ELGIP peat group-outline of research into peat behaviour

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ABSTRACT: This paper summarises some of the work to date of the ELGIP working group on peat. ELGIP stands for European Large Geotechnical Institutes Platforms and has a dedicated group working on peat behaviour. The main purpose of the group is to collaborate in solving engineering peat related problems and improving tools for practical engineering. The group is working towards a common understanding of the peat mechanics, geology, geophysics and chemistry, by experimental laboratory and field tests and numerical simulations. The paper will outline some of the progress that has been made by group members in recent years for example:

- the full-scale field trials, the large diameter sampler, the large triaxial and direct simple shear tests conducted by Deltares,
- the novel 1g laboratory model tests carried out by SGI to aid the understanding of embankment foundations in peat
- the characterisation of peat in the Trondheim area of Norway by NGI,
- the use of geophysical techniques for the purposes of peat characterisation by UCD.

Keywords: Organic soils, peats, engineering properties

1. Introduction

Due to its fibrous nature, strong susceptibility for creep, compressible nature and strong heterogeneity at any level, peat is considered to be a complex engineering material. A large portion of the land in the Northern hemisphere as well as in the tropics contain peat deposits, [1]. In those areas a further development of infrastructure and urbanisation forces engineering practice to use peat layers as foundation material. This is further enhanced by increasing climate awareness which results in restrictions for replacing peat layers with more stiff construction material.

The European Large Geotechnical Institutes Platform, ELGIP is an organisation which supports international cooperation in improving geotechnical knowledge and solving societal issues related to soil mechanics [2]. Within ELGIP the problems with peat as a foundation layer is well acknowledged. For example; land subsidence in peat areas with strong consequences for the maintenance of infrastructure in those areas. Climate change might increase oxidation of peat and therefore, increase land subsidence rate resulting in a decay of or further increase in maintenance effort of existing infrastructure. Moreover, oxidation of peat leads to CO_2 emission and as such contributes to the effects that cause climate change.

To improve efficiency in the studies of the individual ELGIP members and to mutually benefit from study results, a working group on peat was established within ELGIP. The main purpose of the group is to collaborate in solving engineering peat related problems and improving tools for practical engineering. The group is working towards a common understanding of the peat mechanics, geology, geophysics and chemistry, by experimental laboratory and field tests and numerical simulations. The focus of the working group is knowledge exchange, which is amongst other issue, realised by the annual workshop. This paper will briefly highlight some of the items discussed in the working group and provide references for more in depth background reading.

2. Test Side Uitdam, the Netherlands

At Uitdam, approximately 30 km North of Amsterdam, a test site was erected. The purpose of the test site was to establish the strength characteristics of peat by comparing results of laboratory testing, in situ tests and full-scale field tests. The test site is well described by [3], [4] and [5].

The field trials consisted of containers that could be filled remotely until sub soil failure. In total six tests were conducted, in which fluctuations in pre-loading and excavation in the front of the container row were applied. As an illustration of the outcome of the test site, this paper discusses some results of Test 6.

Test number 6 contained a pre-loading of 33 kPa, induced by placing concrete slabs, for approximately 6 months, see Figure 1. After that the middle row of concrete slabs was further loaded by 10 extra concrete slabs and the container row. Failure was found while filling the containers with water, at load of 78.6 kPa (45.6 kPa extra to the 33 kPa loading)

Figure 1. Test number 6 at the Uitdam test site. Left; Application of extra load to the pre-loading. Right; test set up at failure

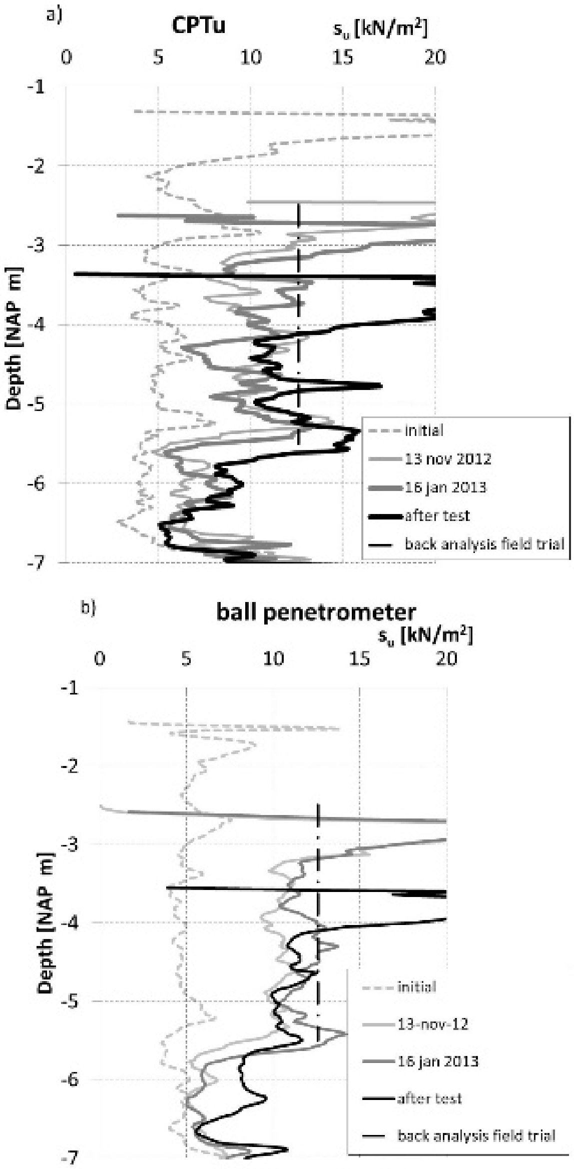

Figure 2. Some test results of the Uitdam test site. Comparison of s_u from back analysis of the field trial with a) CPTu data and b) ball penetrometer tests, after [4], [5].

Figure 2 shows the analysis of the in situ measurements. CPTu and ball penetrometer data are analysed. Based on correlations derived for the test site, see [4], values for the undrained shear strength, s_u are derived. Field measurements are conducted initially as well as during construction and after the test. The in-situ measurements clearly show the increase in strength due to pre-loading. Back analysis shows the average mobilised shear strength at failure. This value is also plotted in Figure 2. The comparison shows that the correlations for s_u based on laboratory testing agree well to the outcome of the field trial.

The tests show that despite the complex nature of peat and the shortcomings of the individual testing techniques the combination of in situ and laboratory tests provide a consistent description of peat behaviour.

3. Development block sampler

The field trials at the Uitdam test site showed the complexity and necessity of undisturbed peat sampling. To improve the quality of sampling a block sampler was developed. The Deltares Large Diameter Sampler, DLDS can obtain samples with a diameter of 0.4 m and 0.5 or 1.0 m in height. Details of the sampler are described in [6].

Figure 3 shows the set-up of the sampler. The sampler uses a pre-drilled borehole. The sampler is lowered in the casing and fixed by using the struts. The sampler is steadily pushed into the soil. Next a set of knives cuts the sample from below and the sample can be brought to ground level.

The sampler contains the sample tube in which the sample is transported to the laboratory. Consequently, the sample is laterally supported at all phases during sampling, transport and storage.

The cutting shoe has the same diameter as the sample tube leading to an inside clearance ratio, IC = 0. The cutting shoe contains a sharp cutting edge and a cutting angle of 10 degrees to the vertical.

The samples show good recovery ratios. This indicates that the samples are not compressed during sampling.

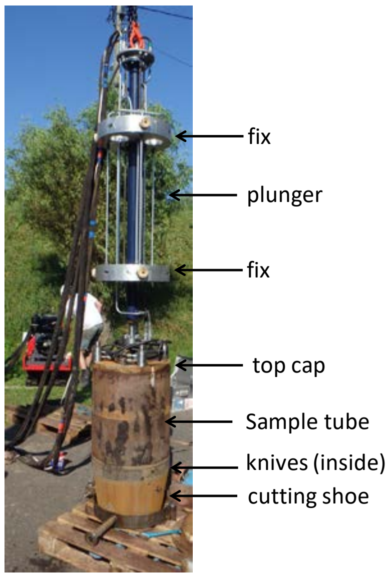

Figure 3. Deltares Large Diameter Sampler, DLDS set up after [6].

4. Size effects in laboratory testing

Figure 4 show an MRI scan of a typical peat block obtained from the Uitdam test sit. The Figure shows the organic content in white and grey. The fibres are clearly recognisable. The fibre length is in the order of several centimetres.

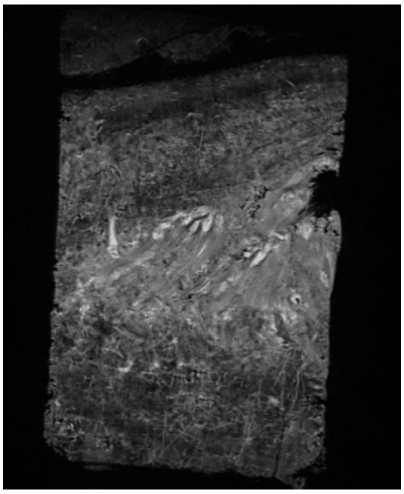

Figure 4. MRI scan of peat block, sample height 200 mm, white and grey represents organic content

The observed fibre lengths are in the same order of magnitude as specimen dimensions in conventional triaxial testing, here 50 to 65 mm in diameter and 100 to 130 mm in height. Consequently, due to the relatively large dimensions of the fibres, continuum mechanics might not be applicable for interpretation of triaxial tests on conventional sized peat specimens. To test size effects a large triaxial device was developed, which can test specimens of 400 mm in diameter and length 800 mm, see Figure 5. More details of the tests are given in [7] and [8].

All tested large sized samples showed steep sliding planes. In contrast conventionally sized specimens fail rarely and the test is ended when maximum displacement in the test is reached. The observed difference in failure behaviour is explained by size effects.

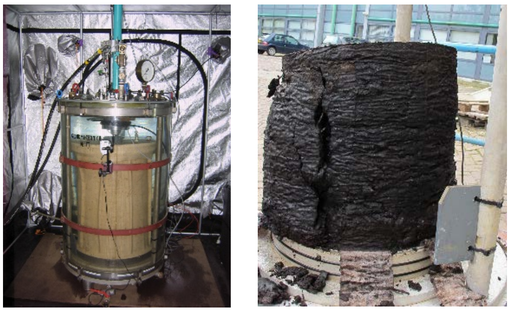

Figure 5. Large triaxial tests left: test set-up right: sample after testing. From: [7]

The differences are explained by the hypothesis that a sliding plane can only develop when the fibres that cross the sliding slide, entangle or break. This will only occur after some displacement. For large sized specimen, displacements are larger at the same strain level, compared to conventionally sized specimens which might explain that failure is found in large sized tests and not in conventional sized tests.

5. Characterization of peat in the Trondheim area (Trøndelag) of Norway

During 2019, a research project mainly funded by the Research Council of Norway (RCN) through the basic grant (GBV) 20190149 and the Norwegian Geotechnical Society (NGF) through the 2019 NGF scholarship, was carried out at NGI on the topic: "Characterization of Norwegian Peat". In addition, some more funding was received by the Norwegian GeoTest Site project (No. 245650/F50) supported by RCN and the CREEP (Creep of Geomaterials, PIAP-GA-2011-286397) project supported by the European Community through the programme Marie Curie Industry-Academia Partnerships and Pathways (IAPP) under the 7th Framework Program.' The project's main objective was to characterize the Norwegian peat by putting together a database with historical peat data from Norway, performing field and laboratory work on peat samples collected from selected peat sites and evaluating the results obtained in terms of strength and deformation parameters.

Data from 19 sites were collected, in addition to data from five large scale tests. A database of peat properties, including index data, strength and deformation characteristics and geophysical data was established [9]. Furthermore, seven sites were chosen to collect additional field and laboratory data during the summer of 2019. The field work included sampling with a peat sampler (Fig. 6a), block sampling (Fig. 6b) and shear wave velocity measurements with a portable downhole probe developed by [10]. See [11] for further details on the method.

Figure 6. (top) Peat sample taken at Tanemsmyra, Trøndelag at 7-7,5 meters depth where the clay boundary was encountered. (bottom) Block sample taken at Tanemsmyra from 0,5 m depth.

The peat was classified in the field according to the extended version [12] of the original classification described by von Post and Granlund [13]. The laboratory work included measurements of water content in accordance with BS1377-02 [14], organic content (i.e.

loss of ignition at 440 °C for 5 hours [15]), constant rate of strain (CRS) tests on 20 mm thick samples using the procedures outlined by Sandbækken et al. [16], peat odometers in 54 mm thick samples using the Janbu torvodometer [17] (see Fig. 7) and Direct Simple Shear (DSS) tests [18].

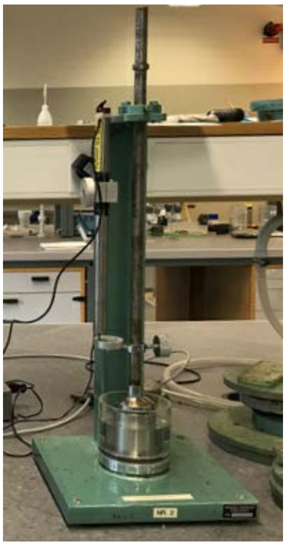

Figure 7. Set-up for the Janbu torvodometer apparatus.

Correlations based on water content and shear wave velocity for strength estimation were tested and compared to DSS tests results. Additionally, a back-calculation of a peat slide that occurred in 2017 in Trøndelag, Norway was performed [19]. Currently during 2020, the possibility of developing correlations for estimation of deformation properties following a similar procedure to the ones used for strength correlations is being investigated.

Figure 8 shows an example of the output from the vertical shear wave profiling showing the correlation between physical log and undrained shear strength profile. The shear wave profiling along with routinely used methods (water content and Von Post classification) carried out at the sites allowed to establish the layering, thickness, distribution and strength profile of the peat at each study area.

In general, the Norwegian peat (with focus on the Trondheim area) have water contents around 500-1000%. The peat thickness at the sites generally ranges from 3-4 m with exceptional sites having peat thicknesses up to 12 m. The most common von Post number is 3 which means very slight degree of humification / decomposition. This data is similar to values for peat from other countries [9]. The same authors present also typical geotechnical values for the Norwegian peat (see Table 1).

Table 2 Typical geotechnical values for the Norwegian peat [9].

Parameter	Value
Total unit weight	10-12 kN/m³
Organic content	90-99%
Water content	500-1000%
Degree of humification	H3 (H2-H4)
Peat thickness	3-4 m
Preconsolidation stress	10-12 kPa
Modulus number	3-10
Coefficient of consolidation*	3-30 m²/year
Undrained shear strength	2-8 kPa at 0,6 m (DSS)
Resistivity	50-350 Ωm
Shear wave velocity	16-24 m/s

*just beyond the preconsolidation stress

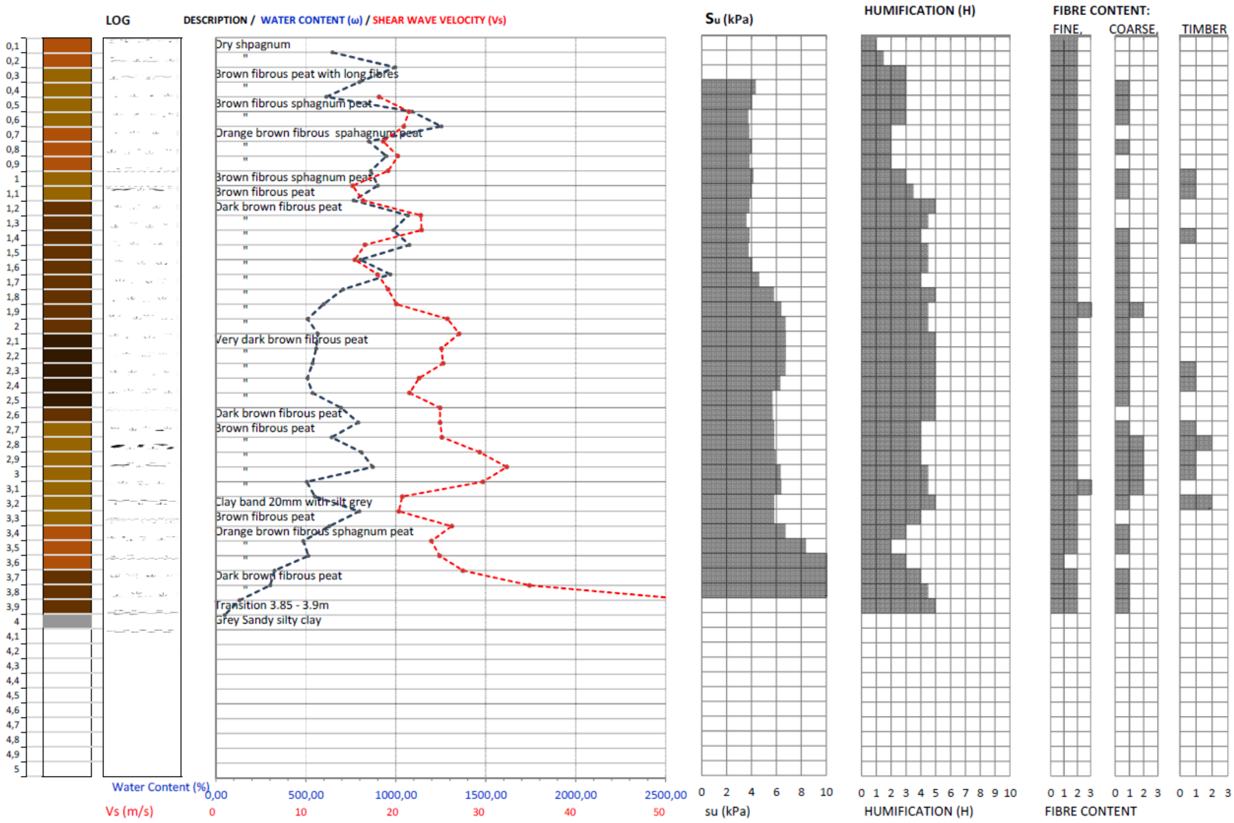

Figure 8. Example output from vertical shear wave profiling showing correlation between physical log and undrained shear strength profile for a peat site around Trondheim surveyed in 2019

6. Use of geophysical techniques in peat characterization

6.1. Ground penetrating radar

Ground penetrating radar (GPR) techniques involve the transmisison and reflection measurement of electromagnetic waves. The penetration depth achievable depends on the nature of the peat (especially its electrical conductivity), the location of the water table and on the frequency of the transmitted wave.

These techniques have been also used successfully for many years in Sweden [20], Finland [21] and the US [22] for the determination of the thickness of both the road pavements and that of the underlying peat. This work also showed that not only could the peat thickness be estimated accurately, some information can be obtained on the material beneath the peat.

To date most equipment has involved moving a single frequency transmitter over the surface of the peat. For example [23] reported on use of a 100 and 250 MHz transmittera for the survey of a large area of peatlands in Central Ireland, either by man hauling the antenna or by use of all terrain vehicle (Figures 9a and 9b). A variety of challenging conditions can therefore be dealt with. In this study it was found that the maximum depth of penetration for the 100 MHz transmitter in Irish raised bogs was typically 6 m.

Transmitters with varying input frequency have also been used. For example for the equipment shown on Figure 9c the input frequency can be altered by changing the length of the boom. In Ireland it has been found that a good compromise between depth of penetration and resolution of data can possible be found by combining results from two different frequency inputs, e.g. 80 MHz and 40 MHz [24], [25].

Some output from the work at Clara raised bog in Central Ireland in shown on Figure 10. Probing (left hand side on Figure 10) revealed approximately 5.6 m of peat over silt and clay. This boundary is clearly identified in the GPR data. In addition GPR is able to resolve some internal boundaries in the peat for example that at about 2.5 m between the sphagnum and underlying fen peat. Further work in this area is well warrented.

GPR work is now usually linked to an accurate GPS system which allows spatial relocation to GPS co-ordinates as well as providing topographic information. These systems are now being used regularly in design and risk assessment for infrastructural works on peatlands. The example on Figure 11 is for a windfarm site in western Ireland where the combined GPR, LiDAR and GPS data are integrated to produce contour maps for planning and design purposes.

6.2. Electrical resistivity tomography (ERT)

Long et al. [26] used two-dimensional (2D) electrical resistivity tomography (ERT) surveys at the sites of some failures in two Irish raised bogs. An electrode spacing of 2 m was chosen in order to provide an adequate trade-off between depth and resolution. ERT output from one of the sites is shown on Figure 12. Peat thickness is clearly defined. The profile also shows a clear thinning of the peat in the area of the failures corresponding to a reduction in volume from dewatering by edge drains / peat harvesting. This finding is supported by detailed water content measurements. It was also shown that the peat base topography is relatively flat and indicates that the observed surface movement has come from within the peat rather than from the material below the peat.

A reduction in resistivity was observed towards the edge of the failure, relating to a reduction in measured water content. The relationship between water content and resistivity may, following further work, provide an innovative way in which to monitor the relative fluctuations in water content in peat without the need for in situ sampling and subsequent laboratory testing. This approach would be very useful where continued access to sensitive sites is not possible.

Figure 9. (a) Man hauling 250 MHz antenna and (b) all terrain "quad" with 100 MHz antenna and (c) variable frequency antenna

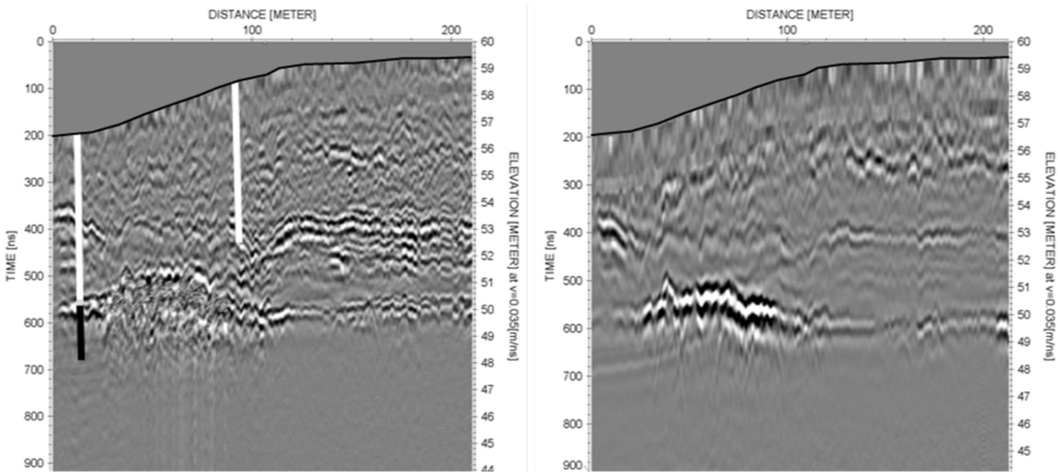

Figure 10. Output for 80 and 40 MHz transmitters at Clara bog [24, 25]

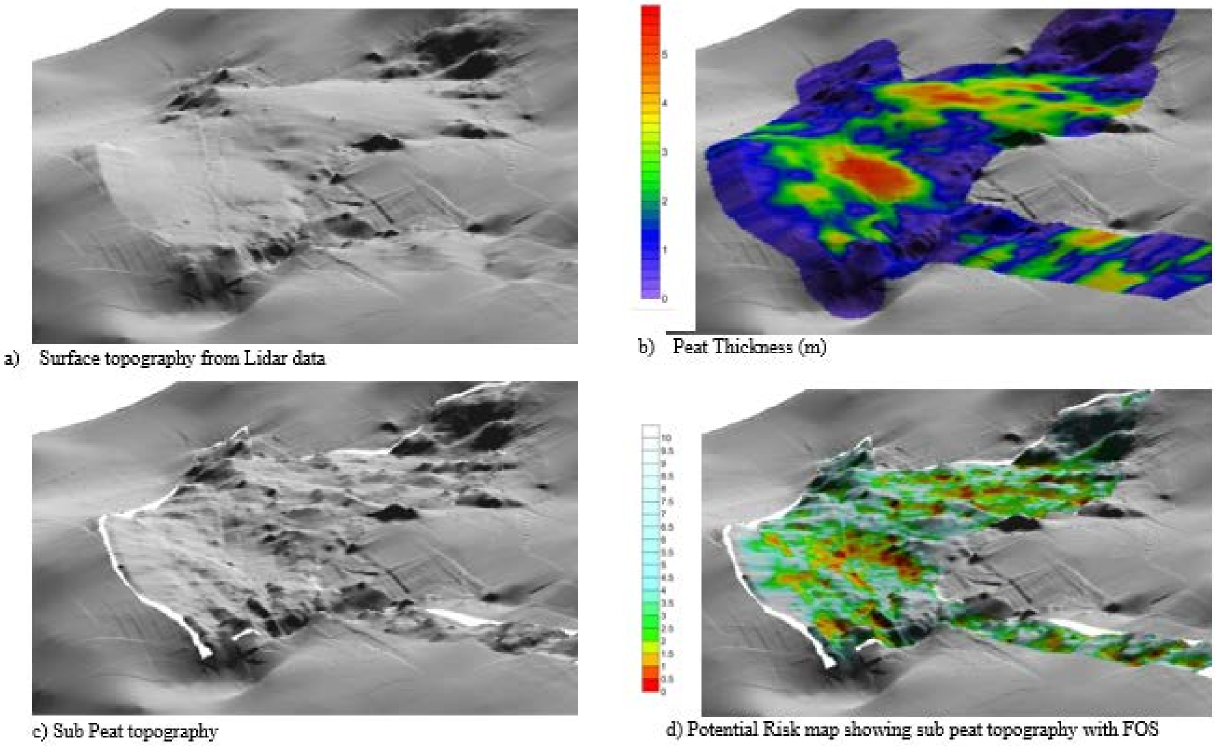

Figure 11. Results from GPR investigation of peat site in Connemara, Ireland [25]

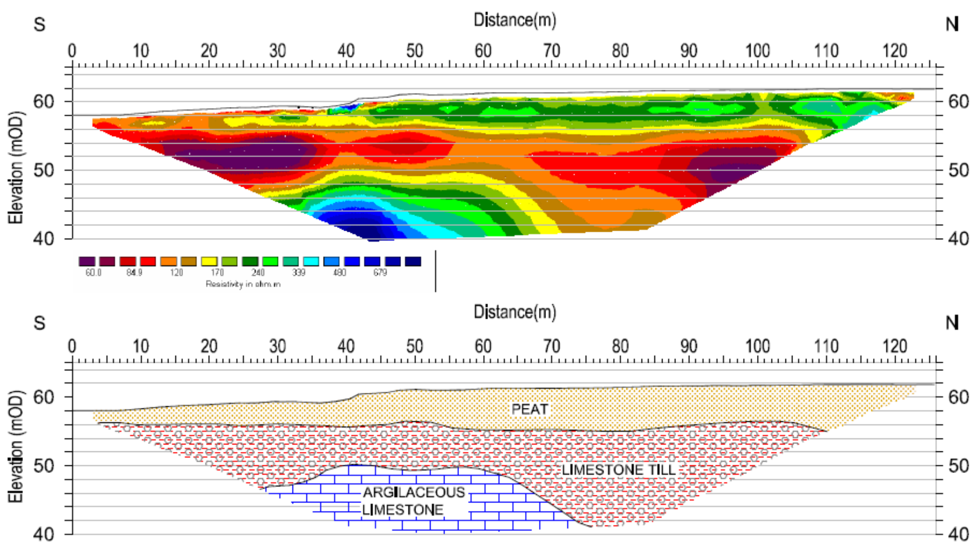

Figure 12. ERT profiles for Carn Park rasied bog in Ireland [26]

6.3. Shear wave velocity profiling

Trafford and Trafford and Long [24, 27] describe a portable downhole sonde which has been developed in order to take shear wave velocity V_s readings through the vertical peat column. The V_s profiles can help identify variations in peat properties across a site, in particular the influnece of drainage or any construction activities on the peat. It is also hoped to develop correlations between V_s and undrained shear strength. The objective was to produce a lightweight down-hole sonde for the purposes of measuring V_s of peat in remote environments.

The sonde is connected to a seismograph and records as single channel data at different depths within the peat. A shear wave was produced at the surface by striking a hammer against a block within the peat. An integral trigger within the source was used to start the recording of the traces. A reference geophone was also used to check the consistency of the time break. The integral trigger switch was found to be both reliable and repeatable. The down-hole field set-up is shown on Figure 13a. The down-hole sonde and shear wave source are shown in diagrammatic form on Figure 13b.

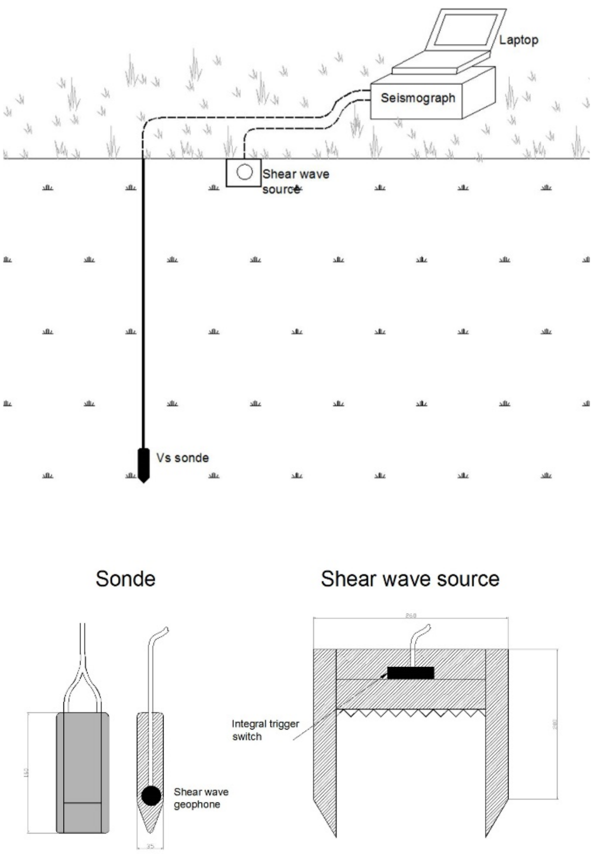

Figure 13. Shear wave velocity profiling (a) down-hole field set up and (b) sonde and shear wave source [25]

An example of a shear wave velocity profile for a site in Trondheim is shown on Figure 8 together with the profile of undrained shear stregth (s_u) versus depth that was derived between correlations between V_s and s_u from laboratory direct simple shear testing.

Work is ongoing on the development of a relationship between in situ V_s and the undrained shear strgth of peat for the purposes of landslide stability assessment.

7. Laboratory model test

In an on-going research project at the Swedish Geotechnical Institute, an extensive suite of 1g laboratory model test on fibrous peat have been conducted. The test set up including loading frame and loading system are shown in Figure 14.

Figure 14. Test set up for 1g laboratory model tests.

In the project new equipment and techniques have been developed for field sampling of "undisturbed" large block samples (1x0,5x0,25 m^3) and for model testing of these large samples, including loading equipment and trimming and installation of sample in test cell. Deformations of the loaded peat has been captured by continously taking photographs of the sample with the white markers installed in the sample behind a transparent wall, see Figure 14. PIV (particle image velocimetry) techniques have been used to analyse the movements of the markers from the photograhps.

The aim of the project is to contribute to a better understanding of how fibrous peat soils can be deformed below embankments (through laboratory model tests) and as an experimental basis for the future development of better material models for fibrous peat soils. The need for this research has been pointed out in [28] and [29].

Model tests have been conducted with loading at the upper surface of the sample with either mid-plate (simulating embankment only) or with mid-plate plus two side plates (simulating embankment plus two pressure berms). In addition fast (´undrained´) and slow (drained) loading rates have been applied to the mid-plate. Pore pressures have been measured through a needle at 3 cm or 10 cm below the mid-plate. The mid-plate can automatically either be stress controlled or deformation controlled but the side plates can only be stress controlled through dead weights.

Figure 15 shows a photograph of one of the tests where side plates were used. The photograph was taken at a deformation state before failure occured. In the photograph it can be seen that the two side plates, (which here are kept at the constant stress of 20 kPa while the mid-plate is controlled through constant vertical movements) are tilting. This as a result of the deformation of the peat, tensile stresses and tensile strains caused by the movements of the mid-plate, contributes to the tilting movements.

Figure 15. Model test with mid plate and side plates.

From the results of the laboratory model tests thus far, some conclusions that can be made are:

- the model tests are repeatable,
- the deformation pattern of the peat, identified through markers, can be followed and seems reasonable,
- failure and local failure can be identified by studying the movements of different markers (and photographs),
- by calculating the movement velocity of a marker between the different time steps (between each photo) an objective measure can be used to define failure.
- with side plates the vertical stress (bearing capacity) is higher of the mid plate than without side plates.

8. Conclusions

This paper gives a brief summary of some of the work to date of the ELGIP (European Large Geotechnical Institutes Platforms) working group on peat behaviour. The main purpose of the group is to collaborate in solving engineering peat related problems and improving tools for practical engineering. The paper outlines some of the progress that has been made by group members in recent years. This has involved comprehensive laboratory work including the development of new testing devices, for example novel 1g laboratory model tests to aid the understanding of embankment foundations in peat, new sampling techniques for peat, full scale highly instrumented field trials, developments in the use of various geophysical methods in characterising peat as well as comprehensive peat characterisation in the Trondheim area of Norway.

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