe their existence not to the wetness of the present climate, but the peculiar history of the environment in which they formed. Each raised bog started its development as one or several small bogs to begin with, growing on post-glacial lakes; which in time outgrew its boundaries and eventually fused to create a large expanse of bog (Feehan and O'Donovan, 1996). Blanket bogs on the other hand form in mountainous environments primarily due to the wet climate. As as result of the different modes of formation, the resulting peat tends to be quite different. Raised bog peats tend to consist of sedge leaf with a strong structural anisotropy visible. Blanket bogs tend to be rather fibrous with less visible structural anisotropy.

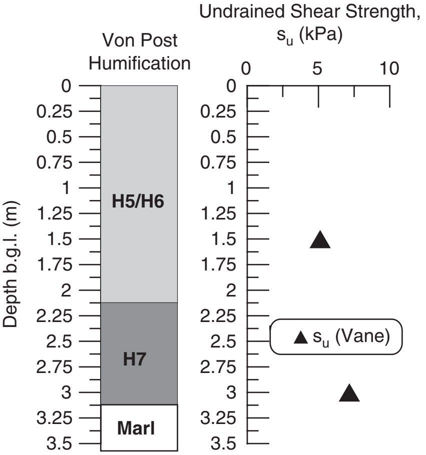

Figure 5. Basic properties and strength data for Limerick.

4.2 *Limerick*

The Limerick raised bog site consists of 3.1 m of peat underlain by marl and silty sand. As can be seen from Figure 5, the peat humification is generally H5/H6 to 2.1 m on the Von Post scale (Von Post and Granlund, 1926) increasing to H7 between 2.1 m and 3.1 m. Peat at this location is made up of sedge leaf which is generally aligned horizontally giving a very distinct structural anisotropy. In-situ vane tests were carried out by the method described in Section 3.1.3. Undrained shear strengths (s_u) in Figure 5 varied between 5 and 7 kPa.

4.3 *Loughrea*

The blanket bog site at Loughrea consists of 3.65 m of peat overlying silty clay. The peat humification increases with depth to a peak of H8 at about 2.8 m below ground level before reducing to H5/H6 (see

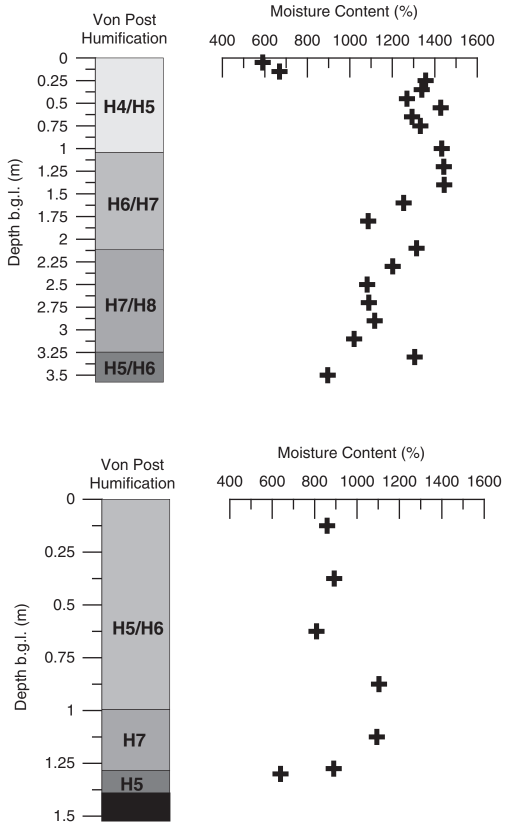

Figure 6a and 6b. Basic properties for Loughrea and Tuam.

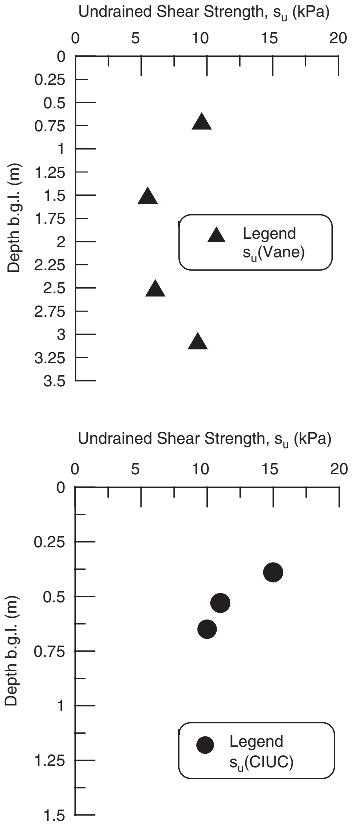

Figure 7a and 7b. Strength data for Loughrea and Tuam.

Figure 6a). Peat at this location is quite fibrous to 2 m and then starts becoming sedge-like with increasing amounts of wood. Moisture content tests conducted at 80°C are generally between 1000% and 1500%. Low values measured in surface peat are probably due to moisture loss during sampling. Bulk densities are uniform with a mean value of 1030 Mg/m^3. Organic contents were greater than 95% throughout. In-situ vane tests were carried out as per the method described in Section 3.1.3. Undrained shear strengths (s_u) in Figure 7a varied between 5 and 10 kPa.

4.4 *Tuam*

The Tuam raised bog site consists of 1.3 m of peat underlain by marl and silts. As can be seen from Figure 6b, the peat humification is generally H5/H6 with a distinct transition to H7 peat from 1 m – 1.25 m. Peat at this location is quite fibrous to 0.8 m and then becomes sedge like to 1.25 m. Moisture contents are generally between 800% – 1100%. Bulk densities are uniform with a mean value of 1040 Mg/m^3. Organic contents were generally greater than 94% throughout. A limited number of triaxial compression tests were carried out (see Figure 7b) as per the method described in Section 3.2.1 with the resulting strengths varying between 10 and 15 kPa.

5 RESULTS OF PENETROMETER TESTS

5.1 *Limerick*

Testing at the Limerick site was the first comparative study of the CPTU, T-bar and Ball conducted in peat. The results of this comparison in Figure 8a show the net cone resistances (q_{net}) for the CPTU to reduce from initial values of 0.14 MPa to zero and small negative values before increasing from 0.7 MPa to 1.5 MPa between 1.5 m and 3.1 m. At the time of writing this paper, the reasons behind the negative cone resistances between 0.5 m and 1.3 m are not fully understood and

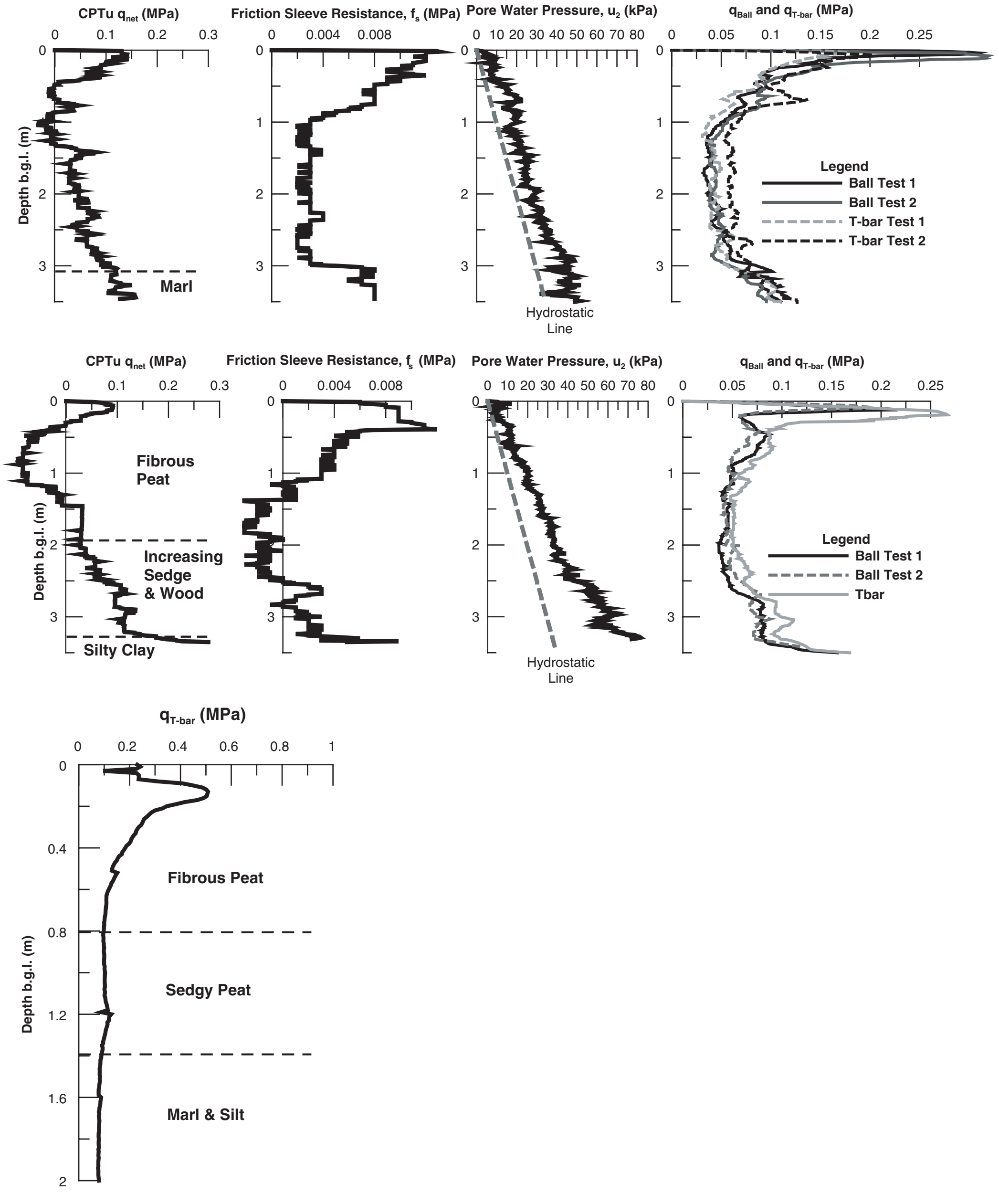

Figure 8a to 8c. Results of penetrometer tests at Limerick, Loughrea and Tuam.

may be due to slight zero offsets due to temperature variations between the peat mass and the surface. Excess pore water pressures (u_2) show a relatively uniform trend with depth. Measured sleeve friction values (f_s) show a distinct transition at 1 m where the peat becomes uniform. The results of the Ball and T-bar test show very good agreement with resistances reducing to 0.05 MPa at 1 m and increasing slightly with depth to 0.07 MPa at 3 m.

5.2 *Loughrea*

Further comparative tests of the three penetrometers were conducted at the Loughrea blanket bog site with the results shown in Figure 8b. Net cone resistances (q_{net}) from the CPTU test again reduced from initial values of 0.09MPa to negative values at 0.4m before becoming positive again at 1.5 m and increasing gradually to 0.14 MPa at 3 m. Measured sleeve resistances (f_s) show a gradual reduction before becoming negative at 1.1 m and only becoming positive at 2.6 m. The reasons behind the negative cone and sleeve resistances are the same as Section 5.1. Excess pore water pressures (u_2) increase steadily with depth with the rate of increase increasing slightly at 2.5 m before reducing significantly in the sandstone after passing through the impermeable clay beneath the peat. Results from the Ball and T-bar again show good agreement and little scatter. Net cone resistances (q_{net}) reduce from 0.2 MPa to a steady value of 0.05 MPa between 1 m and 2 m before increasing to 0.08 MPa at the 3 m.

5.3 *Tuam*

A single T-bar test was conducted at the Tuam site (see Figure 8c) with shallow samples retrieved for laboratory strength testing. Resistances measured by the T-bar, show a peak value of 0.5 MPa at 0.15 m before becoming uniform at 0.1 MPa throughout the sedge peat and marl.

6 UNDRAINED SHEAR STRENGTH

6.1 *General*

Values of N_{kt}, $N_{\Delta u}$, $N_{T\text{-}bar}$, N_{Ball} and $N_{\Delta uBall}$have been calculated for 3 sites based on results of in-situ vane tests for Limerick and Loughrea and on the results of laboratory CIUC triaxial compression tests for Tuam shown in Figures 9a to 9c. Only $N_{T\text{-}bar}$ results were calculated for Tuam as neither CPTU or Ball penetrometer tests were conducted at this site.

6.2 *Undrained shear strengths from CPTU*

The range of N_{kt} factors are between 5.8 and 15.5 when in-situ vane tests are used to calibrate the relationship. $N_{\Delta u}$ values varied from 0.7 to 3.2.

6.3 *Undrained shear strengths from T-bar*

$N_{T\text{-}bar}$ factors determined for the T-bar are compared with the theoretical value of 10.5 determined by Randolph and Houslby (1984) for an interface friction of 0.4 to take account of any adhesion due to the lightly sandblasted surface. The range of $N_{T\text{-}bar}$ varies from between 10.8 to 13.2 when compared to the laboratory CIUC tests and from between 7.8 to 13.6 when compared to in-situ vane tests

N_{Ball} factors determined for the Ball are compared to an upper bound of 13.3 and a lower bound of 12.9 determined by a theoretical analysis by Randolph et al. (2000) for an interface friction ratio of 0.4. The range of N_{Ball}factors varies between 5.4 and 12 when computed using strengths derived from in-situ vane tests. $N_{\Delta uBall}$ values varied from 1 to 1.8.

6.4 *Range of N factors*

Research into the empirical relationships between the measured resistance of full flow penetrometers (N_{Ball}, N_{Tbar}) and laboratory tests has shown them to have a slightly narrower range of N factors than the standard CPTU (N_{kt}) (Lunne et al., 2005).

6.5 *Undrained shear strengths from ball*

Table 1 summarises the data presented in Figures 9a to 9c. It is clear for the standard deviations that the range of factors for the Ball and T-bar based on measured resistance (N_{Ball} and N_{Tbar}) occupy a narrower range than N_{kt} factors for the CPTU.

It must be noted that much of the variance of the CPTU N_{kt} factors is due to the problematic behaviour of the cone in extremely soft peat tending to questionable resistance values close to zero and its tendency to increase with depth at a rate above the other penetrometers. The values of $N_{T\text{-}bar}$ compare well with the theoretical value of 10.5. Values of N_{Ball} are always less than the theoretical limits and even less than the lower bound value of 10.98 for zero interface friction for the vast majority of the results. The narrow trend of $N_{T\text{-}bar}$ factor and the strong correlation with analytical solutions would suggest that the T-bar is a better tool for profiling peat strength based on measured resistance than the CPTU. The Ball penetrometer holds promise as a strength profiling tool in peat although the reasons for divergence from analytical solutions needs to be understood first.

Empirical factors relating the excess pore water pressure generated during penetration for the CPTU ($N_{\Delta u}$) and the Ball penetrometer ($N_{\Delta uBall}$) yield smaller standard deviations than those based on measured resistance. Although factors based on excess pore water pressure show better results than those based on measured resistance during penetration, it should be borne in mind that the results presented here are based on a very limited data set and relationship between excess pore pressure and undrained shear strength (s_u) is not verified in peats. $N_{\Delta u}$ and $N_{\Delta uBall}$ factors correlate quite well with the pore pressure parameters B_q and B_{Ball}, which is similar to the relationship noted between $N_{\Delta u}$and B_q for CPTU tests in clays. (Lunne et al, 1997).

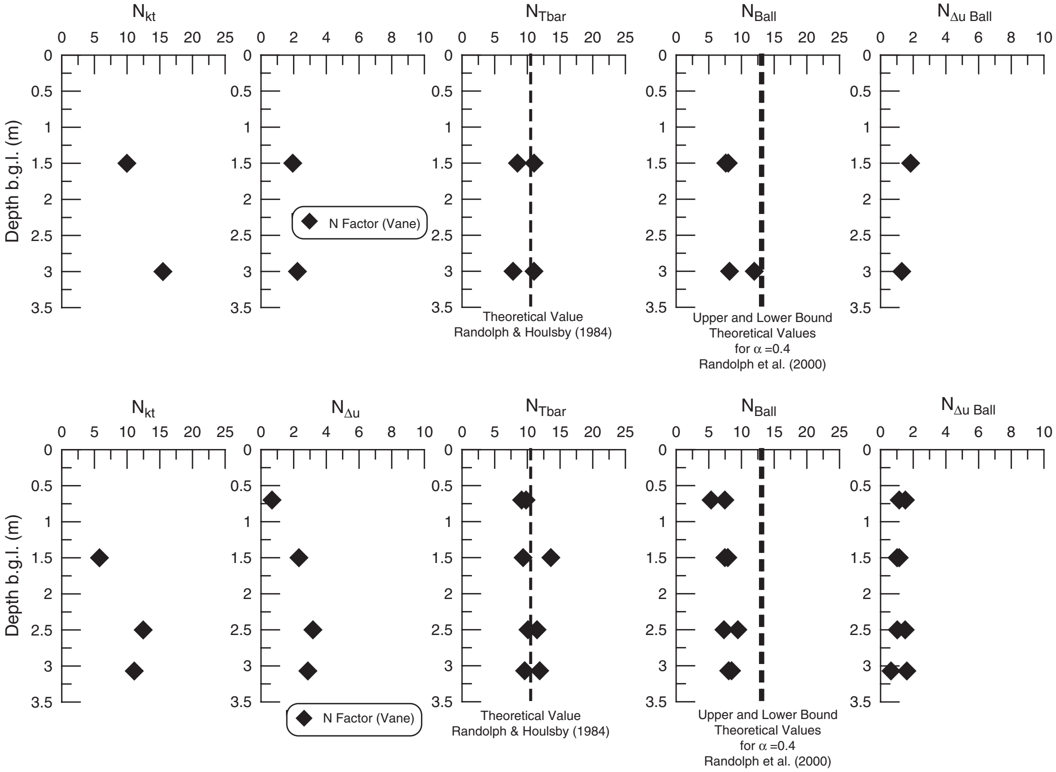

Figure 9a and 9b. N_{kt}, $N_{\Delta u}$, $N_{T\text{-}bar}$, N_{Ball} and $N_{\Delta uBall}$ factors determined for Limerick and Loughrea.

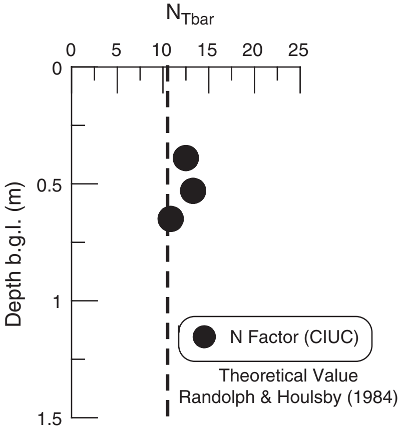

Figure 9c. $N_{T\text{-}bar}$ factors determined for Tuam.

Table 1. Summary of N factors.

Site	N Factor	Range	Mean	Std. Dev.
Limerick	N_{kt}	10–15.5	12.7	3.9
	N_{Ball}	7.6–12	8.9	2
	N_{Tbar}	7.8–11	9.6	1.7
	$N_{\Delta u}$	1.9–2.2	2.1	0.2
	$N_{\Delta uBall}$	1.3–1.8	1.6	0.4
Loughrea	N_{kt}	5.8–12.5	9.8	3.5
	N_{Ball}	5.4–9.5	7.7	1.2
	N_{Tbar}	9.1–13.6	10.6	1.6
	$N_{\Delta u}$	0.7–3.2	2.3	1.1
	$N_{\Delta uBall}$	1–1.6	1.2	0.3
Tuam	N_{Tbar}	10.8–13.3	12.2	1.3

7 PERFORMANCE OF PENETROMETERS

7.1 *Tip resistances & repeatability*

Comparing the performance of the Ball and T-bar penetrometers with the CPTU, they have overcome many of the problems associated with the CPTU in peat. The Ball and T-bar do not tend to zero and negative resistances in soft fibrous peat. The resulting profiles are well defined compared to the scattered profile which is often found with the CPTU. Resistance profiles from the CPTU show a tendency to increase with depth at a rate higher than the T-bar and Ball which has been noted in other soft soils (Long & Gudjonsson, 2004;

Chung & Randolph, 2004). Although the tip resistance profiles for the T-bar and Ball penetrometers are well defined compared to the CPTU, repeat profiles of the individual penetrometer can differ by up to 30% in peat.

7.2 *Comparison of T-bar and ball*

It is interesting to note that although analytical solutions of the T-bar and Ball would suggest that measured resistances from the Ball should be about 25% greater than the T-bar when interface friction ratio is 0.4, measured Ball resistance tend to be less than the T-bar. Comparison of the medians of several Ball tests with the median of several T-bar tests showed the T-bar resistances to be up to 25% more than the Ball resistances.

DeJong et al. (2004) conducted similar penetrometer tests on Connecticut Valley varved clay and found the T-bar to give resistances 38% larger than the Ball. On the other hand Chung and Randolph (2004) carried out T-bar and Ball tests in reconstituted Burswood clay and found the T-bar and Ball yielded similar resistances. Long and Gudjonsson (2004) found large variance of $N_{T\text{-bar}}$ factors in the varved clays of Athlone compared to uniform $N_{T\text{-bar}}$ factors in the relatively uniform clays at Portumna. The divergence seems to be associated with soils where there is a strong structural anisotropy i.e. varved clays and peats.

7.3 *Assessment of zero offsets*

In order to be confident of the relationships found in Section 7.3, careful assessment of the zero offsets was undertaken. Randolph (2004) points out that minor corrections to the load cell zero may need to be considered, due to zero drift or bending effects of the T-bar. Plots of extraction to penetration resistance ratio are used to assess if the ratio is relatively constant or if a correction needs to be applied. Randolph (2006) suggests using cyclic penetrometer tests as another method to assess the level of "penetrometer based sensitivity" by invoking symmetry to the cycle profile to calculate the level of zero offset.

7.3.1 *Extraction to penetration ratio*

Analysis of extraction to penetration resistance ratio was carried out for the T-bar and Ball tests conducted at Limerick and Loughrea. Figure 10 shows a typical example of the extraction to penetration ratio for the T-bar and Ball penetrometer at Loughrea. Although the ratio is not uniform in the top 0.5 m, correction of this was not deemed suitable, as the material is strongly fibrous in this zone. The penetration would have resulted in tearing of fibres that would have resulted in the lower extraction resistance. Correction of the zero drift was not undertaken on the basis of the extraction to penetration ratio for any of the penetration tests due to the uniformity of the profiles.

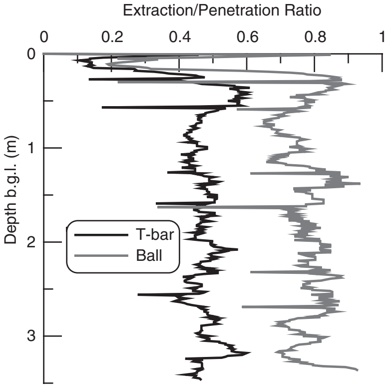

Figure 10. Ratio of extraction to penetration resistance.

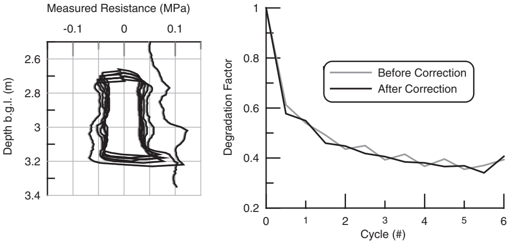

Figure 11. Cyclic T-bar with zero offset correction.

7.3.2 *Cyclic penetration tests*

Cyclic T-bar tests were carried out at several depths to ascertain the level of "penetrometer based" sensitivity. Cyclic tests are carried out by continually penetrating and extracting the penetrometer over a distance of 0.5 m until the measured resistance becomes relatively constant. The degradation factor is computed as the ratio of the measured resistance of a particular penetration or extraction cycle to the initial measured penetration. Figure 11 shows an example of a cyclic T-bar test before and after correction. The zero offset correction is calculated by adjusting the plot of cycle resistance until it becomes symmetrical about zero. The level of correction was quite small and was typically about 2 – 3% of the measured resistance. This cyclic test also suggests that the sensitivity of peat is low, with a sensitivity of 2.5.

7.4 *Pore water pressures*

The Ball penetrometer used in this study has the facility to measure pore water pressures as described in Section 3.1.2. Figure 12 compares the pore pressure

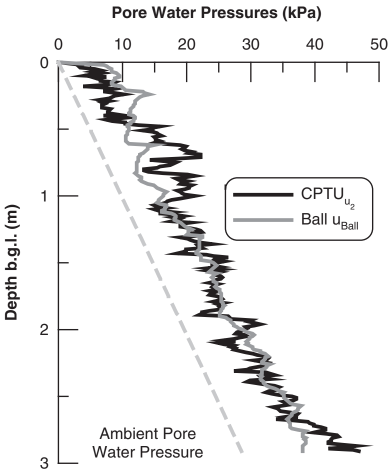

Figure 12. Comparison of Ball and CPTU PWP.

measured from the Ball and CPTU at Limerick showing the Ball to give a comparable profile but with less scattered results than the CPTU. The Ball would be useful for defining parameters that rely on the pore water pressure e.g. pore pressure parameter (B_{Ball}).

8 CHARACTERISATION OF PEAT HUMIFICATION

8.1 *General*

The use of the pore pressure parameter (B_q) to profile peat humification suggested by Long (2005) is examined at both Limerick and Loughrea. At Loughrea, a detailed study of several indicators of peat humification was undertaken to evaluate this theory.

8.2 *Limerick*

The pore pressure parameter from a CPTU test (B_q) is compared to the pore pressure parameter from a Ball penetrometer test (B_{Ball}) in Figure 13 at the Limerick site. The B_q parameter is seen to be unreliable between 0.25 m and 1.5 m where the the measured resistance became negative and quite scattered throughout the rest of the profile. The B_{Ball} parameter is well defined throughout, showing an increase with depth to about 2 m and reaching peak values of 0.14 within the more humified peat between 2.1 and 3.1 m.

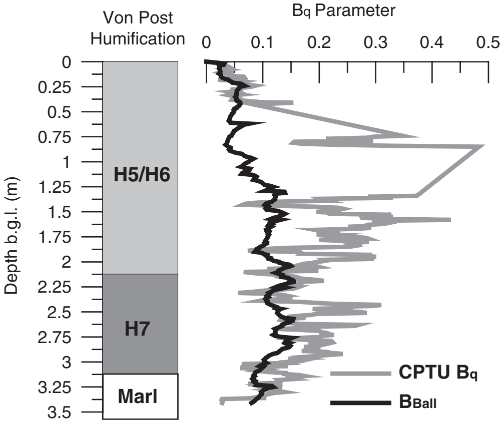

Figure 13. B_q and B_{Ball} parameter at Limerick.

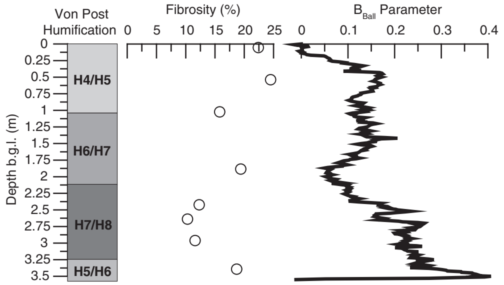

Figure 14. Comparison of B_{Ball} parameter with humification and fibrosity at Loughrea.

8.3 *Loughrea*

Figure 14 shows a comparison of the B_{Ball} parameter with the humification profile. The B_{Ball} value increases to 0.15 and is constant at this value to 1.5 m before suddenly dropping to 0.05. This sudden drop occurs at a depth where there is a significant amount of wood fragments in the peat that are quite resistance to decay. After the woody layer, B_q increases to 0.25 in the highly humified peat.

Lévesque and Mathur (1979) have shown that fibrosity of to be the most useful indicator of humification in peat. In general, as humification increases the amount of fibres in the peat reduces as they decay. The decrease in fibrosity and VonPost scale in Figure 14 suggest a similar trend of humification throughout the profile. Samples of peat at several depths were also examined using Scanning Electron Microscopy (SEM) to observe the physical changes with increased humification and gain confidence in the Von Post profiles. Figures 15a shows an image of peat with a low degree of humification (H4) with its cage like structure of decaying leaf. The increase in decay can be clearly seen in the transformation of links between the decaying leaf particles to weak strings in Figure 15b where the humification is H8. From this analysis, it seems that the B_{Ball} parameter is a good indicator of the relative humification in a peat deposit.

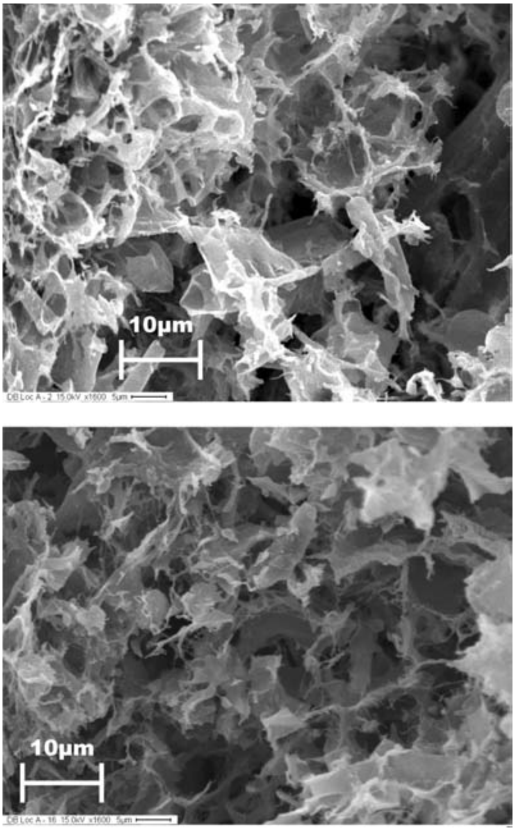

Figure 15. SEM Images of H4 and H8 Peat from Loughrea.

9 CONCLUSIONS

The results of penetration tests using the T-bar and ball show that they overcome some of the problems of the CPTU in peat namely the scattering due to interaction with fibres and inability to attain resistance in extremely soft peat. Resistance profiles from the T-bar and Ball are similar and show a high degree of resolution compared to the CPTU. Resistance profiles from the CPTU show a tendency to increase with depth at a rate higher than the T-bar and Ball which has been noted in other soft soils (Long & Gudjonsson, 2004; Chung & Randolph, 2004).

Resistance profiles from the T-bar have tended to be higher than those from the Ball although analytical solutions suggest that Ball resistances should be higher. It is the opinion of the authors that structural anisotropy in certain soils such as varved clays and peats may inhibit the full flow mechanism from occurring around the Ball and lead to lower resistances than expected.

End effects of the T-bar may also be more significant in these soils, leading to higher measured resistances. It is suggested that laboratory studies be carried out to see the effect of structural anisotropy on the full flow mechanism around the T-bar and the Ball.

Computed $N_{T\text{-}bar}$ and N_{Ball} factors for the T-bar and Ball show less variance than the N_{kt} factor for the CPTU. $N_{T\text{-}bar}$ values show good agreement with the theoretical value of 10.5. N_{Ball} values were generally less than the suggested theoretical bounds. The variance in $N_{T\text{-}bar}$ and N_{Ball} values is largely due to the level of repeatability of profile which can differ by as much as 30%. The narrow range of $N_{T\text{-}bar}$ and N_{Ball} factors compared to the CPTU N_{kt} factors would suggest that the T-bar and Ball are more reliable strength profiling tools in peat than the standard CPTU. Factors based on the excess pore water pressure during penetration for the CPTU ($N_{\Delta u}$) and the Ball ($N_{\Delta uBall}$) seem to be superior to their counterparts based on measured resistance, although further research is required to validate their applicability to peats. $N_{\Delta u}$ and $N_{\Delta uBall}$ factors show good correlation with the pore pressure parameters B_q and B_{Ball}.

The pore pressure parameter (B_{Ball}) from Ball penetrometer tests has been shown to be a useful parameter to differentiate the humification of peat within peat deposits. B_{Ball} values show a tendency to increase with peat humification. The Ball penetrometer has been shown to be superior over the CPTU as a tool for characterising parameters that are dependent on the pore water pressure value.

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