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Correlations between dynamic probe blow count and undrained shear strength for peat at a well-characterised raised bog in Ireland

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ABSTRACT: Peat deposits are generally heterogeneous, with large variations over small areas. Peat has an extremely high water content, high compressibility and low shear strength. This presents a major issue in studying the geomechanical behavior of peat. For this study, field and laboratory tests were conducted to establish the undrained shear strength (s_u) of peat at a cutover industrial peatland in Ireland which had been extensively characterized in the past. The new field work included TRL-type Dynamic Cone Penetrometer, Mackintosh probe and field vane shear tests. A correlation was developed between the Mackintosh probe "M-value" blow count and the undrained shear strength of peat. The correlation can be expressed as s_u=16.54$M^{0.373}$. Unconsolidated undrained triaxial tests and laboratory vane tests were carried out on samples retrieved from the field. The shear strength results thus derived were lower than the field test results, but consistent with each other. The suggested reason for the reduced undrained shear strength measured in the lab is sample disturbance during extraction, transport and storage prior to testing.

KEY WORDS: peat; shear strength; field vane test; dynamic probing; dynamic cone penetrometer.

1 INTRODUCTION

Peat deposits have an extremely high water content, low bulk density, high compressibility, creep behavior and low shear strength. Peat is a highly heterogeneous and anisotropic material, and its geotechnical properties are generally extremely variable over small distances since peat is formed from different plant species and the decay process is not uniform throughout the bog mass. However, the geotechnical properties of peat are generally closely interrelated [1]. Due to these inherent characteristics, peat is considered to be one of the most problematic types of materials for geotechnical engineers [2], [3]. Furthermore, different forms of anthropic intervention can also significantly alter the geotechnical properties of peat [4]. All these factors present major issues when studying the geomechanical behavior of peat.

The strength and stiffness of peat are dependent on a number of factors, the predominant one being the presence of organic fibers [5]. These fibers are mainly in a horizontal direction, which has been attributed to the large vertical strains associated with one-dimensional consolidation during natural formation of the peat. These fibers readily come apart in the vertical direction but provide tensile strength in the horizontal direction [6].

This research examines the validity of using a field vane testing apparatus in conjunction with a TRL-type dynamic cone penetrometer and Mackintosh probe as a quick and reliable method of testing the in-situ shear strength of organic peat soils was investigated. The results from the in-situ testing were then compared with laboratory-based experiments on samples taken from the same site.

The field vane apparatus is used to measure the undrained shear strength of silt and soft clay deposits. However, it has shortcomings when used to measure the shear strength of peat. This is due to the fibrous nature of peat. According to Radford [9], the effect of the fibers on the shear vane generally decreases with increases in the size of the vane.

The Mackintosh probe is a probing tool which provides a quick and economical method for determining the depth of soft deposits, and it provides a profile of penetration resistance with depth [10]. The driving point has a diameter of 27mm, and the drive hammer has a total weight of 4kg. The connecting rods are 1.2m in length and 12mm in diameter. The hammer is dropped at full drop height, which drives the driving point and connecting rods into the ground. The number of blows for each 100mm of penetration is then recorded as the M-value.

Dynamic cone penetrometer (DCP) tests are usually carried out in clays, silts, sands and gravels down to a maximum depth of one meter and mainly used for pavement design. However, for this research, it was proposed to extend the maximum depth of the test to three metres. The additional depth was provided by using two additional adapter shafts joined using couplers. The aim of this was to establish whether the DCP test could be used to approximate the undrained shear strength of peat using a correlation between shear vane results and the n-value recorded. The test results were reported in terms of the n-value, the number of blows for each 100mm of penetration.

2 TEST SITE DESCRIPTION

Ballydermot Bog was selected as a suitable location for carrying out field testing. This raised bog is situated approximately 2.7 km north of Rathangan, Co. Kildare and 12 km south of Edenderry, Co. Offaly, in the Irish Midlands (Figure 1). The bog was harvested for milled peat.

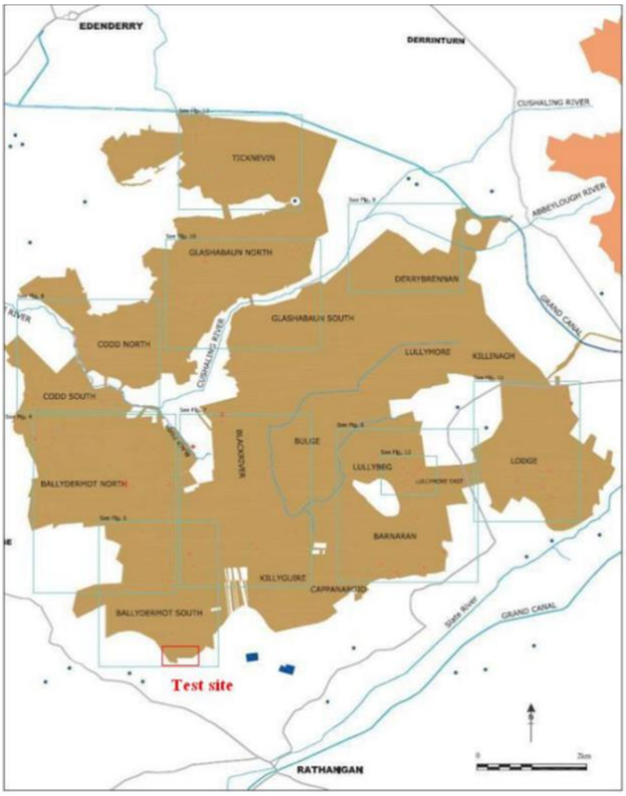

Figure 1. Ballydermot-Lullymore Bog Complex [11].

Authors such as Hanrahan [13], [14], Hanrahan and Rogers [15], Cuddy [16], Hebib [17], O'Loughlin [18], Osorio et al. [19] and Osorio-Salas [20] have conducted multiple research projects into the compressibility behavior and shear strength of peat at Ballydermot bog, producing a detailed characterization of the bog profile.

Figure 2 presents an approximated soil profile, based on the field investigation and soils classification conducted by Osorio-Salas [20]. As it can be seen, the profile is mainly composed of three layers (i) a 0.8 m thick man-made fill, (ii) a 3.2 m pseudo-fibrous peat layer, and (iii) a 1.9 m gravel layer with very high contents of fines and sand, reducing with depth.

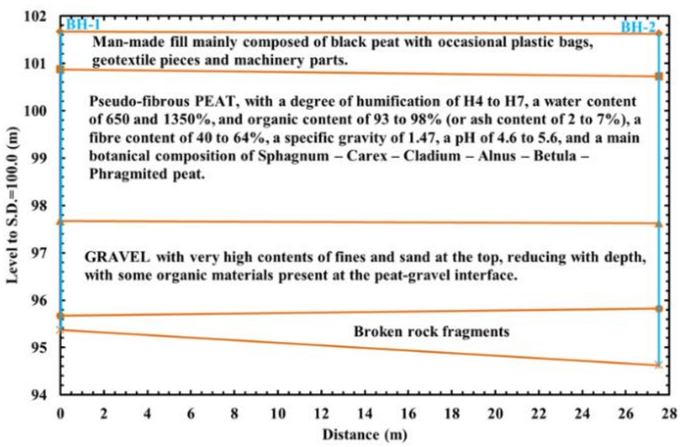

Figure 2. Approximated soil profile at Ballydermot bog [20].

Using the extended von Post system by Hobbs [21] the peat layer classifies as:

$$SCWPh\ H_{4\text{-}7}\ B_{3\text{-}4}\ F_2\ R_2\ W_1\ N_5\ A_0\ pHL$$

According to the ASTM 4427–18 [22], Ballydermot peat can be then classified as: Fibric to Hemic, Low to Medium Ash, Moderately Acidic, Sphagnum – Carex – Cladium – Alnus – Betula – Phragmited peat.

3 RESEARCH METHODOLOGY

The research work carried out was broken into three phases: (i) field testing and sampling, (ii) laboratory testing and (iii) data analysis.

Field testing consisted of the execution of field vane, Mackintosh probe and DCP tests at three selected locations on the Ballydermot Bog site. At each location, the tests were performed near one another. All three tests were carried out at depths ranging from ground level to 3.0m below ground level. Continuous profiles were obtained where possible so that the results from the tests could be compared at similar incremental depths. The general arrangement of the tests carried out is shown schematically in Figure 3.

Peat samples were retrieved from test locations 1 and 2 for laboratory testing. The samples were taken at depths of 0.3m and 1.0m. This allowed a direct comparison between the measurements from the field tests and the laboratory tests. A mechanical excavator was used to dig down to the required sample depths; U100 sampling tubes were then driven into the exposed peat to carefully obtain undisturbed samples of peat at 0.3m and 1.0m below ground level. The samples were extracted and immediately wrapped in plastic wrap to reduce moisture loss, and they were placed in cardboard boxes for transportation to the laboratory.

Four main laboratory tests were carried out on the samples; these included classifying the peat on the von Post scale, measurement of water content, undrained unconsolidated (UU) triaxial testing and laboratory vane testing.

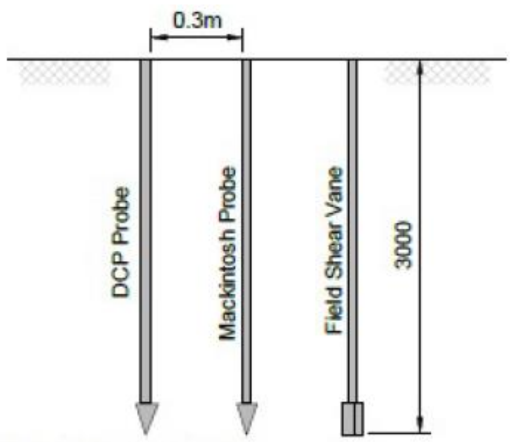

Figure 3. Close proximity of DCP, Mackintosh probe and field vane tests

4 RESULTS AND DISCUSSION

4.1 Field vane tests

Field vane tests were carried out using a Geonor H-60 device. Tests were carried out using the medium and large vanes supplied with the device. The test results are shown graphically in Figure 4.

It is evident from these results that the medium vane gave higher shear strength values than the large vane. This is in keeping with the findings of Radford [9], that the effect of the fibers on the shear strength measured by a field vane generally decreases with increases in the size of the vane. Therefore, the shear strength values measured by the large vane are preferred for data analysis.

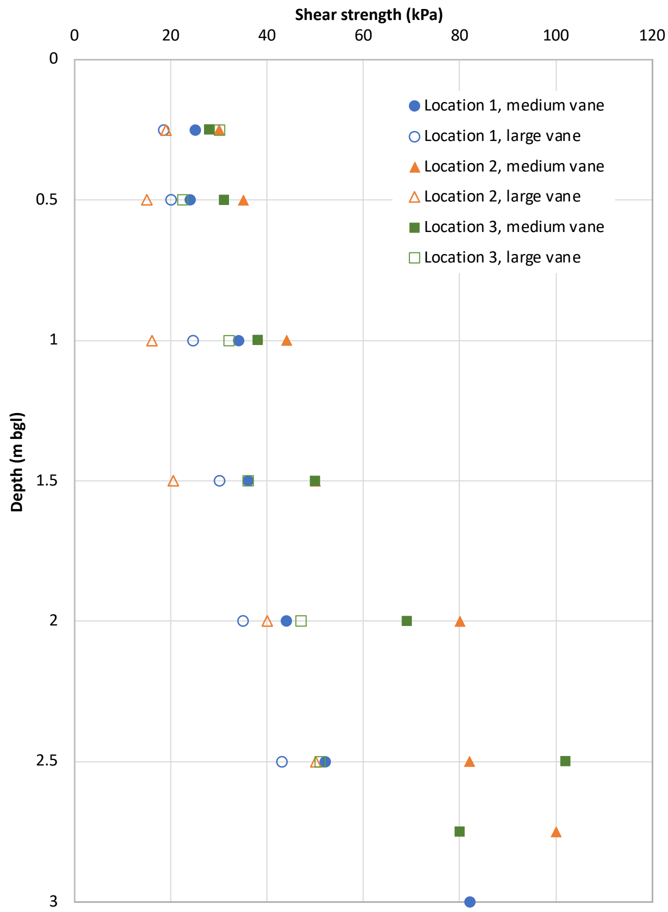

Figure 4. Field vane test results

4.2 Dynamic cone penetrometer test

The DPC tests results gave very low n-values (blows/100mm) for each of the two tests conducted on site (Figure 5). The first single blows resulted in the probe being driven to depths of 630 and 820mm. It was established from the results that the peat layer extended from ground level down to depths of approximately 2.5 to 2.75m at both locations. The n-value at both test locations increased to a maximum of 5, indicating the probe had passed into a stiff clay with an undrained shear strength (s_u) ranging between 50 and 100 kPa [23].

4.3 Mackintosh probe test

The results from the Mackintosh probe tests are shown graphically in Figure 6. The results show similar M-value results, with corresponding probe depths. Similarly to the DCP tests, stiff clay was encountered at depths between 2.4 and 2.75m, resulting in increased M-values.

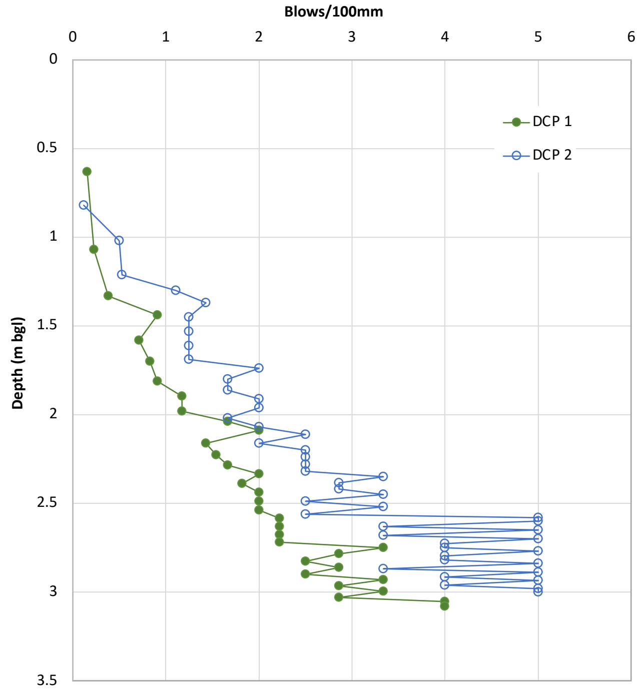

Figure 5. Dynamic Cone Penetrometer Results

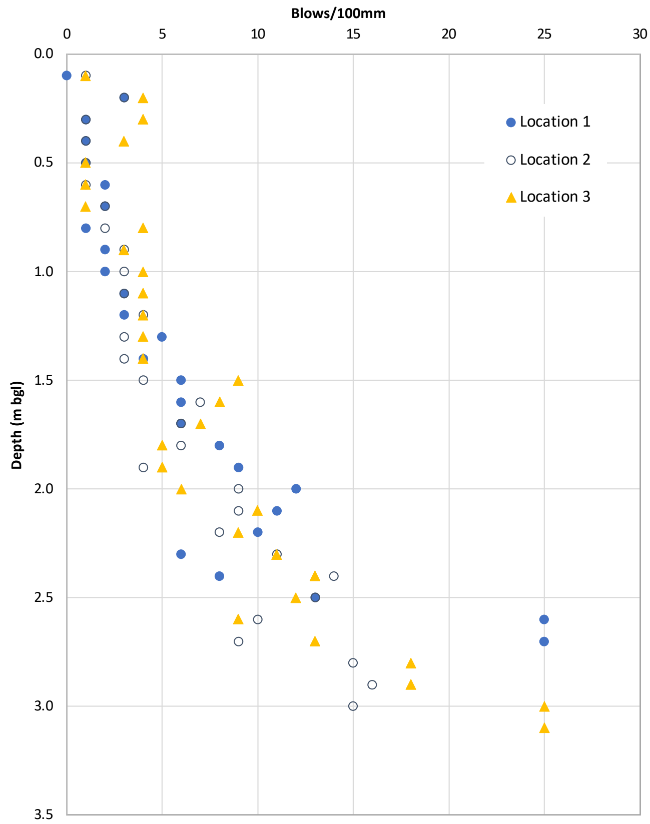

Figure 6. Mackintosh Probe Test Results

It is evident from the Mackintosh probe and the DCP tests that the M-value for peat is higher than the n-value obtained from the DCP test. This suggests that the M-value is more sensitive than n-values to variations in soft soil properties and that the Mackintosh Probe is a more appropriate test to use in very soft soils such as peat. A correlation between the Mackintosh Probe M-value and the undrained shear strength of peat was established.

4.4 Correlation between s_u and M-value

To develop a correlation between undrained shear strength (s_u) and M-value, the field vane and Mackintosh Probe Tests were conducted on site. The Mackintosh Probe test was carried out at three locations to a maximum depth of three meters. The field vane tests were conducted in close proximity to obtain a good correlation. The M-value, which represents the number of blows taken for every 100mm of penetration of the Mackintosh Probe, was recorded down to a depth of three meters. The shear vane test was performed repeatedly for every increase of 0.5m in depth. A total of 90 data points were obtained from the Macintosh Probe and a total of 18 from the large shear vane tests. A graph of the uncorrected undrained shear strength measured using the field vane (s_u) versus the number of blows (M) was developed to establish the correlation (Figure 7). The resulting power correlation developed is as follows:

$$s_u = 16.54M^{0.373} \quad (1)$$

The resulting coefficient of determination for the proposed correlation equation is 0.765, which is classified as a strong positive correlation.

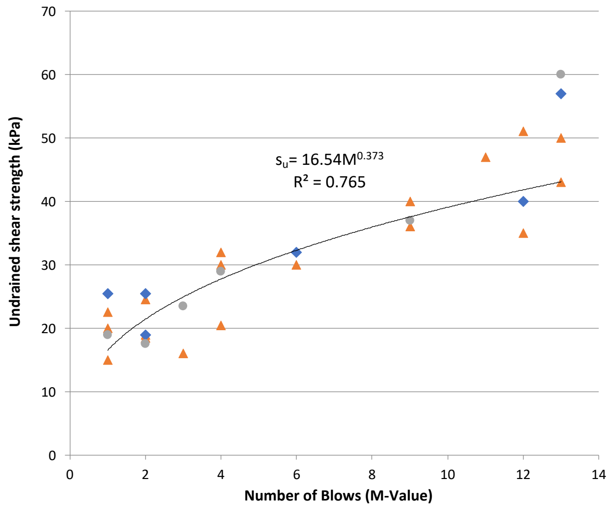

Figure 7. Correlation between s_u and M-value

The results from the proposed correlation between M and s_u were then plotted against the results recorded from the field shear vane tests for each of the three test locations on site (Figure 8, Figure 9 and Figure 10). This undrained shear strength was normalized by total stress (dimensionless). It can be observed from the graphs that the correlation between M and s_u produces results that closely match the uncorrected results of the field vane tests.

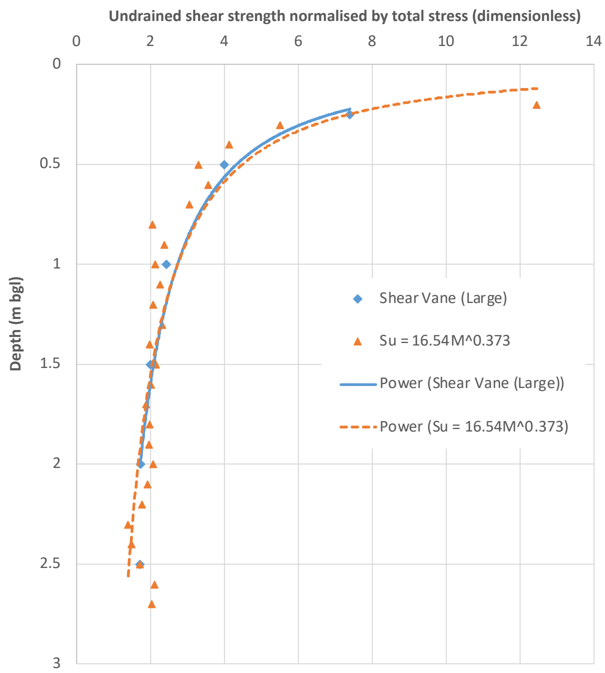

Figure 8. Correlation of M-value and Shear Vane, location 1

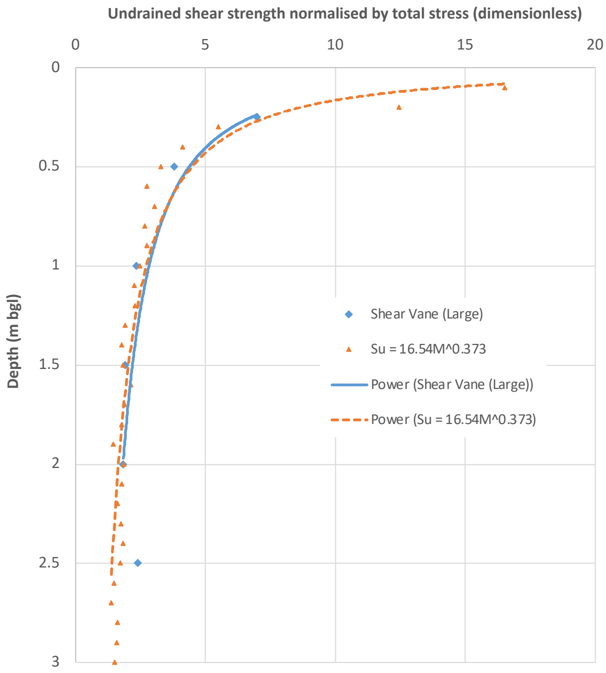

Figure 9. Correlation of M-value and Shear Vane, location 2

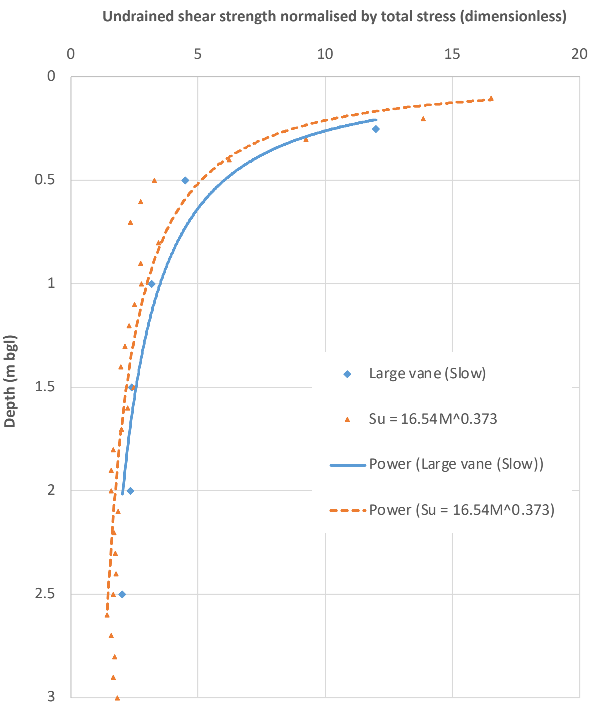

Figure 10. Correlation of M-value and Shear Vane, location 3

4.5 Laboratory testing

Samples of peat were taken at Locations 1 and 2 on site and carefully transported to the TU Dublin soil mechanics laboratory for testing. The samples were taken at depths of 0.3m and 1.0m. This allowed a direct comparison between the measurements from the field tests and the laboratory tests.

4.5.1 Water content

The water content test was conducted on six samples in total using a low-heat oven; three were taken at a depth of 0.3m and three were taken at a depth of 1.0m. The water content for the samples taken at 0.3m ranged between 765-814%; while for samples from 1.0m it ranged between 913-964%.

4.5.2 Von Post classification

The degree of humification of the peat was determined using the von Post system as described by Head [24]. The results of the test indicated that the peat sample could be classified as H3 on the scale, which is in relatively good agreement with what was described in Section 2.

4.5.3 Laboratory vane

Like the water content tests, the laboratory vane tests were conducted on six samples in total; three were from a depth of 0.3m and three from a depth of 1.0m as shown in Table 2. The results indicated an average shear strength of 13.7 kPa at a depth of 0.3m and average shear strength of 8.1 kPa at a depth of 1.0m.

It can be observed from Figure 11 that the laboratory vane test results were consistently lower than the results recorded from field vane tests at similar depths. The suggested reason for this is sample disturbance during extraction and transport, along with possible slight decay of the sample during the short storage in the lab prior to testing. In addition, uncorrected field vane strengths were used, and it is known that the field vane tends to overestimate peat strength [25].

Table 1. Laboratory vane results

Sample Number	**Depth (m)**	**Undrained shear strength (kPa)**
1	0.3	14.4
2	0.3	14.5
3	0.3	12.2
Average for depth of 0.3m		**13.7**
4	1.0	9.5
5	1.0	7.0
6	1.0	7.8
Average for depth of 1.0m		**8.1**

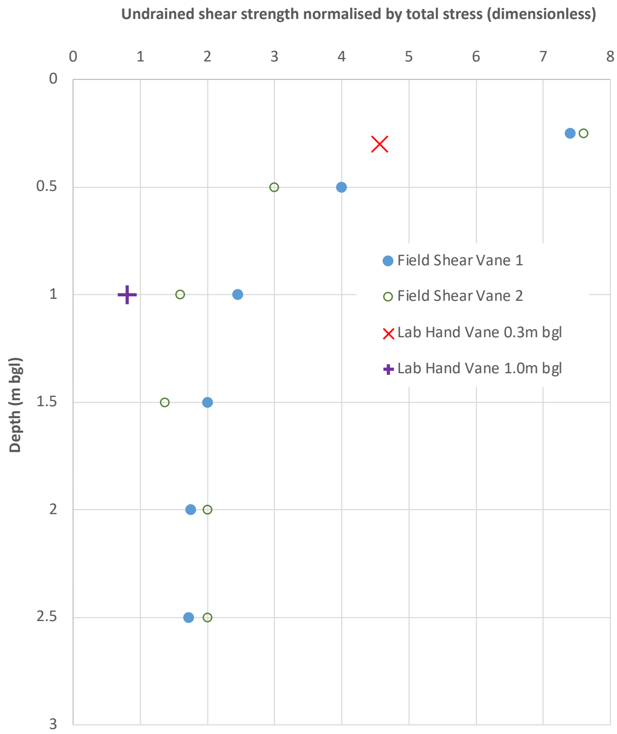

Figure 11. Lab shear vane vs. field shear vane

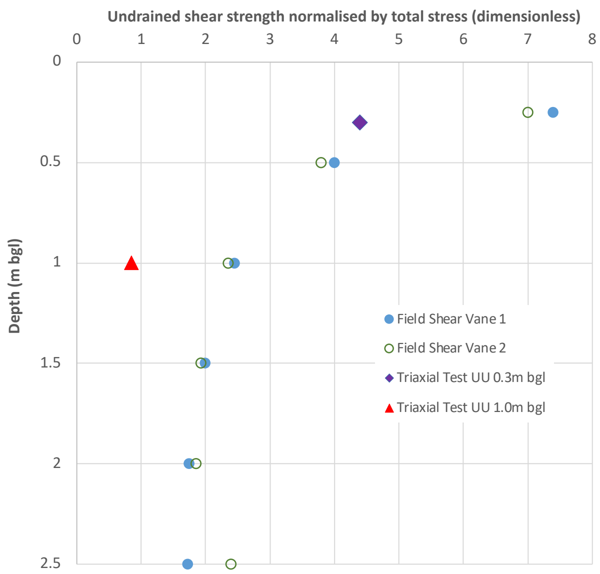

Figure 12. UU triaxial tests vs. field shear vane

4.5.4 Unconsolidated undrained triaxial tests

Unconsolidated undrained (UU) triaxial tests were conducted on six samples in total: three taken at a depth of 0.3m, and three taken at a depth of 1.0m, as indicated in Figure 12. The results recorded from the UU triaxial tests indicated average shear strength of 13.2 kPa at a depth of 0.3m and average shear strength of 8.5 kPa at a depth of 1.0m. It can be observed from Figure 12 that the triaxial test results are lower that the results recorded from field shear vane tests. The results from the triaxial test are very similar to those of the lab shear vane test and follow a similar trend of reducing shear strength with increasing depth. This further strengthens the suggestion that the reason for this is sample disturbance during extraction, transport, and storage in the lab prior to testing.

5 CONCLUSIONS

A program of field and laboratory tests were carried out to investigate the relationship between the undrained shear strength of peat as measured in the field using the field vane and two types of dynamic probe and in the laboratory using the triaxial test and the laboratory vane test. The following conclusions are drawn from the work carried out:

1. From the field vane tests conducted on site, it is evident that the shear strength results from the medium vane are consistently higher than the large vane at each of the three test locations. This suggests that the fibrous nature of peat has a larger effect on the medium vane test results and that the effect of the fibers on the shear vane generally decreases with an increase in the size of the vane.
2. It is evident from the Mackintosh probe and the DCP tests that the M-value for peat is higher than the n-value obtained from the DCP test. This suggests that the M-value is more sensitive than the n-value to variations in soft soil properties and that the Mackintosh probe is a more appropriate test to use in very soft soils such as peat.
3. A correlation between the Mackintosh probe M-value and the uncorrected undrained shear strength as measured by the field vane test was established for peat. This equation is expressed as: $s_u = 16.54M^{0.373}$. This allows the Mackintosh probe to be used as a quick and efficient tool to both profile the depth and assess the undrained shear strength of peat. The Mackintosh probe could also be used to interpolate soil properties between boreholes, reducing the cost of ground investigations.
4. The shear strengths measured by the UU triaxial tests and laboratory vane were consistently lower than the field test results. The results from the triaxial test were very similar to those of the laboratory vane test and also followed a similar trend of reducing shear strength with increasing depth. The reason suggested for the reduced undrained shear strength is sample disturbance during extraction, transport and storage prior to testing.

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