THE TILLER-FLOTTEN PEAT SITE: A NATURAL PEAT SOIL DEPOSIT AIMED FOR GEOTESTING

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KEYWORDS

Peat, Geophysics, CPTU, Sampling

ABSTRACT

Better understanding of the properties of peat are necessary in the context of finding alternative construction methods that reduce the impact and degradation of bogs. In this context, a peat research site at Tiller-Flotten, Trondheim has been established. The site covers an area of 35,000 m^2 with a low to medium decomposed peat deposit of at least 4 m depth over marine clay. Conditions on the site are very typical of other peat deposits found in Norway. This paper presents the initial characterisation of the site including geophysical and geotechnical in-situ and laboratory testing. The aim is to establish a benchmark site for the engineering characteristics of peat that can contribute as training and teaching facilities and as ground for development to further advance the state-of-the-art in the understanding of peat soils.

1. INTRODUCTION

This paper builds on the work of the Norwegian Geo-Test Site program (NGTS). In the NGTS project five geo-test sites were carefully characterised using a wide range of geotechnical techniques for the purposes of benchmarking in geological and geotechnical engineering [1]. These five sites included those on soft clay, quick clay, silt, sand, and frozen soil. There has been significant recent interest in the engineering properties of peat and highly organic soils, which has encouraged adding new sites to the NGTS. This is mostly due to environmental reasons as peat is an excellent carbon sink and peatlands are home to a wide range of biodiversity. This interest is mainly motivated by the fact that the common technique of digging out and replacing the peat by granular material, due to its poor engineering properties of high compressibility and

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low strength for road projects for example, is no longer deemed applicable. In fact, regulatory authorities are now very reluctant to permit such work and it is often encouraged to find alternatives such as constructing directly on the peat. Establishing such test sites on peat, as at other test sites in the world, e.g. that at Uitdam in the Netherlands [2], sheds light on understanding the complex mechanical behaviour of peat for design and maintenance of infrastructure.

This paper presents the results of the testing carried out to develop a peat research site at Tiller-Flotten, Trondheim, Norway. Geotechnical and geophysical testing to date are summarised with a particular emphasis being placed on the difficulties encountered in investigating peat due to its natural variability. The site has already been used for several research projects including the extraction of block samples of natural peat for centrifuge testing (EU GEOLAB project CLARIFIER) [3, 4] and for investigation of the use of industrial by-products in stabilisation of soft clay, quick clay and peat [5] (Norwegian Research Council project GOAL). The Tiller-Flotten peat site may also be seen as a potential research station for further characterization in other areas as biology, ecology, hydrology, and chemistry.

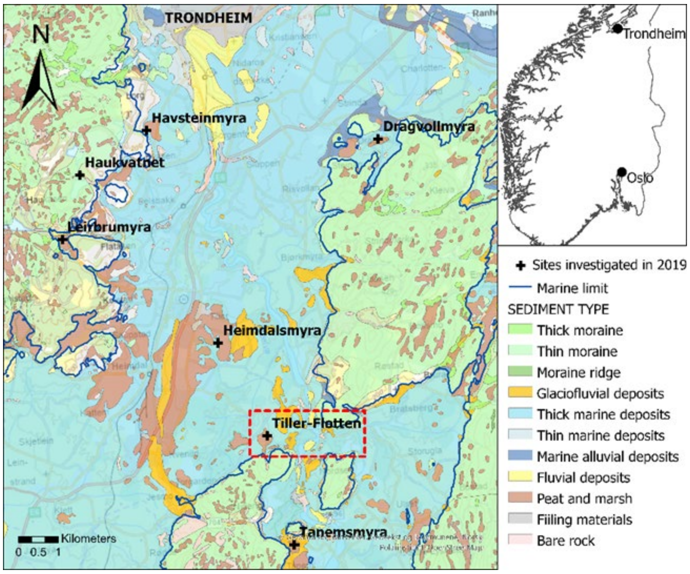

Figure 1 Location of test site, and other peat sites in the area, superimposed on Quaternary geological map. Base map from Norwegian Geological Survey (NGU) http://geo.ngu.no/kart/losmasse/. Figure modified from [7].

2. SITE LOCATION AND GEOLOGICAL BACKGROUND

The Tiller-Flotten peat site is situated approximately 14 km south of Trondheim in Norway (Figure 1). The peat research site is immediately adjacent and just south of the NGTS quick clay research site [6]. The area developed as a natural raised bog ("myr" in Norwegian) since the retreat of the glaciers some 10,000 years before present. The site is characterised by a thrifty vegetation with species growing in very nutrient-poor bogs and bogs only receiving water from rainfall. The peat is underlain by a thick deposit of marine clays. The geological background for the neighbouring quick clay site is of deposition occurring in a saline environment of 30-40 m depth with changing conditions towards estuarine and beach conditions and that the site emerged from the sea ca. 9,500 years ago. More on the geological background of the area is described by [6].

The general stratigraphy in the area is dominated by the peat layer over sensitive clay, overlying non-sensitive clay. This is illustrated by the Electrical Resistivity Tomography (ERT) profile in Figure 2 (after [7]) where the top 1-5 m is characterised by a resistive layer ($\rho > 100$ Ωm) (i.e. peat) and fairly constant values ranging from 30 to 40 Ωm down to about 35 m below ground level (i.e. sensitive clay) over a non-sensitive clay with resistivity less than 10 Ωm.

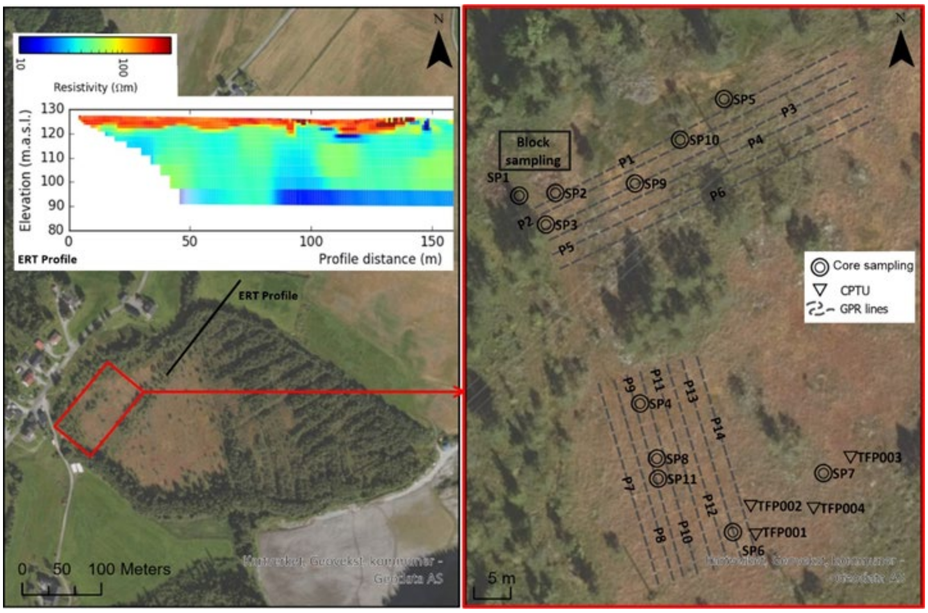

Figure 2 Site detail showing peat sampling area (quick clay area is to north), locations of block sampling, peat cores, CPTU, ERT and GPS lines. ERT profile shown in inset.

3. DETAILS OF INVESTIGATION ON THE SITE

The location of all tests on the site including the ground penetrating radar profiles (GPR), the block sample locations, the position of the Jowsey auger probes, the shear wave velocity (V_s) soundings and the piezocone penetration tests (CPTU) are shown on Figure 2.

Resistivity was measured using the Electrical Resistivity Tomography (ERT) technique. The final RMS (root mean square of the misfit between the data and the models) is 0.7%, which is considered good.

GPR data was obtained using a 250 MHz unit which was hauled by the operator across the study area. GPR involves the transmission of high frequency radio waves into the subsurface and recording the reflected waveforms. The radio frequency (rf) velocity through peat is taken to equal 0.035m/ns, which is very close to that of pure water (0.03m/ns) as might be expected due to the very high water contents found in many peat soils.

In situ shear wave velocity profiles were obtained using a portable downhole sonde which was developed for the purposes of taking V_s readings through a vertical peat column by [8].

Soil sampling was either by block sampling according to [9] or by using a Jowsey auger [10] which produces a 52 mm diameter "half core" of the peat over the full depth profile).

CPTU testing was by means of a lightweight 1t Pagani rig. Work was carried out during the summer of 2023 when the water table was low and the rig was able to traffic over the peat surface.

4. GPR RESULTS

An example of a GPR profile (Profile 1, P1, in Figure 2) is shown on Figure 3. A clear reflection of the propagating wave can be seen at the base of the peat which allows "picking" the peat base profile. The GPR derived peat depth was checked at several locations (e.g. SP2 and SP10 on Figure 3) using the Jowsey probes or shear wave velocity sonde and was proven to be very accurate.

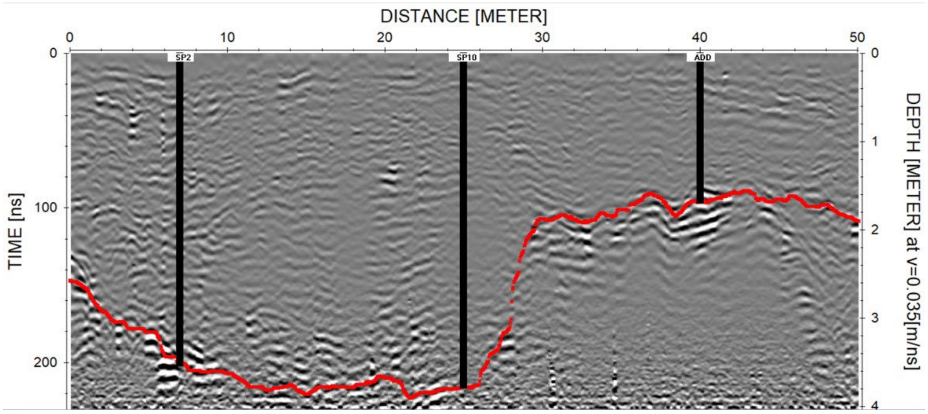

Figure 3 GPR Profile 1 showing a clear reflection of the signal at base of peat. Peat depths at SP2 and SP10 (which were proven to be 3.55 m and 3.8 m respectively) are shown as reference. An additional probe at the location indicated would be very useful.

The results of the GPR work can then be used to develop a series of contours of peat thickness as shown in Figure 4. The peat thickness is very variable across this relatively small study area and varies between some 1 m in the east of the study area to 4 m in the west. A north-south clear relatively deep channel can be observed in the western side of the study area. The underlying soils also appear to form a high ridge in the to the east.

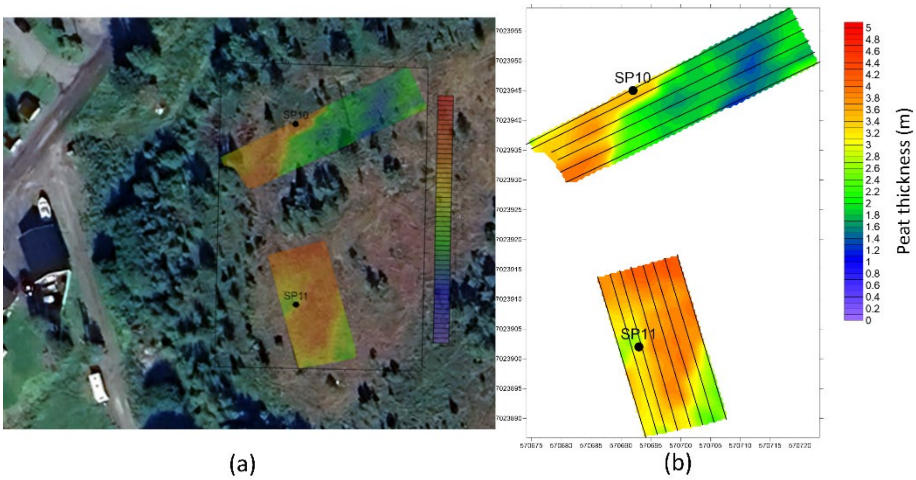

Figure 4 Peat thickness contours as derived from GPR (and verified by probing, e.g. proven peat thickness at SP10 and SP11 was 3.8 m and 2.9 m respectively)

5. PEAT INDEX PROPERTIES

Values of the water content (w) and the von Post [11] degree of decomposition of the peat are shown on Figure 5. The water content data, in particular, is characterised by its extremely high variability. Values vary between some 500% to over 2000% with an average of about 1150%. It is likely that the sampling processes, both the block sampling and the Jowsey auger sampling, led to some loss of water in the samples. Nevertheless, the material seem to be highly variable and thus forms a significant challenge for geotechnical design and analysis.

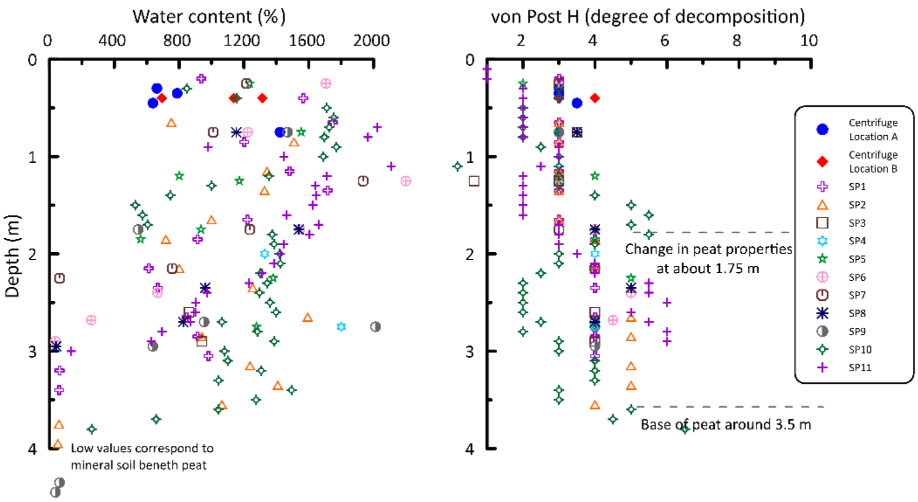

Figure 5 Peat index properties (a) water content and (b) degree of decomposition

The von Post H values (and visual observations of the peat) show a clear change in the peat properties at about 1.75 m depth. The material becomes more decomposed below this level with von Post H increasing from ca. of 3 to 4-5.

Similarly, the von Post F (fine fibre content) and R (coarse fibre content) indicate that, although the material is highly fibrous throughout the profile, there is a greater percentage of fibres over the top 1.75 m. The material has an average bulk density of about 1.01 Mg/m^3 (i.e. very close to that of water) and an average loss on ignition (LOI) of 96.5% (i.e. it is more or less completely organic).

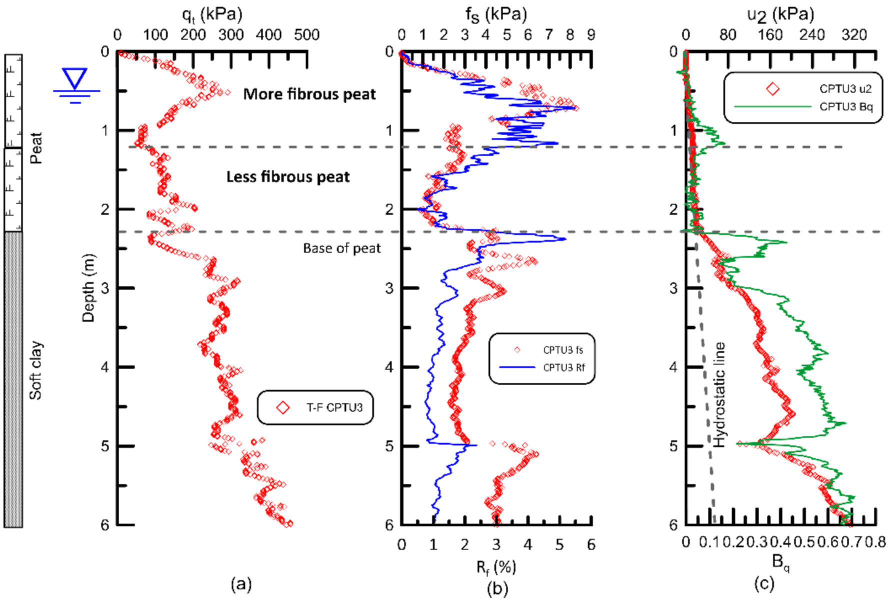

Figure 6 Typical CPTU test (CPTU3) showing all data (a) q_t, (b) f_s / R_f and (c) u_2 / B_q

6. CPTU TESTING

All CPTU data for one specific test (CPTU3) is shown on Figure 6. The figure gives plots of corrected CPTU cone resistance (q_t), sleeve friction (f_s), friction ratio (R_f), generated pore pressure (u_2) and pore pressure parameter [$B_q = (u_2-u_0)/(q_t-\sigma_{v0})$; where u_0 is the in situ pore water pressure and σ_{v0} is the total overburden stress]. The test was performed to 6 m depth which means that the probe penetrated the complete peat layer and the soft clay under. The peat layer can be identified by the low cone resistance (q_t < 200 kPa), high friction ratio (R_f = 100*f_s/q_t up to 7%), low pore pressures (u_2) with a tendency towards negative values in the more fibrous zone (i.e. over the top 1.75 m.) and low normalised pore pressure (B_q < 0.1 compared to the clay layer below). These observations agree with those of others, who have shown that peat can be characterised by CPTU by low q_t, high R_f and low u_2 / B_q [12]. In addition, the q_t and R_f data clearly distinguishes between the two peat layers with the upper less decomposed layer having relatively higher q_t and higher R_f. The upper peat layer is about 1.25 m at the location of CPTU3. However, the q_t and R_f data do not clearly identify the difference between the peat and the underlying soft clay. This boundary however is defined well by the u_2 / B_q data with penetration in the peat being largely drained and showing high u_2 / B_q values in the soft clay.

On Figures 7a and 7b the focus is on the CPTU data in the peat only with data from all 4 positions shown. Generally, the q_t and f_s data are similar at all four locations for the upper 1.25 m layer of peat. In the lower layer q_t is particularly variable, varying between values as high as 200 kPa to 20 kPa.

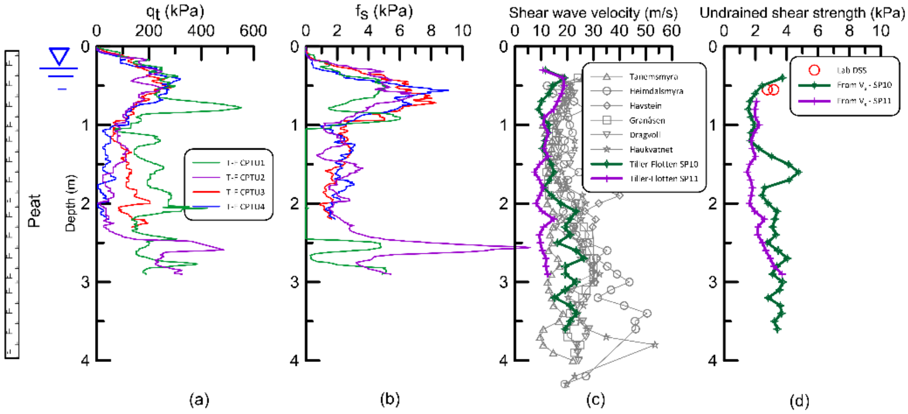

Figure 7 All CPTU tests with focus on peat and shear wave velocity profiles (a) q_t and (b) f_s, (c) shear wave velocity V_s and (d) undrained shear strength s_u.

7. SHEAR WAVE VELOCITY TESTING

The two shear wave velocity profiles from Tiller-Flotten are compared to those from six other Trondheim sites (see Figure 1 for site locations) on Figure 7c. Values of V_s are very low being on average 17 m/s for SP10 and 12 m/s for SP11. The Tiller-Flotten data falls to the lower V_s end of the Trondheim profiles and is most similar to data from Tanemsmyra. This is not surprising as both of these sites are effectively undisturbed natural peatlands. Many of the other sites have been altered by drainage or nearby construction works. There is no clear reduction in V_s with depth, a finding perhaps inconsistent with the CPTU2 and CPTU3 q_t profiles.

The value of undrained shear strength (s_u) derived from the V_s data is shown on Figure 7c. The formula derived by [9] was used:

$$s_u = 55.4\left(\frac{V_s}{w}\right)^{0.68} \tag{1}$$

This formula was based on laboratory direct simple shear (DSS) tests consolidated to in situ (i.e. very low) effective stresses and V_s measurements on the same samples at equivalent stress. The profiles suggest the s_u values are very low, increasing very from about 2 kPa near the surface to 3 kPa with depth.

8. DIRECT SIMPLE SHEAR (DSS) TESTING

Some DSS tests were carried out on specimens derived from one of the block samples (depth 0.6 m) at the geotechnical laboratory of Deltares in Delft. The samples were prepared by careful trimming of the block with a serrated knife and were 63 mm in diameter and 20 mm high. They were initially consolidated to vertical stresses between 5 kPa and 60 kPa (σ_{vc}') and then sheared undrained (sample height maintained constant). The undrained shear strength ($s_{u\text{-}DSS}$) was taken at the point where the shear strain equals 15%, which is normal practice at NGI. The results, plotted as shear stress versus shear strain and normalised shear strength $s_{u\text{-}DSS}/\sigma_{vc}'$ versus σ_{vc}', are shown on Figures 8a and 8b respectively and compared to a series of other test results on Trondheim peat.

At low stresses (i.e. less than the yield stress, which is estimated to be of the order of 10 kPa to 15 kPa) the values are very variable but as the stresses are increased beyond 10 kPa the $s_{u\text{-}DSS}/\sigma_{vc}'$ values becomes constant at about 0.4. A very similar value was reported for Swedish peats [13].

The $s_{u\text{-}DSS}$ values obtained at σ_{vc}' equal to 5 kPa (i.e. approximately equal to the in situ stress) are compared to those derived from the V_s profile on Figure 7d. It can be seen the comparison between the two sets of data is very good.

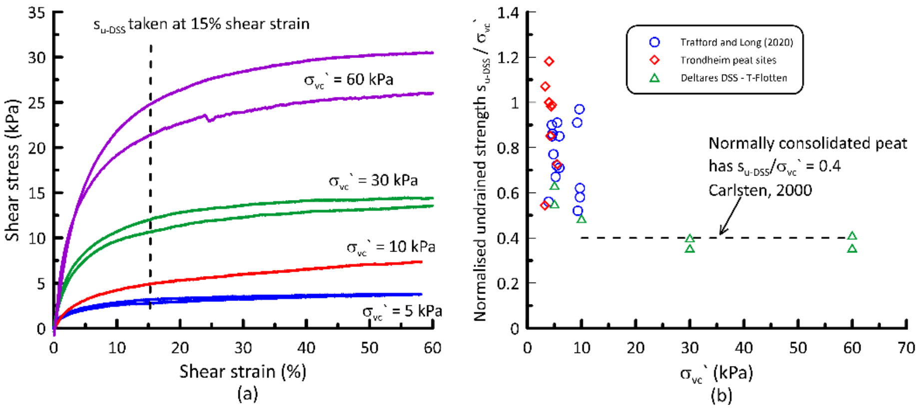

Figure 8 DSS test results (a) shear stress vs shear strain and (b)normalised undrained shear strength versus consolidation stress.

9. CONCLUSIONS

The Tiller-Flotten peat research site development addresses the increasing interest in engineering related peat research due to environmental reasons. Investigations carried out at the site indicate that the successful application of geophysics in demonstrating the thickness variability of the peat layer. The CPTU results are useful in characterising peat and complemented by shear velocity measurements shed light on the strength properties of the peat. Limited "advanced" lab tests are currently available at the test site, however, the DSS results show consistency with those found elsewhere and with values derived from shear wave velocity measurements.

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