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Compressibility of Some Peats and Organic Soils

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Abstract

The level of compressibility-anisotropy present in natural fibrous peats and peaty silt was studied and the test data compared with the levels of compressibility predicted using existing empirical correlations. Multiple-increment oedometer tests were conducted on pairs of identical test specimens prepared such that the axis of one specimen was orthogonal to, and the axis of the second specimen parallel to the cross-anisotropic plane.

The soils were highly compressible, largely due to high rates of secondary compression. Fine fibrous peat and peaty silt generally exhibited isotropic compressibility. The level of compressibility anisotropy for coarse peat, quantified in terms of the ratio of the horizontal C_{sh}, to vertical C_{sv} coefficient of secondary compression values, decreased with increasing applied stress. A step change in the values of the compression index and the coefficient of secondary compression occurred at the pre-consolidation pressure. Artificially high values for the pre-consolidation pressure may have been measured due to compression during sampling. Values of C_c predicted from the liquid limit values using Terzaghi and Peck's (1967) correlation were in close agreement with the laboratory-measured values for the test soils.

Keywords: *organic soils, compressibility, anisotropy, soil fabric, empirical correlations.*

1 Introduction

Natural organic soils have an inherent cross-anisotropic fabric due to the preferred horizontal alignment of the constituent organic and plate-like mineral particles. The aim of this study was to assess the level of compressibility-anisotropy present in a range of organic soils with different fabrics and at different stages of decomposition. The test data was also compared with the levels of compressibility predicted using existing empirical correlations for organic deposits.

2 Test Soils

The test soils were soft to firm peaty silt, and two bog peats, obtained from sites at Shannon and Carrick on Shannon, respectively, (Figure 1) using a 100 mm diameter, thin-walled tube sampler, the standard sampler used in Irish practice. The soil descriptions to BS5930 (1999), index properties and *insitu* properties are listed in Table 1. Coarse H_3, and fine H_6, fibrous peats, classified using the von Post system (Head, 1992), were sampled. H_3 indicates very slight, and H_6 moderately strong degrees of decomposition by humification.

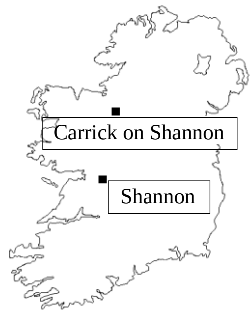


Figure 1. Locations of soft-soil sites.

The soils had very high *insitu* water content (w_o), and plasticity index (I_P), values due to the high organic content. The *insitu* vertical effective stress (σ_{vo}') values, calculated using the bulk unit weight, and with the groundwater level located at the ground surface, were very low. σ_{vo}' was zero for both peats as their bulk unit weights were less than that of water.

Table 1. Description and insitu properties of soils.

Soil label	**Depth (m)**	**Soil description and classification** (BS5930,1999)	w_l (%)	w_p (%)	I_p	G_s	LOI (%)	Insitu properties				
								w_o (%)	e_o	γ (kN/m³)	γ_d (kN/m³)	σ_{vo}' (kPa)
[1]	3.5	Soft to firm, black, peaty SILT (MEO)	170	85	85	2.26	–	143	3.2	12.3	5.2	9
[2]	1.5	Very soft, fine fibrous PEAT (H_6 von Post)	710	380	330	1.41	88	712	10.3	9.5	1.2	0
[3]	1.2	Soft, coarse fibrous PEAT (H_3 von Post)	470	280	190	1.53	–	554	9.5	9.5	1.5	0

3 Consolidation Tests

Standard multiple-increment oedometer tests were conducted on undisturbed specimens, 76.2 mm diameter by 19.0 mm high. The oedometer apparatus facilitated one-dimensional compression of the specimens under zero lateral strain. Hence, pairs of identical test specimens were carefully prepared from the 100 mm diameter tube samples such that the axis of one specimen was orthogonal to, and the axis of the second specimen parallel to the cross-anisotropic plane (Figure 2). The vertical and horizontal compressibility characteristics were determined from specimens prepared in this manner. The specimen pairs were taken from the same locations and depths in the ground, hence they were subject to the same *insitu* vertical effective stress.

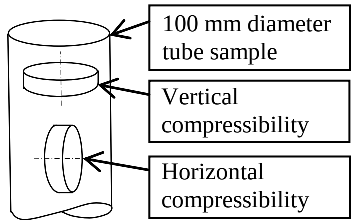
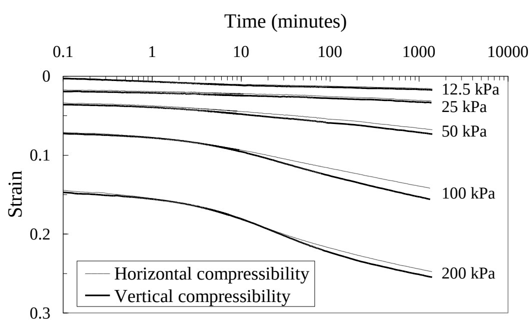


Figure 2. Orientation of specimen pairs for oedometer tests.

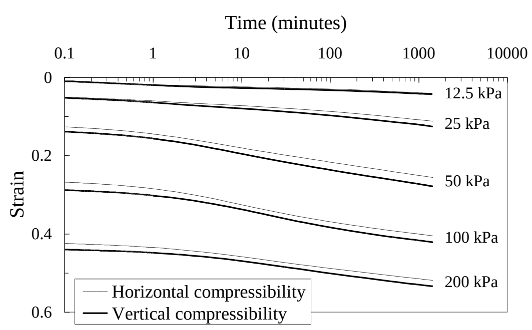
The oedometer tests comprised five incremental-load stages. Each load stage lasted 24 hours for the peaty silt and fine peat, and 48 hours for the course peat. An initial stress of 12.5 kPa was applied, and the stress was increased in steps at the end of each load stage using a load increment ratio of unity until a final stress of 200 kPa had been applied.

4 Experimental Results

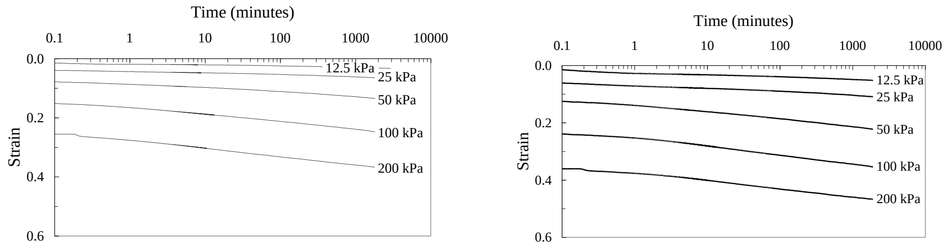
The compression data recorded for the different soils are presented as cumulative specimen strain, calculated in terms of the initial specimen thickness, versus log time (Figure 3).



(a) Firm peaty silt.



(b) Fine peat.



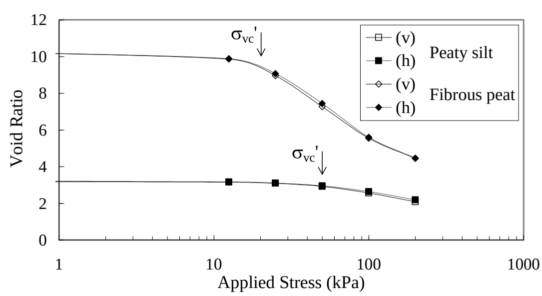
(c) Coarse peat: horizontal compressibility.

(d) Coarse peat: vertical compressibility.

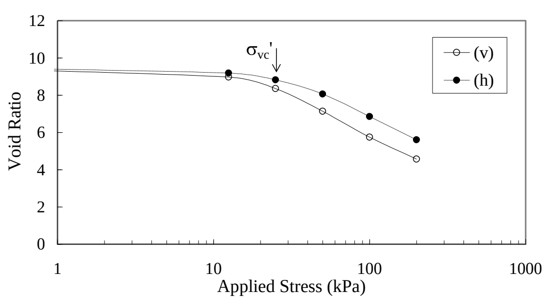
Figure 3. Cumulative strain–log time plots.

5 Compressibility

The compressibility of the soils, expressed in terms of void ratio–log applied stress (e–log σ) plots, is shown in Figure 4. Calculations for the amounts of settlement for organic deposits are based on strains, hence cumulative strain–log σ plots are also presented (Figure 5).



(a) Firm peaty silt and fine peat.



(b) Coarse peat.

Figure 4. Void ratio–log applied stress: (v) vertical, (h) horizontal compressibility.

Values of the compression index (C_c), calculated from the slope over the linear portion of the e–log σ plots; the compression ratio (C_c*) values calculated using Equation 1, and the pre-consolidation pressure (σ_{vc}'), determined for the vertical direction using Casagrande's empirical method, are listed in Table 2.

$$C_c^* = \frac{C_c}{1+e_o} \tag{1}$$

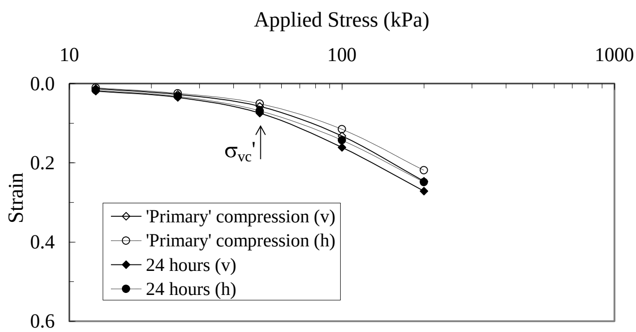
where e_o = the *insitu* void ratio,
and C_c = the compression index.

Table 2. Compression properties of soils; (v) vertical, (h) horizontal compressibility.

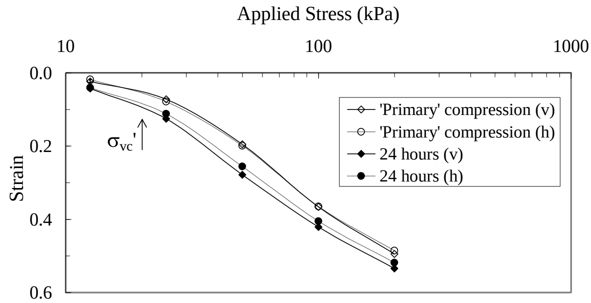
	Peaty silt	Fibrous peat		
		Fine	Coarse (v)	Coarse (h)
Compression index, C_c (void ratio related)	1.6	5.8	4.6	4.2
Compression ratio, C_c* (strain related)	0.37	0.51	0.44	0.40
Preconsolidation pressure, σ_{vc}' (kPa)	50	20	23	

The pre-consolidation pressure for the horizontal direction would be about one-half of that measured for the vertical direction. It is possible that the pre-consolidation pressures measured for both peats were artificially high due possibly to sample compression through friction, arching and fiber resistance during the sampling process (Landva and La Rochelle, 1983). Each pair of specimens had the same initial void ratios, which confirmed that the specimens were initially identical.

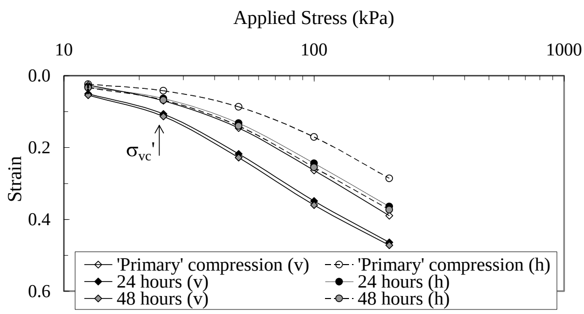
The 'primary' compression strains in Figure 5 encompassed the initial compression and any secondary compression from the previous load stage (Head, 1994). The secondary compression strains were due to compression that only became apparent after the 'primary' phase, and showed a linear relationship with log time.



(a) Firm peaty silt.



(b) Fine peat.



(c) Coarse peat.

Figure 5. Strain–log applied stress from multiple-increment tests: (v) vertical, (h) horizontal.

As expected, the more organic and coarser the constituent particles, the higher the soil compressibility. The vertical compressibility was slightly greater than that measured for the horizontal load direction, especially when the applied stress exceeded the pre-consolidation pressure (Figure 5), and is typical of soft soil behavior (O'Kelly, 2005). Similar specimen strains were recorded at the end of each load stage for the peaty silt and fine peat, although the strain rates appeared to be slightly greater when the load direction was orthogonal, instead of parallel to the cross-anisotropic plane. Overall, the differences were small, and for practical purposes, both soils exhibited isotropic compressibility.

However, the coarse peat, with its dominant inherent cross-anisotropic fabric, was strongly anisotropic in compression, for example final specimen strains of 47 and 37 % were recorded for the vertical and horizontal load directions, respectively, under an applied stress of 200 kPa (Figures 4b, 5c).

6 Secondary Compression

Secondary compression due to deformation of the organic particles themselves and readjustment of the soil fabric with increasing effective stress, was the dominant mechanism causing settlement. Initial compression, and primary consolidation due to the dissipation of the excess pore water pressures which occurred rapidly, together produced roughly equal strains in the vertical and horizontal load directions, contributing for up to only about 15 and 12 % strains at the start of the load stages for the fine and coarse peats, respectively.

The creep rate was quantified in terms of the coefficient of secondary compression (C_s), defined as the strain that occurred over one log cycle of time during the secondary compression phase, calculated in terms of the initial specimen thickness of 19.0 mm. The vertical (C_{sv}) and horizontal (C_{sh}) coefficient of secondary compression values for the different load stages, along with the C_{sh} to C_{sv} ratios, which are used to assess the level of compressibility anisotropy, are listed in table 3. A C_{sh} to C_{sv} ratio of unity indicates isotropic compressibility properties.

The soils were highly compressible (C_s = 0.024–0.036) when the applied stress exceeded the pre-consolidation pressure, with a step increase in the C_s values at this critical pressure (Figure 6). Overall, above the pre-consolidation pressure, the coefficient of secondary compression values appeared to be largely independent of the stress level. The soils had a low to medium compressibility (C_s = 0.003–0.011) when the applied stress was lower than the pre-consolidation pressure, and is analogous to over consolidated soil behavior. In general, the C_{sv} and C_{sh} values were equal for a given load stage, indicating isotropic compressibility. This is consistent with the secondary compression behavior of natural inorganic soft soils (O'Kelly, 2005).

Table 3. Secondary compression values, C_{sv} and C_{sh}, for the soils.

	C_{sv}	**C_{sh}**	**h : v ratio**	**C_{sv}**	**C_{sh}**	**h : v ratio**	**C_{sv}**	**C_{sh}**	**h : v ratio**	**C_{sv}**	**C_{sh}**	**h : v ratio**	**C_{sv}**	**C_{sh}**	**h : v ratio**	**Mean ratio**
Firm peaty silt	0.003	0.002	0.9	0.005	0.005	1.0	0.012	0.012	1.0	0.029	0.033	1.2	0.024	0.025	1.0	1.0
Fine fibrous peat	0.006	0.006	1.0	0.024	0.023	1.0	0.036	0.034	0.9	0.029	0.029	1.0	0.027	0.029	1.1	1.0
Coarse fibrous peat	0.006	0.003	0.6	0.009	0.005	0.6	0.024	0.014	0.6	0.032	0.026	0.8	0.029	0.029	1.0	0.7
Stress range (kPa)	0 to 12.5			12.5 to 25			25 to 50			50 to 100			100 to 200			0.9

However, the coarse peat was initially strongly anisotropic, with $C_{sh} \cong 0.6 \times C_{sv}$ below the pre-consolidation pressure. The peat material became more isotropic at higher stress levels with the development of the new stress-induced soil fabric, with the C_{sh} to C_{sv} ratio reaching unity for an applied stress of 200 kPa. The difference in compressibility behavior indicates a difference in soil stiffness, with the greater resistance mobilized when the applied stress acts parallel to, instead of orthogonal to the cross-anisotropic plane. The difference in stiffness is explained by the reinforcement mobilized along the length of the constituent fibers.

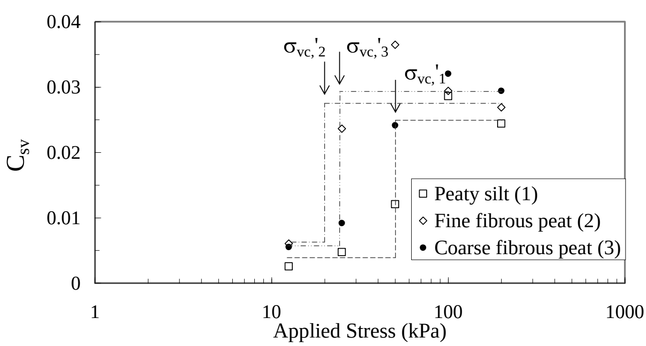


Figure 6. Coefficient of secondary compression–log applied stress (vertical compressibility).

7 Empirical Correlations for Compression Index

Values of the field compression index were estimated from the *insitu* water content (w_o) and liquid limit (w_l) values, given as percentages, using empirical correlations documented in the literature (Equations 2–4). Hobbs (1986) reported that Equations. 2 and 3 can be used for bog peats. Of these empirical correlations, the C_c values predicted by Equation 2 are in closest agreement with the laboratory-measured values. Equation 3 consistently underestimates the laboratory C_c values. Hence, design settlement predictions based on Equation 3 are likely to be conservative, considering that the field C_c values are usually slightly greater than the laboratory values due, in part, to the effects of sample disturbance.

$$C_c = 0.009\,(w_l - 10) \quad \text{(Terzaghi and Peck, 1967)} \quad (2)$$

$$C_c = 0.0065\,w_o \quad \text{(Hobbs, 1986)} \quad (3)$$

$$C_c = 0.0115\,w_o \quad \text{(Azzouz et al., 1976)} \quad (4)$$

Table 4. Predicted compression index (C_c) values.

Compression index	Peaty silt	Fibrous peat	
Predicetd value		Fine	Coarse
Eq. (2)	1.4	6.3	4.1
Eq. (3)	0.9	4.6	3.6
Eq. (4)	1.6	8.2	6.4
Measured value	1.6	5.8	4.6

8 Summary and Conclusions

The peaty silt and bog peats tested were highly compressible, largely due to high rates of secondary compression. The soils generally exhibited isotropic compressibility, except where the soil fabric was dominant, as was the case for the coarse fibrous peat. The level of compressibility anisotropy of the coarse peat, quantified in terms of the ratio of the horizontal C_{sh}, to vertical C_{sv}, coefficient of secondary compression values, decreased with increasing applied stress, from $C_{sh} \cong 0.6 \times C_{sv}$ around the pre-consolidation pressure, to unity at 200 kPa.

A step change in the values of the compression index C_c, used to calculate the amount of settlement, and the coefficient of secondary compression C_s, used to calculate the settlement rate, occurred at the pre-consolidation pressure. The C_s values above and below this critical pressure were generally independent of the applied stress. Artificially high values for the pre-consolidation pressure may have been measured due to pre-loading caused by the sampling technique. Further studies should be conducted on larger diameter test specimens.

The values of C_c and C_s measured for the vertical load direction are the critical values in determining the amounts and rates of ground settlement for design. Values of C_c predicted using Terzaghi and Peck's (1967) correlation were in close agreement with the laboratory-measured values for the test soils.

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