Geotechnical characterization of Norwegian peat: database

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Abstract. Peat is widely available in the Northern hemisphere and tropics. However, soil mechanics traditionally focuses on sands, clays and silts, and there is relatively little attention given to peats. Still, many engineering peat related problems like differential settlements or slides have an impact on society. The present paper presents the results of a large data collection of Norwegian peat properties from different consultancy and research projects related to road constructions and field tests during the last 60 years. Basic and advanced peat data like water content, von Post classification, total unit weight, organic content, shear wave velocity, deformation and strength properties are gathered in the database. The data presented may contribute to a larger database from different countries that will help to understand the behaviour of peat, define the best site investigation techniques in the laboratory and the field, and propose better practices on how to deal with peat in the future, towards more sustainable geotechnical solutions.

1. Introduction
Peat is frequently found in the high latitudes of the Northern Hemisphere. Canada and Russia have the most extensive areas of peatlands although extensive areas are found in northern Europe, especially Fennoscandia. This type of soil has high compressibility and low strength when subjected to external loads from civil engineering structures. To geotechnical engineers, peat is an example of extreme type of soft soil (or problematic type of soils) often leading to problems like differential settlements or slides that have an impact on society. Therefore, a common solution is to remove the peat layer in many civil engineering works or stabilize the peat layer by drainage, preloading, among other methods.

Due to population increase and demand for social improvements, there is a strong need to find better ways to cope with peat soils while keeping project costs as low as possible. Understanding peat behavior is necessary to help overcome some of the nowadays challenges, like for example resilience of infrastructure, CO2 emissions from the development of infrastructure projects and climate change adaptation.

According to NIBIO, there is 28 300 km\textsuperscript{2} of peat in Norway which represents 9% of its country area. Trøndelag is the largest peat region in Norway where peat covers 18% of its surface area. It is estimated that 10 000 m\textsuperscript{2} of peat can store ca. 5 000 tons of carbon and that Norwegian peat areas contain carbon equivalent to Norway's total climate emissions for 66 years [1].

This paper presents a database of peat properties in Norway. The aim is to characterize the Norwegian peat from a geotechnical perspective. The data has been collected from different road projects and fields tests performed in Norway during the last 60 years. The database mainly contains basic and advanced peat data like water content, von Post [2] classification, density, organic content, shear wave velocity, strength and deformation parameters. The data presented will be added to a larger database from different countries (that are mainly part of ELGIP: European Large Geotechnical Institutes Platform).
that will help to understand the behavior of peat, define the best site investigation techniques in the laboratory and the field, and propose better practices about how to deal with peat in the future, towards more sustainable geotechnical solutions.

2. Data collection
Data from 19 sites around Norway has been collected. Seventeen of the sites are under the marine limit. The sites included in the database are presented in table 1. Selection of the sites was based on two main criteria: a) available information regarding peat thickness and/or b) available sampling data or advanced test data (i.e. geophysics). The type of data collected is described in figure 1, while the site locations are shown on figure 2. Based on the original collected data, seven sites were selected to conduct field work during summer 2019. These sites are in Trøndelag, near Trondheim. The new data collected is included in the database.

The data collection includes 464 data points for water content, 483 data points for peat thicknesses, 469 data points for sampling depths, 62 data points for total unit weight, 56 data points for organic content, 383 data points for von Post [2] number and 263 data points for shear wave velocities.

The majority of the collected samples included in the database come from 0 - 2 m (327 samples) representing almost 70% of the samples in the database. The typical total unit weight is 10-12 kN/m². The most typical value for organic content is in the range of 90-99 % indicating a very high organic content of the material. The preconsolidation stress mostly varies between 10-12 kPa. The modulus number (m) varies between 3-10 and the coefficient of consolidation just beyond the preconsolidation stress varies between 3-30 m²/year.

The undrained shear strength (s_u) depends on the consolidation stress and the method used to determine it. A few samples included in the database had s_u values varying between 1.5-8 kPa when a fall cone test (these samples come from 2.5 m depth) was performed and 12-18 kPa when using a vane test (the tests were carried out between 0.5-2.0 m depth). New collected samples from Trøndelag were tested in a DSS apparatus and the values varied between 2 kPa and 8 kPa. It should be remarked that the range of deformation and strength parameters are strongly influenced by the lack of advanced testing (i.e. CRS, peat odometers, triaxial tests or direct shear). Only a small sample is available to establish typical values.

Figure 1. Type of data included in the database
Figure 2. Location of sites included in the database. The numbers refer to the sites of table 1.

Regarding some of the geophysical data about resistivity, ERT (Electrical Resistivity Tomography) measurements collected in the database vary between 50-130 $\Omega$m while AG (Airborne Geoscaning) measurements gave values varying between 100-350 $\Omega$m.

Figure 3 shows the range of water content, peat thickness, sample depth, total unit weight, organic content, von Post [2] number and shear wave velocity available in the database. For example, natural water content ($w$) range from 100% to 3000%, with most of the data in the range 500-1000%. The most common peat thickness is 3-4 m with some samples coming from peat areas with thicknesses between 11-12 m. The most common von Post [2] number is 3 which means very slight degree of humification. The shear wave velocity values are mostly around 16-24 m/s.

3. Large scale field tests
Reports from large scale field testing on peat areas in Norway are available in the literature. An example is the work of Gautschi [3] with test fields near Kongsvinger and Oslo where dams were built on peat areas and settlements up to 31% of the original peat layer thickness at different depths were registered during a period of 100 days. Some of the peat data reported by the same author have a von Post [2]
classification of H2-H3 with water content values of 1080-1910%, organic content of 98-99% and total unit weight of 10.18-10.29 kN/m³. Another set of samples by the same author have von Post [2] classification of H5-H10 with water contents varying between 610-1090 %, lower organic content (60-79%) and a similar total unit weight of 10.44-10.64 kN/m³.

Hove [4] followed a similar procedure for calculation and measurement of settlements as presented by Gautschi [3] to calculate the settlements as a result of drainage of a peat area at Liermossen in the south-east of Norway. The peat there was homogeneous. Settlements up to 10% of the original peat layer thickness were measured after 5 years of completion of the drainage measurements. Good agreement between the calculated and measured values were found.

Hove [5] presented the results of full-scale loading trials at Heimdalmyra, Norway. Full-scale loading trials were undertaken to assess the feasibility of constructing noise protection bunds of locally excavated peat. Several loading trials were undertaken; for example, a 2.5 m high noise protection bund at Station 5 (c. 25 kPa load) and the 0.5 m gravel platform at Station 3 (c. 10 kPa load). Long and Boylan [6] have further analyzed this data and discussed that at Station 3 the consolidation was rapid, and that primary compression was completed about 2 days after initial loading. It was assumed that the applied stresses did not exceed the yield stress (especially for Station 3) and hence the rapid rate of consolidation.

| ID  | Site                              | Full scale tests | Sampling | Soundings | Geophysics |
|-----|-----------------------------------|------------------|----------|-----------|------------|
| 1   | Brumunddal-Lillehammer            | x                |          |           |            |
| 2   | Dyrstad (Fv17)                    | x                | x        |           |            |
| 3   | Betna-Klettelva (Betnamyra)       | x                | x        |           |            |
| 4   | Haukvanet                         | x                | x        | x         |            |
| 5   | Havstein                          | x                | x        | x         |            |
| 6   | Heimdalsmyra (Kattem)             |                  | x        | x         | x          |
| 7   | Leibrumyra-Granåsen               |                  | x        | x         | x          |
| 8   | Leistad (Ranheim-Væernes)         |                  | x        | x         |            |
| 9   | Lund                              |                  | x        | x         |            |
| 10  | Moss                              |                  | x        | x         |            |
| 11  | Nybakk-Slomarka                   |                  |          |           |            |
| 12  | Paulertjønn + Solum               |                  | x        | x         |            |
| 13  | Ramdalsmyra                       |                  | x        | x         |            |
| 14  | Ringeriksbanken E16               |                  | x        | x         | x          |
| 15  | Rv710 Selva-Agdenes               |                  | x        |           |            |
| 16  | Steinarmyra/Dravigoll             |                  | x        |           |            |
| 17  | Tanemsmyra-Klæbu                  |                  | x        | x         |            |
| 18  | Tiller-Flotten                    |                  | x        | x         |            |
| 19  | Ugla                              |                  |          |           | x          |
Figure 3. Histogram distributions of typical values of the data in Norwegian peat database.
Trondheim municipality [7] presented some measurements of the peat layer thickness at Granåsen (Leirbrumyra). The area had been used as a parking place since 1980 and filling with gravel has periodically been done during 1980s-2010s. Settlements have been observed during this period. In 2015, soundings indicated that the gravel layer was varied between 0.7-1.4 m thickness with some points up to 3.7 m. Measurements from 2015 estimate that the peat layer has experienced around 30-50% vertical deformation during a period of around 30 years.

SVV [8] summarized the settlement measurements performed at Rv.710 Selva-Agdenes where a road was built on a peat layer with thickness up to 2.3 m. The road embankment was built higher than needed to compensate for settlements after 1.5 years. Settlements up to 0.8 m were registered after 5 months. The main contribution to the settlements occurs during the first two weeks.

These field cases show the importance of field measurements for estimation of settlements and also the importance of understanding the variation in parameters depending on whether you are less than or more than the preconsolidation stress. Additional analyses of these cases are out of the scope of this paper and will be presented in a publication by the same authors [9].

4. Comparison of the Norwegian peat with peats from other countries

Tropical peats [10] like the ones found in West Malaysia show water content between 200 and 700%. In the east of Malaysia, the water content can increase up to 2007%. The high water content values are explained by the same authors to be an effect of the high fibre content (>65%) which allow more water absorption.

Three peat sites in Sweden (Färgelanda, Ageröds Mosse and Mullsjö) [11] show von Post values between 3-7 at shallow depths (< 2 m) and between 5-6 at larger depths. The water content values at the same sites varied between 800-1250% with some values close to 2000%. Shear wave velocity measurements increased with depth from 15-20 m/s up to 25-30 m/s around 6 m depth.

Long [12] presents a review of peat strength and peat characterization with reference to landslides. The characteristics of Irish peat are very similar to those of the Norwegian peats presented here with water contents typically between 750% and 1000%, unit weight about 10 kN/m³ and organic contents often close to 100%. An issue in characterising Irish peat for landslide studies concerns the estimate of undrained shear strength. Methods commonly used for mineral soils such as in situ vane or CPTU testing or laboratory triaxial testing often prove problematic in Irish peat. Recent efforts have involved use of in situ shear wave velocity measurements correlated against direct simple shear tests [13].

Forsmann et al. [14] describes Finnish peat to be 1.4 m thick in average with depths down to 4-6 m in the south of Finland. Common water content values vary between 500 and 2000%. Ronkainen [15] reports that the mean water content for Finnish peats is 710% and median 673% (N = 172). The same author reports a mean unit weight of 10.3 kN/m³ (N = 159). The undrained shear strength of normally consolidated fibrous peat may range between 6 and 7 kPa. Undrained shear strengths defined with vane test are reported to be between 5 and 30 kPa, with majority of results occurring between 10 and 15 kPa.

Zwanenburg and Erkens [16] presented data for a Dutch peat site "Uitdam". The peat there was classified as H2-H3 on the von Post [2] scale. The total unit weight for the peat deposit was 9.5 kN/m³ ± 7% which is slightly lower than the density of pore water and it can be explained by the observed presence of gas. Consequently, there are low effective stresses in the peat layer. Organic content varied between 75% and 92%. The water content varied between 640% and 1240%. Shear wave velocity measurements varied between 15-25 m/s.

In general, it seems that Norwegian peat does not differentiate much from the peat found in other countries. A particularity for the Norwegian peat is the presence of thick deposits (i.e. larger than 6 m). Boreal peat accumulation rates are typically 1 mm/year or less [17]. Higher accumulation rates are typical for warmer climates. The conditions for thick formations of peat in some parts of Norway might be related to local climate conditions (i.e. special summer/winter conditions) and local water table. However, this should be further investigated.
5. Summary and conclusions
The present paper summarizes the peat data collected from 19 sites and 5 large scale tests since 1960s. Based on that, a database of peat properties, including index data, strength and deformation characteristics and geophysical data has been established. Furthermore, 7 sites were chosen to collect additional field and laboratory data (i.e. DSS, CRS and peat odometer tests). Results from the advanced testing will be presented in a separate publication [9].

Most of the peat samples in the database 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 [2] number is 3 which means very slight degree of humification/decomposition. The data is compared to peat from other countries and many similarities are found.

Table 2 summarizes typical geotechnical values for the Norwegian peat based on the results of the present study.

| Parameter                                              | Value                        |
|--------------------------------------------------------|------------------------------|
| Total unit weight                                      | 10-12 kN/m³                  |
| Organic content                                        | 90-99%                       |
| Water content                                          | 500-1000%                    |
| Degree of humification according to von Post [2]       | 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

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