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Mechanical properties of stabilised peat based on laboratory testing

Propriétés mécaniques de la tourbe stabilisée basées sur essais en laboratoire

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ABSTRACT

The deep mixing method is becoming a promising technique in the stabilisation of different ground conditions and for different geotechnical applications. However, its application and effectiveness in the stabilisation of peat is still underresearched due to the complex nature of the material. Hence in this paper, some observations are made concerning the binder (cement) quantity and water:cement ratio and their optimum values needed to obtain a workable and more durable peat-cement mixes. These observations are based on unconfined compressive strength and tangent modulus values.

RÉSUMÉ

La méthode de mixage profonde est de plus en plus utilisée pour la stabilisation de diverses conditions de sols et pour plusieurs applications géotechniques. Cependant, son application et efficacité pour la stabilisation de la tourbe restent encore à rechercher dû à ses caractéristiques complexes. Quelques observations sont donc présentées dans cet article concernant la quantité du liant (ciment) et d'eau. La proportion optimale de ces deux est obtenue pour parvenir à un mélange de tourbe et ciment plus durable et utilisable. Les observations sont basées sur la résistance en compression non confinée et la valeur des modules tangent non confinés.

1 INTRODUCTION

Typical geotechnical problems encountered during the service life of peaty materials are mainly a decrease in strength and the development of large settlements. In many cases these problems are solved by the removal of such organic soil and its replacement with mineral soil. For decades, several methods to improve the conditions in peat deposits have been employed. A range of methods, from dynamic compaction to the use of geosynthetics, has been applied. The modification of the *in-situ* properties of peat such as strength and deformation produced by employing the Deep Mixing Method (DMM) has proved to be a promising technique. The use of the DMM has been gaining acceptance among engineers, which highlights a particular interest in increasing the knowledge of its applicability and design parameters. The development of this method began simultaneously in Sweden and Japan in the late 1960s. In Sweden, Kjedd Paus was the pioneer in the implementation of the technique called the Swedish Lime Column method (Holm, 1999) while in Japan it was established by the Ministry of Transport (CDIT, 2001).

The DMM has extensibly been applied using two variants, wet soil mixing and dry soil mixing. The decision of choosing which of these techniques is the more adequate depends of the *in-situ* conditions of the soil to be treated. Peaty deposits usually contain high water contents. Therefore, the dry soil mixing method is usually used in order to stabilise this material (Holm, 2002). For most other soils, the wet mixing method is usually applied because the addition of the binders in a slurry form provides far more effective mixing with the soil. Since peaty soils are often found interlayered with other soil deposits the wet mixing method would be far more effective, practical and economic in such layered soils. For this reason research efforts are being concentrated on the use of the wet mixing method in the stabilisation of peats and also organic and soft soils.

Properties such as strength and deformation of stabilised soft and organic soil material change with time. Such treated soils become stiffer and their behaviour becomes similar to that of very stiff overconsolidated clay or weak rock. Ekman and Holmgren (2001) presented a study of cement-stabilised peat in which properties such as compressive strength and the E_{50} modulus were obtained from unconfined compression tests. They concluded that these two parameters considerably changed over time and deduced that the density directly affected the strength and deformation properties more than any other factor. The stabilisation of peat was also studied in the EuroSoilStab project (DGSSS, 2000). In that study, it was reported that the properties of stabilised peat mainly depended on the type of binder used for stabilisation, its quantity and chemical properties of the soil itself.

Similar research has also being carried out by Hernandez-Martinez and Al-Tabbaa (2004, 2005). The former study reported a comparison of the unconfined compressive strength between treated mechanically-mixed peat specimens and sections of laboratory-scale auger columns. There, it was suggested that the mixing process used to produce auger columns in the laboratory can be easily correlated with that used to install real *in-situ* columns. Hence, mechanical properties obtained from laboratory-scale auger columns can be closer to those obtained in the *in-situ* ground treatment. The latter work, presented results on the influence of different types of binders in stabilising peat. Different cementitious materials including cement, pulverised fuel ash (pfa), blast furnace slag (bfs), gypsum and lime were used in six distinct mixes. By far, two mixes, peat-cement and peat-lime-gypsum-bfs, gave the best strength and stiffness.

This paper represents additional information related to those studies. It concentrates on the effect of the initial moisture content of the peat and its relation to the quantity of cement only binder added. It also presents additional results in terms of unconfined Young's modulus, its correlation with the unconfined compressive strength and the results of some microstructural analyses.

2 MATERIALS AND METHODS

2.1 *Peat and cement binder*

The peat used here is an Irish (sphagnum) moss peat. It contains fibrous and amorphous material as a result of varying growth and degradation processes. Classified based on the Von

Post scale (Hartlén and Wolski, 1996), it is brown-black, with a moderate decomposition (H6), indistinct plant structure, low fine fibre content (F_1, R_1) and roots residue more resistant to decomposition, zero tensile strength (T_0), and moderate smell (A_2). It has a natural density of around 294kg/m^3, water content of around 210% and an organic matter content of 94%.

As well as testing the peat at its natural water content (wc) of 210%, peat was also prepared at two higher water contents of 500% and 1000%. The density of those three peats were 294, 446 and 1014kg/m^3 respectively.

The binder used is Portland cement. Table 1 summarises its chemical composition. The cement was added as a grout in different water:cement (w/c) ratios.

Table 1. Composition of the cement used.

Components	(%)
SO_3	3.00
Cl	0.03
Na_20	0.60
C_3S	56.37
C_2S	22.00
C_3A	10.00
C_4AF	8.00
Surface area	340 (m^2/kg)

2.2 *The peat-cement admixtures*

Nine quantities of cement, from 100 to 500 kg/m^3, with different peat:grout ratios were mixed with the peats with wc of 210%, 500% and 1000%. Two size specimen moulds were used: (i) 50mm diameter x 100mm height and (ii) 100mm diameter x 100mm height. Samples were prepared in triplicates. Table 2 shows the different peat:cement grout ratios and the total proportions of all the mixes used. The percentage water quoted is that of the grout alone. Two different w/c ratios of 1:1 and 0.5:1 were used. The ratio of 1:1 is consistent with similar works reported in the literature for water contents similar to the natural water content of the peat (Hampton and Edil, 1998; Axelsson *et al,* 2002). However, using this w/c ratio for the peat with 1000% water content resulted in bleeding. Therefore, a w/c ratio of 0.5:1 was also used. This reduced w/c ratio still caused bleedings and this is discussed in a later section. For the peat with the wc of 500% the higher w/c ratio of 1:1 was used for the lower cement content binder additions of up to 250kg/m^3 while for the higher binder addition mixes this w/c ratio was reduced to 0.8:1.

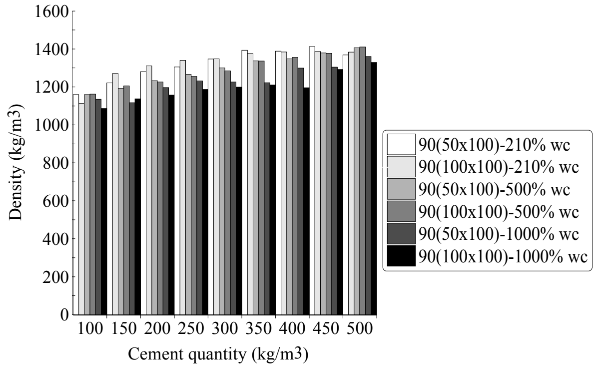

Figure 1. Densities of the treated peat after 90 days of curing. In the legend the first number (90) is the age of the sample and the second set of numbers in brackets is the size of the sample.

3 EXPERIMENTAL RESULTS

3.1 *Densities*

Figure 1 summarises the sample densities obtained after 90 days of curing time. Firstly, it is observed that the higher the water content of the sample the lower the density obtained. Secondly, the density obtained for the two specimen sizes used was similar which facilitated direct comparisons. The results in Figure 1 show that generally the higher the quantity of cement used the higher the density obtained. Values of the density varied from 1100 to 1450kg/m$^{3.}$

3.2 *Unconfined compressive strength*

In this work, only unconfined compression tests were conducted. The load was applied to a constant rate of 1.5 mm/min until an axial strain of 10% is reached. The compressive stress corresponding to each reading was calculated including a simplified area correction (Head, 1982). Also, a strain correction owe to the initial bedding deformation during loading was adopted (DGSSS, 2000).

Figure 2 shows typical stress-axial strain curves. These plots emphasise three main aspects of behaviour; i) the increase in strength of a given peat-cement mix with time with an increase of up to 30% in strength from 28 to 90 days, ii) the increase in stiffness of a given peat-cement mix with time and iii) the change in stiffness as the peat water content increased from a more brittle behaviour to a more ductile behaviour.

Figure 3 presents all the unconfined compressive strength (UCS) values of all the different cement-treated peat at 28 days. It also presents the results obtained by Axelsson *et al*, (2002) who used two peats, the Arlanda peat at a wc of 480% and the Örebro peat at a wc of 1400% and tested cement stablised samples of 68x136 diameter:height ratio. The results in Figure 3 generally show that the higher the quantity of cement added the higher the UCS values obtained. However, the results of the peat at 210% wc show a notable decrease in UCS for cement quantities greater than 300 kg/m^3. This is related to the high water content used in the binder (w/c of 1:1). Hence it appears that a 1:1 w/c ratio is unsuitable for mixes with higher quantities of cement, above 300 kg/m^3.

For the peat with 1000% wc the use of w/c of 0.5:1 in the grout proved to be effective in producing a continual increase in UCS with higher quantities of cement.

Table 2. Proportions of the peat-cement mixes used

Quantity of	Peat 210% wc				Peat 500% wc				Peat 1000% wc			
Cement	Peat:grout	Peat	Water	PC	Peat:grout	Peat	Water	PC	Peat:grout	Peat	Water	PC
kg/m^3		%	%	%		%	%	%		%	%	%
100	1:0.68	59.60	20.20	20.20	1:0.45	69.0	15.5	15.5	1:0.15	87.1	4.3	8.6
150	1:1	49.60	25.20	25.20	1:0.67	59.8	20.1	20.1	1:0.22	81.9	6.1	12.1
200	1:1.36	42.40	28.80	28.80	1:0.9	52.8	23.6	23.6	1:0.29	77.2	7.6	15.2
250	1:1.70	37.00	31.50	31.50	1:1.12	47.2	26.4	26.4	1:0.37	73.0	9.0	18.0
300	1:2	32.80	33.60	33.60	1:1.35	42.6	28.7	28.7	1:0.44	69.3	10.3	20.5
350	1:2.38	29.60	35.20	35.20	1:1.41	41.5	26.0	32.5	1:0.52	66.0	11.4	22.7
400	1:2.73	26.80	36.60	36.60	1:1.61	38.3	27.4	34.3	1:0.59	62.8	12.4	24.8
450	1:3	24.60	37.70	37.70	1:82	35.5	28.7	35.9	1:0.66	60.1	13.3	26.6
500	1:3.38	22.80	38.60	38.60	1:2.0	33.1	29.7	37.1	1:0.74	57.6	14.2	28.3

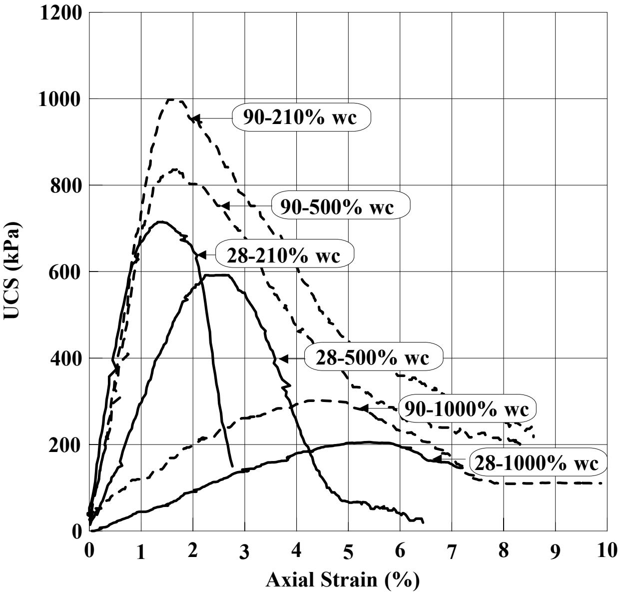

Figure 2. Stress-strain curves for 50mmx100mm samples both at 28 and 90 days and for all three water content peats.

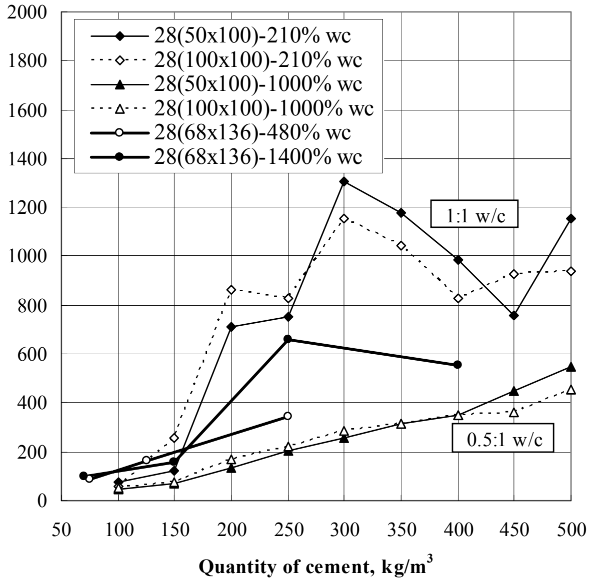

Figure 3. The effect of cement quantity and w/c ratio on UCS at 28 days. The 480% and 1400% wc results are those of Axelsson *et al*, (2002).

However the strength obtained was always lower, sometimes up to 3 times lower, than the peat with wc of 210%.This is as a result of the still much higher water content in the 1000% wc peat-cement mixes. In addition, those samples continued to suffer some degree of bleeding and associated settlement of solid particles (Taylor, 1997). The results of Axelsson *et al* (2002) presented in Figure 3 show the reverse trend between the 480% and the 1400% water content in that the latter produced higher UCS for higher cement content. This behaviour can be linked to the fact that all those specimens were subjected to a pressure of 18 kPa during the 28 days of curing time.

Figure 4 shows the results of the cement-stabilised peat with 500% wc also at 28 days. Using the trends from both the 210% and 1000% wc peats, for the 500% wc peat the w/c ratio in the binder used was 1:1 for cement content up to 250kg/m^3 and 0.8:1 for the higher cement contents. The results and trend observed now show a continual increase in UCS with an increase in the cement content in the binder. Therefore in peat-cement mixes a reduction in the w/c ratio for quantities of cement larger than 300 kg/m^3 is recommended.

In an attempt to compare the different wc peats, it is only feasible to compare those with the same w/c ratio, hence a comparison can be made between the 210% and 500% wc peats for cement content between 100 and 250kg/m^3 in Figures 3 and 4 respectively. The results show that the two sets of UCS values are almost similar. Nevertheless, higher strength is achieved for those samples where the wc (210%) is smaller. This indicates that the initial water moisture of the peat has an influence on the UCS of the mix at 28 days.

Considering the specimen size, Figures 3 and 4, show that similar values and trends in UCS are obtained in both cases.

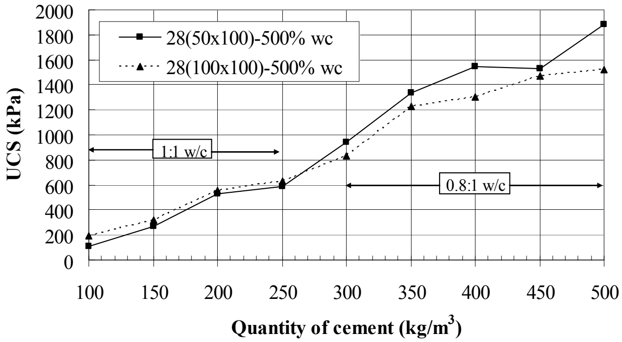

Figure 4. The effect of w/c ratio on UCS, at 28 days.

3.3 *Unconfined tangent modulus*

The initial unconfined tangent module, E, was calculated from the stress-strain curves obtained during the UCS testing and the results are presented in Figure 5 against their corresponding value of UCS. Contrary to the UCS values, the E results show differences between those calculated from the 50mmx100mm specimens and those obtained from the 100mmx100mm samples. This is particularly noticeable as the UCS value increased. This variability can be directly correlated with the smaller volume to surface area for the 50mmx100mm specimens (Vincent, 2003). From Figure 5 one can also observe a notable linear increase of E as a function of UCS for the 50mmx100mm specimens according to: E (kPa)= 74 x UCS(kPa). The relationship between E and UCS evaluated from 100mmx100mm is only linear for the values of UCS of around 1000kPa according to E (kPa)= 42 x UCS (kPa). Above this value of UCS the value of E appears to become constant and hence unrelated to the UCS values as they increase.

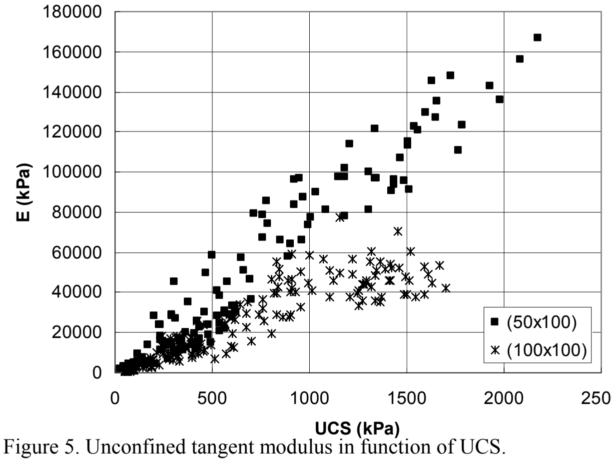

Figure 5. Unconfined tangent modulus in function of UCS.

3.4 *Effect of curing time on UCS*

Figure 6 shows the UCS results of the 500% wc at both 28 days and 90 days to investigate the effect of curing time. The figures shows that the UCS at 90 days are slightly higher that those at 28 days. Hence it is clear that most of the strength development of the peat-cement mixes has taken place within the first 28 days.

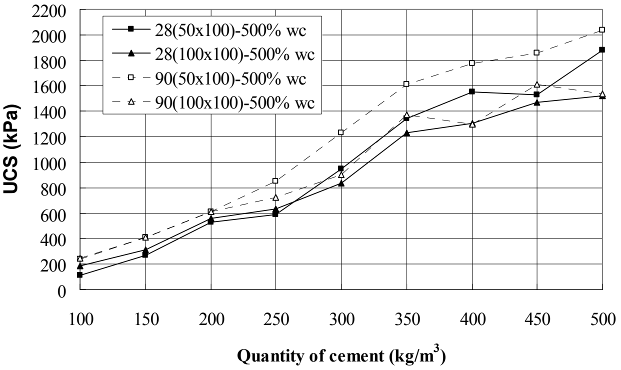

Figure 6. The effect of curing time on UCS, 28 and 90 days.

3.5 *Microstructure of peat-cement mixtures*

Scanning electron microscopy has been extensively useful in improving our understanding of the hydration process of cement. Figure 7 shows a scanning electron micrograph (x1000 magnification) of a section of the peat-cement mix at 28 days (quantity of binder 250kg/m^3 and wc of 210%). One can observe a peat particle in the centre of the picture. Also, typical hydration products such as C-S-H gel and needle-like ettringite are present surrounding the peat. This technique is being employed here to understand the interaction between the cement and the peat.

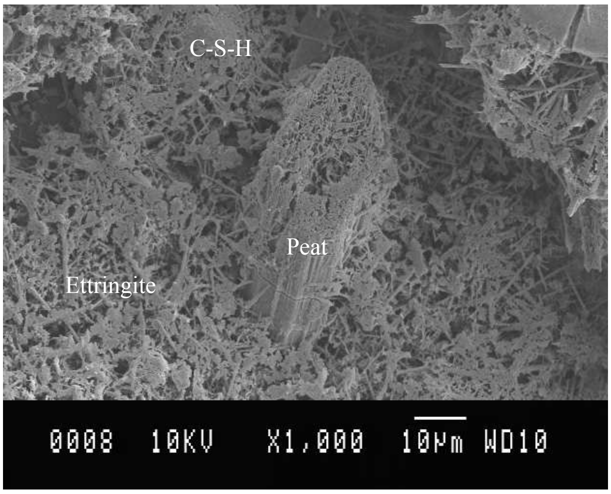

Figure 7. Typical scanning electron micrograph of a peat-cement sample, 28 days of curing.

4 CONCLUSIONS

Results of experimental work on the effect of cement stabilisation on peat were presented in this study. Only unconfined compression tests were carried out to examine the influence that the quantity of cement, the initial moisture content, the water:cement ratio and the specimen size have on the mechanical properties of treated peat. It was found that the higher the quantity of cement mixed the higher the strength obtained. On the other hand, the higher the initial moisture content present in the peat the lower strength achieved. In addition, it has been shown that the water:cement ratio in the mix can notably affect the UCS values for w/c ratios of 0.5:1 to 1:1. Based on these results, it is reasonable to recommend a 1:1 w/c ratio for mixes that contain quantities of cement up to 300 kg/m^3. Consequently, a reduction to 0.8:1 and 0.5:1 can be suitable for quantities of cement above that value. Likewise, specimens of different sizes, 50x100 and 100x100 diameter:height, were prepared. It was found that the UCS was independent of the size of the sample tested. On the contrary, a difference in the value of the initial unconfined tangent modulus was obtained for the two specimens. For the first specimen size, the trend of a linear increase of the unconfined tangent modulus as a function of UCS is clear. For the latter sample size a linear trend is also noticed but only for UCS values up to 1000 kPa but a trend change for values above 1000 kPa was observed. This difference of stiffness with size specimen is linked to the smaller volume to surface area in the 50x100 size specimen. Finally the SEM micrograph provides a clear picture of hydrated cement within a cement-peat mix.

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