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Assessment of peat compressibility: is there an easy way?

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Abstract

Peat compression can significantly alter the hydraulic parameters that govern flow and storage of water. Physical properties of peat (bulk density, state of decomposition (von Post number, vP) and fibre content) were assessed to determine whether they can be used as indicators of peat compressibility. Bulk density and vP were related to each other (positively), and within a given core were related (negatively) to compressibility. Peat from different locations exhibited different compressibility characteristics for a given value of bulk density or vP. Fibre content was unrelated to bulk density, vP, or to peat compressibility. It was concluded that more commonly and relatively easily measured soil parameters are not good indicators of soil compressibility. Copyright © 2005 John Wiley & Sons, Ltd.

Key Words peat; consolidation; compressibility; von Post; bulk density; fibre content

Introduction

The hydrological implications of peat compressibility have scarcely been considered in the literature. A few studies, however, have shown that change in peat volume caused by water table fluctuations is an important water storage mechanism in peatlands (Chow *et al*., 1992; Price, 2003), and may be essential to evaluating the water balance correctly (Price and Schlotzhauer, 1999). Changes in peat volume also influence moisture content of peat near the surface (Kellner and Halldin, 2002), redox conditions that affect carbon exchange (Strack *et al*., 2004), and ecological responses dependent on water table depth (Bubier, 1995). In engineering applications, peat compressibility is important for road and foundation design (Hobbs, 1986). Although there have been numerous measurements made of peat compressibility for engineering applications with high loads (McFarlane, 1969), scarcely any have been reported for small loadings associated with seasonal water table fluctuations (Price, 2003) or peat drainage (Silins and Rothwell, 1998). However, in developing a model that includes peatland transient hydrologic properties, Kennedy and Price (2004) have shown that water balance simulations are very sensitive to peat consolidation characteristics.

Compressibility is a function of soil structure (Spivey *et al*., 1986). Increases in effective stress (loading) cause water to be expressed from pore spaces, resulting in soil settlement. This process was documented by Terzaghi (1943) as

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$$\sigma' = \sigma - \psi \qquad (1)$$

whereby increases in effective stress σ' occur as a consequence of changes in total stress σ caused by external loads, or by a reduction of pore-water pressure ψ (all units in kilopascals). In natural and artificially drained peatlands, changes in water table position can cause changes in effective stress large enough to alter the peat volume significantly (i.e. cause subsidence) (Roulet, 1991), decrease the hydraulic conductivity of the soil (Chow *et al.*, 1992; Price, 2003), affect the water retention relationship (Oleszczuk *et al.*, 2000), and thus the pattern of soil moisture variability (Kennedy and Price, 2005).

Evaluation of compressibility is a tedious process (e.g. Rampino *et al.*, 1999), so an assessment based on more readily available and commonly determined peat characteristics would be useful. In general, it is known that deeper, more decomposed peat is more consolidated (Clymo, 1983; Ingram, 1983). However, quantification of peat compressibility on the basis of decomposition is generally unavailable.

The goal of this study, therefore, is to determine the compressibility characteristics of a variety of peat types, and to determine how they are related to the physical properties of the soil. Specifically, this note explores the relationship between compressibility and peat bulk density, fibre content, and von Post number vP.

Sampling Location and Methods

Peat was collected from two sites for which previous hydrological research has been reported: St Charles-de-Bellechasse (Kellner *et al.*, 2003) and Bois-des-Bel, Quebec (e.g. Petrone *et al.*, 2004; Shantz and Price, 2005). The site located near St Charles-de-Bellechasse (46°40′N, 71°10′W) is a remnant section of poor fen characterized by pool and ridge topography, bordered by ongoing peat mining operations that have been active for approximately 10 years (Kellner *et al.*, 2003). This study area comprises three pool–ridge sub-sites: an undisturbed control site (scb-c); an experimental pool (scb-x) in which the water table was lowered by approximately 20 cm with a drainage ditch, to replicate a change to a drier condition (see Strack *et al.* (2004) for details); and a pool similarly drained (scb-d) about 10 years previously. Peat thicknesses at scb-c, scb-x, and scb-d were 1·2 m, 1·0 m and 0·8 m respectively. Studies of peat compressibility at all sub-sites were made at peat lawns, where the dominant moss is *Sphagnum papillosum*. One peat core was extracted from fen peat lawn at each site except at scb-x, where two cores were taken, one each on the east (scb-xe) and west (scb-xw) sides of the pool. Cores were sawed out and taken up with negligible compression within 10 cm × 25 cm ventilation ducts, which were also used as containers for transportation. Cores at scb-c, scb-xe, scb-xw, and scb-d were 0·55 m, 0·45 m, 0·4 m and 0·6 m deep respectively.

Samples were also taken from a mined section of an ombrotrophic peatland (bog) at Bois-des-Bel, Quebec (47°53′N, 69°27′W), approximately 10 km north of Rivière-du-Loup. An 11·5 ha section of this bog was mined by vacuum harvesting, but abandoned about 1980 (PERG, 2003; www.gret-perg.ulaval.ca). Peat depth ranges from 1 to 3 m, and is composed mainly of *Sphagnum magellanicum* and *Sphagnum fuscum*. Restoration measures were implemented in 1999 on an 8·1 ha portion (bdb-rest), with the remaining 1·9 ha left unrestored (bdb-unrest) for comparison (Rochefort *et al.*, 2004). The 'restored' section was thus considerably wetter than the unrestored section (Shantz and Price, 2005). One peat core each was removed from the restored site (bdb-rest) and unrestored site (bdb-unrest) using a Wardenaar peat corer, both being approximately 35 cm deep. All cores were frozen after sampling.

Peat properties were assessed from ∼3 cm subsamples cut from the frozen cores. To reduce the chance of spatial bias, bulk density ρ_b and fibre content F_c were assessed from horizontally adjacent pieces of the same core. The von Post number vP and compressibility were determined from cuttings vertically adjacent to the above samples.

The vP (e.g. Clymo, 1983) is a commonly used measure of the state of peat decomposition, based upon the colour of the water, structure of the residue, and the amount of peat that passes through the fingers when the fresh peat sample is squeezed (Damman and French, 1987). The vP scale ranges from H1 to H10, with H1 being the least decomposed (Clymo, 1983).

Fibre content, a more quantitative method of describing peat decomposition than the von Post method (e.g. Boelter, 1969), was performed according to ASTM (1997). Approximately 100 g of peat of a known volume was saturated for 24 h in a dispersing agent solution of 5% hexametaphosphate to loosen the peat fibre before wet sieving began. The sample was placed on a number 100 sieve (125 μm) and water was gently washed through the sieve to expel any fine particulates until the water exiting the sieve was clear. The remaining particles larger than 125 μm were oven-dried at 103 °C until a constant mass M_{fibre} was reached. The proportion of fibre retained by the sieve F_c was determined by relating M_{fibre} to the original mass of the sample M_{sample}, where

$$F_c = M_{\text{fibre}}/M_{\text{sample}} \quad (2)$$

The original mass M_{sample} was calculated in the determination of ρ_b as outlined below.

Dry bulk density ρ_b was calculated as a step in the fibre analysis based on the original sample volume and fibre mass. The finer particles washed through the number 100 sieve in the fibre content analysis were caught on a number 400 sieve (37 μm) and placed on standard filter paper to dry at 103 °C in an oven until constant mass was achieved. This mass was then added to the fibre-content dry mass (i.e. that retained on the 125 μm sieve) to achieve the original mass of the sample M_{dry}. Finer particulates that passed through the number 400 sieve were of negligible mass. A full test capturing all particulate matter (i.e. less than 400 μm) was performed on two samples to estimate the error. For a less-decomposed peat the error was calculated at 0·50%, whereas a highly decomposed peat had an error near 3% of the original mass. ρ_b was determined using the volume of the original sample V_{sample} and M_{dry}, where

$$\rho_b = M_{\text{dry}}/V_{\text{sample}} \quad (3)$$

Compressibility was measured on a 2·5 to 3 cm thickness layer of peat. The samples were cut frozen from rectangular core blocks using a hole-saw, then thawed under water to maintain water saturation near 100%. The frozen samples were cut slightly larger than the inner diameter of the cell in which compressibility was determined, to compensate for volume decrease after thaw. The test was a one-dimensional multi-increment loading and unloading consolidation test to determine primary peat consolidation (Head, 1985). An ELE/Rowe-type consolidation cell with an internal diameter of 75·3 mm was used. These multi-increment tests were designed to replicate stress–strain relationships of peat caused by water table fluctuations (Lang, 2002). Loading and unloading tests were conducted in a stress range up to 12 kPa, but the analysis focused on the 0 to 6 kPa range, which approximates the effective stress σ' caused by seasonal water table changes (Price, 2003).

Details of the Rowe cell test are provided by Lang (2002). Briefly, insertion of the peat sample into the cell, followed by system assembly, was performed submerged in de-aerated water to maintain sample saturation and minimize sample disturbance. A porous ceramic stone and plastic plate were placed on the top and bottom of the sample to prevent clogging of the lines and to allow uniform dissipation of water pressure within the test sample. The cell was sealed top and bottom. Stress was applied to the sample by pressurizing a rubber diaphragm through an air–water interface cylinder. Pressure was kept constant using a 0–100 kPa pressure regulator, and a pressure transducer connected to a data logger recorded the diaphragm pressure at 1 s intervals. Calibration of the Rowe cell was performed prior to each test to ensure that pore water pressure, applied pressure, and transducer output were accurate and could account for bladder friction.

Testing of the sample commenced by applying an initial pressure of 7·8 kPa, which matched the hydraulic head attached to a beaker (78 cm above the Rowe cell). The Rowe cell pressure was equilibrated by opening a drainage line at the base of the cell, which drained into the beaker to establish a start point of zero for subsequent measurements. Pressures increments of 1 kPa were applied to the initial pressure and the drainage line was opened to allow water from the sample to drain into the beaker until equilibrium within the sample was reached. This process continued for each sample until a maximum of 12 kPa was reached. A linear displacement transducer measured changes in sample thickness, and a pressure transducer located at the base of the cell recorded pore water pressure changes, all at 1 s intervals.

Compressibility, determined from the slope of the relationship between the change in vertical strain $\partial\varepsilon$ and applied effective stress $\partial\sigma'$, is known as the coefficient of volume change m_v, where

$$m_v = \partial\varepsilon/\partial\sigma' \quad (4)$$

In this analysis, m_v represents the virgin compression rate, which occurs beyond the preconsolidation pressure evident from its gentler initial strain (details and theory can be found in most soil mechanics texts (e.g. McCarthy, 2001)). The gentler initial strain is called the recompression rate m_r, which occurs in the range of effective stresses previously experienced by a given soil. For example, decompression and subsequent recompression of a sample generally occur at a much lower rate than via virgin compression. To determine the recompression rate, the pressure was decreased by 3 kPa when the initial effective stress reached $\sigma' = 6$ kPa; recompression was determined from the subsequent compression caused by 1 kPa incremental increases in σ'.

Results

The properties of peat at the sampled layers are summarized in Table I. Peat at the St Charles control (scb-c) and experimental sites (scb-xe and scb-xw) was relatively poorly decomposed, with median vP of 3·5, 2 and 4 respectively. The median vP at scb-d was 7·5, and at Bois-des-Bel (bdb-rest and bdb-unrest) it was 5 and 8 respectively, indicating moderately to well-decomposed peat. There is a relationship ($r^2 =$ 0·50) between vP and ρ_b (Figure 1a), with more-decomposed peat having a higher ρ_b. However, fibre content F_c was unrelated to ρ_b (Figure 1b) or vP (Figure 1c), with $r^2 = 0{\cdot}04$ or 0·03 respectively.

F_c was also unrelated to virgin compressibility m_v ($r^2 = 0{\cdot}04$) or recompression m_r ($r^2 = 0{\cdot}05$) (not shown). Even within a site (three or four samples per site) no consistent trend emerged. In contrast, trends did exist between compressibility m_v and both vP and ρ_b (Figure 2a and b), with m_v being highest in poorly decomposed peat (low vP and low ρ_b). Although site-specific linear relationships between m_v and vP or ρ_b may exist, the sample sizes of two to four points are too small to be certain.

The peat recompression rate m_r was linearly related to virgin compressibility m_v (Figure 3). Excluding the point scb-xe_15 cm (which was the highest m_v, greater than two standard deviations from the mean and did not fall on the line)

$$m_r = 0{\cdot}26 m_v - 0{\cdot}0015 (r^2 = 0{\cdot}77; n = 16) \quad (5)$$

Also, recompression m_r had much poorer relationships with ρ_b and vP.

Table I. Physical properties of peat by site and by depth

Site	Depth (cm)		vP	F_c (%)	ρ_b (g cm^{-3})	m_v (kPa^{-1})	m_r (kPa^{-1})
	vP and m_v/m_r	ρ_b and F_c					
scb-c	9·5–12	12–15	2	93	0·05		
	25–27·5	32·5–35·5	3	49	0·08	0·020	0·0030
	41·5–44	44–47·5	4	56	0·09	0·012	0·0026
	56–58·5	52–55	4	43	0·12	0·011	0·0008
scb-d	15–17·5	13–16	5	36	0·10	0·012	0·0240
	27·5–30	29·5–32·5	6	56	0·17	0·010	0·0009
	43–43·5	45–48·5	9	48	0·15	0·011	0·0020
	55–57·5	57·5–60·5	9	32	0·22	0·008	0·0006
scb-xe	15–17·5	13–16	1	46	0·08	0·037	0·0037
	25–27·5	27·5–30·5	2	40	0·14	0·021	0·0025
	40–42·5	42·5–45·5	3	27	0·22		
scb-xw	15–17·5	13–16	3	44	0·09	0·030	0·0073
	25–27·5	27·5–30·5	4	72	0·16	0·020	0·0042
	40–42·5	37–40	5	51	0·20		
bdb-rest	10–12·5	8–11	3	75		0·012	0·0013
	20–22·5	22·5–25·5	5	74	0·17	0·01	0·0004
	30–32·5	32·5–35·5	6	65	0·12	0·008	0·0004
bdb-unrest	12·5–15	15–18	6	64	0·13	0·015	0·0012
	20–22·5	22·5–25·5	8	53	0·23	0·012	0·0030
	30–32·5	32·5–35·5	8	74	0·17	0·0127	0·0026

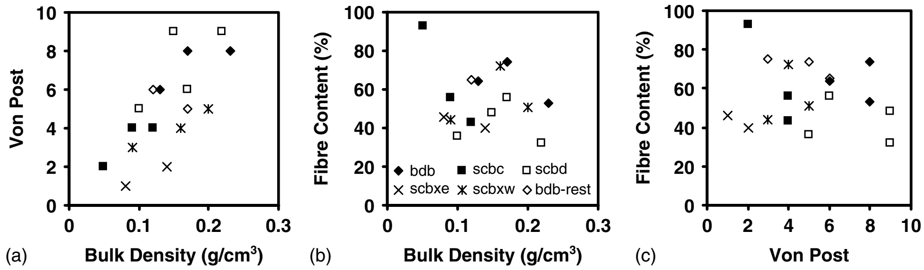

Figure 1. Bulk density versus (a) vP and (b) fibre content; (c) vP versus fibre content for peat from various sites

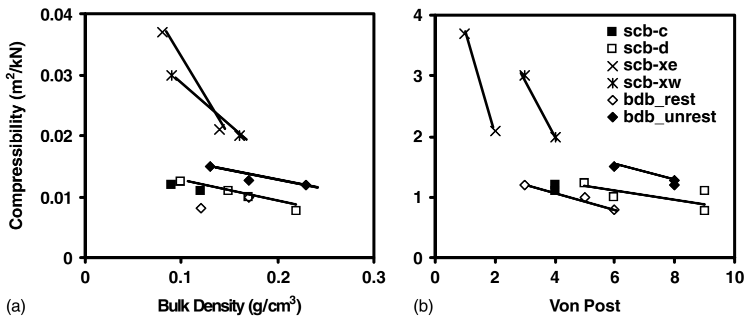

Figure 2. (a) Bulk density and (b) vP versus peat compressibility

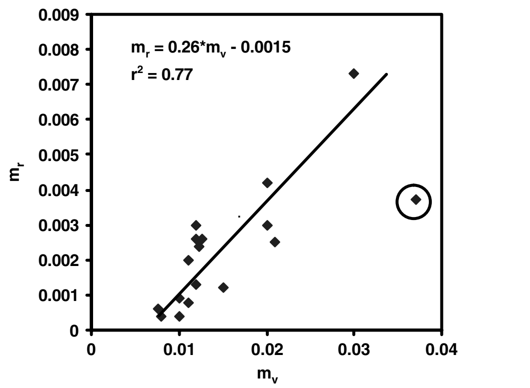

Figure 3. Virgin compressibility versus recompression (kPa^{-1}). Regression was calculated ignoring the encircled point. Including the encircled point, the regression was $m_r = 0{\cdot}17m_v - 0{\cdot}0003$ ($r^2 = 0{\cdot}58$)

Discussion

Various measures have been described in the literature to represent the degree of decomposition of peat, such as vP, bulk density and fibre content (Boelter, 1969). Consequently, one would expect a good correlation between them. Here, a moderate positive relationship existed ($r^2 = 0{\cdot}50$) between ρ_b and degree of decomposition as expressed by vP (Figure 1a). However, F_c was poorly correlated to both ρ_b ($r^2 = 0{\cdot}06$) and vP ($r^2 = 0{\cdot}03$) (Figure 1b and c). In part, the poor correlation was due to the distinctly different peat types tested. However, even trends within sites and within cores were not clearly demonstrated.

Conceptually, a relationship between these descriptors of peat quality makes sense. Peat decomposition destroys its structure (Clymo, 1983), resulting in smaller fibres (lower F_c) that pack together more tightly (higher ρ_b) and reduce the ability of water to be expressed from the smaller pores of the peat when it is squeezed (higher vP). However, since ρ_b varies directly with the load applied to it (Terzaghi, 1943), peat with a given vP or F_c, for example, can exist over a range of ρ_b, and ρ_b can and does change seasonally (Price and Schlotzhauer, 1999). Thus, clear and unique relationships between ρ_b and vP or F_c were not found. The moderate relationship between ρ_b and vP ($r^2 = 0{\cdot}50$) (Figure 1a) does illustrate the general relationship, but scatter is enhanced by processes that cause variability in ρ_b but not vP (e.g. loading and compression).

The poor relationship between F_c and vP (Figure 1c) could be explained by the presence of a few large root fibres or wood inclusions in otherwise moderately decomposed peat. Such fibres would notably increase the mass of fibre retained on a sieve, whereas the appearance of moderately well decomposed peat and organic-stained water squeezed from a sample would suggest a high vP.

There was a clear trend of decreasing compressibility m_v with increasing ρ_b (Figure 2a) and vP (Figure 2b). There was a conspicuous difference in compressibility trends of the two profiles from scb-x, which had higher and more variable m_v compared with the rest of the samples. Their distinct character could not be explained by differences in ρ_b (similar range to other samples), but they were clearly the least decomposed on the basis of vP. As they decompose, plant remnants successively adjust from a disordered to a firmer framework and sometimes layered structure (Clymo, 1983), which will be less prone to further consolidation. Though the overall trend is that peat compressibility decreases with state of decomposition, the variability between sites cannot be estimated on the basis of ρ_b, although it could possibly be estimated on the basis of vP.

F_c was not correlated to compressibility. Large fibres of undecomposed *Sphagnum*, for example, are relatively compressible compared with woody fibres. Thus, two samples having similar mass of fibre retained, one with stiff woody material and the other with *Sphagnum* fibre, would clearly have a different compressibility. Furthermore, two samples containing identical woody root mass would have a substantially different compressibility if one had the fibres oriented vertically and the other horizontally.

The peat structure 'remembers' the previous stresses it has experienced, characterized by the recompression rate rather than virgin compressibility. If it has experienced a high stress, the structure becomes organized in (pressed into) a firmer, less elastic, pattern. In classic soil mechanics this is described in the terms of preconsolidation stress, and volume changes below this stress limit occur according to the coefficient of recompression m_r, and according to the coefficient of virgin compression m_v beyond this stress. All sample tests generated stress–strain relationships that conformed to this theory, and m_r was about 26% of m_v (Equation (5)). On a seasonal basis, changes in water table result in loading and unloading of the peat such that σ' (Equation (1)) remains in the range of recompression m_r, rather than virgin compression m_v. The absence of descriptive relationships with m_v or m_r, therefore, makes estimation of peat compressibility with ρ_b, vP or F_c highly unreliable. Unfortunately, laboratory-based testing to predict field compressibility is also unreliable because of scale issues and unconstrained (three-dimensional) deformation that can occur in field samples but not in the laboratory (Stinette 1998). The results of this study do not support the use of common measures of peat character to predict peat compressibility.

Conclusions

1. Fibre content determined by the standard method was not related to von Post degree of decomposition or bulk density (which were related).
2. Virgin compressibility m_v determined in the Rowe cell was related to bulk density and moderately so to vP values, but only for peat within a given core. However, recompression m_r, which was 26% of m_v, held no such trends. Fibre content was not related to any measure of compressibility.
3. To address the title of this article; this study found no evidence of an easy way to assess peat compressibility.

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