The effect of weather conditions on the trafficability of unfrozen peatlands

Jari Ala-Ilomäki


Abstract. The trafficability of peatland was studied on six bogs in Central Finland by measuring the modulus of elasticity E using a plate loading device. Tests were performed using a circular plate 0.21 m of diameter and a penetration rate of 0.06 ms⁻¹. The total of 218 plate load tests were accomplished on 38 test sites. The bogs were measured four times through the unfrozen season of 2005.

Ground water table depth was chosen to describe the effect of weather conditions. Additionally, the test bogs were described in terms of i.a. the basal area of standing timber, the wetness class of the bog as estimated by the boot method and the degree of decomposition of peat.

Ground water table depth on the bogs varied from 0.18 m to 1.0 m and its variation during the study on one bog was between 0.04 and 0.75 m. The average E of the bogs varied from 144 kPa to 675 kPa.

Ground water table depth variation within the bogs did not have a notable effect on the E, nor did it explain the variation in E between the bogs particularly well. E was best predicted by the basal area of the standing timber. Also the wetness class proved to predict E well since the boot method results actually indicate both wetness and the mechanical strength of the peatland.

Key words: Trafficability, peatland, plate load test, modulus of elasticity, precipitation, ground water level

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Introduction

In Finland, the importance of drained peatlands as a source of roundwood is increasing steadily as the thinning of the stands is becoming acute. The biggest problem when operating in peatland forests is, in addition to poor economy, the low bearing capacity of unfrozen peatland. This is especially true since the tendency in commercial wood harvesting has been towards all-round wheeled machinery with the aim of one machine coping with a large variety of site conditions on mineral soils. These machines are best suited to peatlands during the frost in the wintertime, when the modulus of elasticity E can easily be 10³ fold compared to unfrozen conditions (Onninen, 1990).

The trend in wood harvesting is towards a constant supply of roundwood during the year, as opposed to traditional harvesting in the wintertime. Presently the bearing capacity of soil is not measured in conjunction with harvesting but the bearing capacity is estimated based on the experience of the foreman or the operator. The year-round utilization of all-round wheeled harvesting machinery on peatlands would greatly benefit from a fast and easy-to-use method for measuring trafficability.
Peatland usually consists of top layer with living and slightly decomposed plants, followed by a decomposed peat layer and finally mineral soil. From the trafficability point of view the top layer with considerable tensile strength is essential, and it should not be broken through if a further pass with the vehicle is planned. The strength of the top layer is subject to the variation of density and species of the vegetation, resulting in extreme spatial variation of trafficability.

Ala-Iломäki (2004) predicted the trafficability of unfrozen peatland by measuring E with plate load method and the more down-to-earth method of estimating the bearing capacity and wetness class with the observer’s boot. Both methods were found to be useful predictors of trafficability although the problem of large spatial variation in trafficability remained. The variable with strongest correlation with predicted bearing capacity was the basal area of the stand.

Precipitation or the variation in moisture in peat was not studied in the work of Ala-Iломäki (2004). At least in the field of wood harvesting the amount of precipitation has traditionally been considered as an important factor when estimating the trafficability on peatlands. This may seem a bit contradictory to the fact that the moisture of peat soil is usually around 80 to 90% (Päivänen, 1990). This is especially true since the vertical pressure due to vehicular loading by harvesting machinery typically extends down to the depth of 0.3 to 0.4 m with half of its value at the contact surface. On the other hand precipitation may not be expected to have an influence on the mechanical strength of the crucial top layer of peatland, save for the friction between the members of the compressed vegetation mat.

This work aims at finding out the effect of weather conditions on the trafficability of unfrozen peatland.

Material and methods

The study methods regarding the properties of peatland in the work at hands were similar to those utilized in Ala-Iломäki (2004). The simplified pressure-sinkage relationship of peatland in plate load testing (Figure 1) is characterized by linear increase of pressure with increasing sinkage (Equation 1) up to the punching pressure, followed by a decreasing pressure until the nearly constant response of the decomposed peat is reached. Generally speaking loading due to vehicular traffic should not exceed the linearly increasing part. Therefore E of peatland was determined based on the linearly increasing pressure in plate load tests according to Equation 2 (Wu, 1966; Ala-Iломäki, 2005).

![Figure 1](image-url)
\[ p = b \cdot z \]  \hspace{1cm} (1)

\[ E = \frac{1.5 \cdot p \cdot r}{z} \]  \hspace{1cm} (2)

\[ E = 1.5 \cdot b \cdot r \]  \hspace{1cm} (3)

where
\begin{align*}
b & = \text{Slope of the increasing pressure, kg m}^{-1}s^{-2} \\
P & = \text{Modulus of elasticity, kPa} \\
p & = \text{Pressure, kPa} \\
r & = \text{Radius of the loading plate, m} \\
z & = \text{Sinkage, m}
\end{align*}

The modulus of elasticity was determined on three peatlands in Central Finland on April 27, August 10, November 12 and November 17 in 2005. On the peatlands, six experimental areas with different peatland properties were chosen, later to be called bogs 1 to 6. In plate load tests, a circular plate 0.21 m of diameter and loading rate of 0.06 ms\(^{-1}\) was utilized. A total of 218 plate load tests were performed on 38 test plots.

The measurements on the test plots were made both at the exactly same spot each time and changing the measurement spot on the plot each time. When several measurements were made at the same spot loading was kept well under puncture load, repetitive loading thus having a negligible effect on \(E\) (Ala-Ilomäki, 2005). The location of the measurement spots was chosen avoiding visible tree roots, hummocks etc. in order to achieve homogeneous conditions. In practice this resulted in measuring spots representing the low end of the variation of bearing capacity on the bogs.

The variable chosen to describe the effect of weather conditions was the depth of ground water table measured from pits dug for the purpose. The timing of the experiments aimed at maximum variation in the depth of ground water table. The first measurements were performed right after snowmelt, when lots of surface water was present.

Variables having the strongest effect on trafficability (Ala-Ilomäki, 2005) were measured on the bogs. The relative wetness class was determined by the sinkage of the observator’s boot, the classes being 1=sole does not get wet; 2=sole gets wet; 3=boot tip gets wet; 4=boot leg gets wet; 5=water enters the boot (Lappalainen et al., 1978). The degree of decomposition was determined on von Post scale ranging from 1=poorly decomposed to 10=fully decomposed (Laine & Mannerkoski, 1983). The basal area of the stand was measured and the amount of trees or tree fragments in the peat was determined by the percentage of hits in probing with a metal rod up to 1 m and 2 m depth. Additionally, the depth of peat deposit and the surface layer with live roots were measured.

**Results**

**Properties of the studied bogs**
The properties of the examined bogs are presented in Table 1. All studied bogs were drained, yet on bogs 1 and 2 the ditches were in such a poor condition that they had little effect in draining. The ditches on bogs 4 and 5 were cleared between the 2\(^{\text{nd}}\) and 3\(^{\text{rd}}\) measurement. The ditch network on bog 6 was scarce.
The amount of standing timber varied between the bogs. Saw-log stand occupied bog 3, bogs 4 and 5 were typical drained peatlands with fair stands whereas bogs 1, 2 and 6 were representative for drained peatlands with low timber volume and increment.

The depth of peat deposit varied from 0.3 m to over 4 m. Bog 4 had a 0.15 m layer of fine sand below the depth of 0.20 m.

The summer of 2005 was relatively rainy, whereas rainfall in early autumn was only moderate. Average rainfall in 1971-2000 was estimated on the basis of data by Finnish Meteorological Institute (http://www.fmi.fi/saa/tilastot.htm)

<table>
<thead>
<tr>
<th>Measurement number / Date</th>
<th>Rainfall after previous measurement, mm</th>
<th>Average rainfall 1971–2000, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr 27, 2005</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Aug 10, 2005</td>
<td>326</td>
<td>185</td>
</tr>
<tr>
<td>Oct 12, 2005</td>
<td>104</td>
<td>133</td>
</tr>
<tr>
<td>Nov 17, 2005</td>
<td>68</td>
<td>64</td>
</tr>
</tbody>
</table>

The variation in the depth of ground water table is presented in Figure 1. The depth was at its deepest in the 3rd measurement and it varied most on bogs 3 and 4. Depth was fairly constant on bogs 1 and 2.

The effect of weather conditions on the trafficability

The studied bogs can be divided into two groups: on bog 3 the measurement of E was performed at exactly the same spot each measurement time whereas on the rest of the bogs measurement spot was varied each time. Therefore on bog 3 E may be expected to decrease slightly with increasing number of measurements and on the variation in E is likely to be greater on the rest of the bogs.

The effect of the depth of ground water table on E on the studied bogs is presented in Figures 2 to 4. As can be seen the variation between measurement times is greater than the variation caused by varying ground water table depth.
Figure 1. The variation in the depth of ground water table.

Figure 2. The effect of the depth of ground water table on $E$ on bog 3.

Figure 3. The effect of the depth of ground water table on $E$ on bogs 1 and 2. The letters following depth readings denote the order of measurement times.
The effect of the depth of ground water table on average E on the studied bogs on different measurement times is presented in Figures 5 and 6. Ground water level depth had no clear effect on E.

Other factors affecting trafficability
The material additionally facilitates studying other factors having an effect on trafficability of unfrozen peatland, such as stand basal area and the estimated wetness class of the bog (Ala-Ilomäki, 2005). In Figures 7 to 10 the material of individual E
measurements has been supplemented by measurements with low basal areas and extreme wetness from the data of Ala-Ilomäki (2005). The models presented yield unrealistic values at lowest bearing capacities. In practice the minimum of $E$ on Finnish peatlands is likely to be in the order of 20 to 30 kPa and the puncture pressure measured with plate 0.21 m of diameter in the order of 10 to 20 kPa.

According to Figures 7 and 8 both basal area and wetness class can be used to predict $E$ satisfactorily especially on the bogs with lowest bearing capacity. Increasing average bearing capacity leads to increasing variation in spot vice bearing capacity since tree roots and the like occupy more of the area available. The relative wetness class as determined by the sinkage of the observator’s boot predicted $E$ far better than

Figure 5. The effect of the depth of ground water table on average $E$ on bogs 1 to 3.

Figure 6. The effect of the depth of ground water table on average $E$ on bogs 4 to 6.
Figure 7. Modulus of elasticity E as a function of stand basal area.

Figure 8. Modulus of elasticity E as a function of estimated wetness class.

Figure 9. Modulus of elasticity E as a function of ground water level depth.
Also the puncture pressure the surface layer of peatland, critical concerning the immobilization of a vehicle due to excessive sinkage, can fairly well be predicted with $E$. The size and shape of the plate will affect the observed puncture pressure, but this can be overcome by using the slope of the increasing pressure $b$ (Equation 3) in prediction. The results presented in Figure 10 were obtained with a circular plate 0.21 m of diameter.

**Discussion**

Based on the study material variation in ground water level depth on a particular bog did not have a strong influence on $E$. Also variation in ground water level depth between bogs does not explain variation in $E$ particularly well. The general opinion amongst wood harvesting professionals that rain decreases trafficability on peatlands may thus partly be based on the fact, that peatlands usually are surrounded by wet mineral soils with poor bearing capacity. The trafficability of these soils is deteriorated by precipitation. The wetness class as determined by the sinkage of the observer’s boot actually indicates both the wetness of the peatland surface and its bearing capacity. Therefore, the boot test is capable of predicting $E$ far better than the depth of ground water table.

In the present study $E$ was best predicted by the easily obtainable stand basal area. This is in accordance with the previous study of the author (Ala-Ilomäki, 2004).

The summer of 2005 was not a particularly dry one, so it can be asked if the effect of ground water level depth may have been greater in 2006, when the summer was exceptionally dry. On the other hand the variation in ground water level depth on bog 3 was remarkable without a clear effect on $E$.

The location of the measurement spots was chosen in order to achieve homogeneous conditions. In practice this resulted in measuring spots representing the low end of the variation of bearing capacity on the bogs, the real variation of bearing capacity probably being greater. Yet the variation on one particular bog on one measuring time was large, reflecting the fact that spatial variation is one of the biggest problems in estimating the trafficability of peatlands.
Future emphasis in research should be focused on developing a fast and easily operated measuring method for bearing capacity, possibly based on the boot method, to refine the trafficability estimate based on stand basal area.

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References

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