Physical and geotechnical properties of Urmia peat

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ABSTRACT
The Urmia-Tabriz Shahid Kalantari highway embankment in Iran experienced more than one meter of settlement due to the consolidation of the peaty foundation (Urmia peat). The consolidation and direct shear tests were conducted on samples of peat and the relationship between the key mechanical and physical properties of peat was investigated. The results show that the amount of organic matter (degree of decomposition) and initial void ratio are the two important factors which control the mechanical behaviour of Urmia peat. Also it was found that the $C\alpha/Cc$ concept of compressibility is applicable to Urmia peat.

RÉSUMÉ
Le remblai autoroute de Shahid Kalantari (Urmia à Tabriz) en Iran a connu plus d'un mètre de règlement en raison de la consolidation de la fondation tourbé (tourbe Urmia). Les essais de cisaillement direct et de consolidation ont été effectués sur des échantillons de tourbe et de la relation entre les principales propriétés mécaniques et physiques de la tourbe ont été étudiées. Les résultats montrent que la quantité de matière organique (degré de décomposition) et indice de vide initial sont les deux facteurs importants qui contrôlent le comportement mécanique de la tourbe Urmia. En outre, il a été constaté que le C_α/C_c notion de compressibilité est applicable à la tourbe Urmia.

1 INTRODUCTION

Fibrous peats are characterized by a high fibre and water content and low ash content. They are highly compressible and permeable, particularly during the early stages of loading (Landva and Pheeney, 1980, Munro, 2004, Mesri and Ajlouni, 2007). Embankments constructed on peat deposits often experience large deformations and/or failure (Rowe, 1984, Rowe and Soderman, 1985). Numerous embankments have been constructed over fibrous peat deposits with varying degrees of success (Lea and Brawner, 1963, Hanrahan, 1964, Rowe, 1984, Mesri et al., 1997, Munro, 2004).

At normal construction rates of the embankments on peat, significant excess pore pressures will be developed. In general these excess pore pressures will be far less than would be expected under undrained conditions. Thus the behaviour of fibrous peat foundation cannot be categorized as truly drained or undrained. Because of the large deformations which occur during construction, the usual assumption of small strains implicit in conventional limit equilibrium analysis is not applicable for embankments on highly compressible peat deposits.

In order to make reasonable predictions of the stability and shear deformation of embankments on fibrous peat it is necessary to have both an understanding of the behaviour of fibrous peats, particularly its shear strength, as well as a method of analysis which permits consideration of pore pressures and large strains.

The Shahid-Kalantari highway which connects the Urmia City to Tabriz City in Iran, in 7.8 Kilometres east of Urmia City passes through a relatively deep deposits of peat (Urmia peat). During the past 15 years since the highway construction commenced, the highway embankment experienced over 1 meter of settlement. This caused traffic problems passing through the highway in this location. The need for understanding the physical and geotechnical characteristics of peat and the proper prediction of the embankment settlement due to consolidation of the peat foundation in this location of the highway motivated a laboratory and theoretical investigation (Sayadian, 2010, Badv and Sayadian, 2010). This paper describes some results obtained from this research.

2 FIELD SAMPLING OF URMIA PEAT

The sampling location was on the east side of Urmia-Tabriz Shahid-Kalantary highway, 7.8 Km east of Urmia City. During sampling the groundwater table was at its lowest level of 1 m below the ground surface. During the wet periods the groundwater table rises above the ground surface. The cylindrical samples were taken from Urmia peat using a sharp edged steel cylindrical sampler with 20 cm diameter, 30 cm height, and 0.3 cm thickness. The samples were taken 1 m below the ground surface and to prevent drying, they were waxed and stored in a humid environment. Figure 1 shows the location of sampling and Figure 2 shows the waxed samples inside the samplers.

3 ODOMETER AND SHEAR TESTS

The peat samples were taken from the central part of the cylindrical samples inside the samplers for odometer and direct shear tests to minimize the effect of sample disturbance during field sampling of peat. Ten odometer tests were conducted on the peat samples having 7 cm diameter and 1.9 cm thickness. Also four direct shear tests were conducted on 10 cm square samples with 2 cm thickness. In odometer tests, the vertical stresses of

25, 50, 100, and 200 kPa were applied, each with 24 hours duration. Then, to determine the recompression index the samples were unloaded in two steps to 25 kPa and the deformations were recorded. The direct shear tests were conducted with vertical stresses of 8.98, 17.96, and 26.94 kPa.

Figure 1. Location of Urmia peat sampling point

Figure 2. Waxed peat samples inside the samplers

4 PHYSICAL CHARACTERITICS OF URMIA PEAT

The physical characteristics of Urmia peat was determined based of the Van Post identification system for peat (Van Post, 1922). In the Van Post system the peat samples are categorized into 10 groups of H1 to H10 based on their degree of decomposition. The H1 sample refers to a peat with no decomposition, having a fibrous and a completely herbaceous matter. The H10 sample refers to a completely decomposed peat with an amorphous structure. The parameters included the density, moisture content, specific gravity, initial void ratio, percentage of organic matter content, and degree of decomposition. The tested samples were categorized into two groups of H3 and H6 based on the Van Post system. Table 1 shows the range of physical characteristics of Urmia peat.

Table 1. The range of characteristics of tested soils.

Characteristics	Range of values
Organic matter (%)	25-77
Natural water content (%)	100-623
Initial void ratio	2.4-11.2
Initial degree of saturation	95-100
Natural unit weight (kN/m^3)	9.67-13.61
Specific gravity	1.63-2.36
Pre-consolidation ratio (kN/m^3)	10-60

Figure 3 shows the variation of the percentage of the organic matter content of Urmia peat versus the specific gravity. In this figure other data from the literature is included for comparison. It could be verified from Figure 3 that by increasing the specific gravity, the percentage of the organic matter content is decreased almost linearly. The following relationship was obtained for Urmia peat with a correlation coefficient of R^2=99.0 %.

$$OC = -71.84\ (Gs) + 193.9 \qquad [1]$$

In Equation 1 the OC refers to the percentage of organic matter content and Gs refers to specific gravity. Skempton and Petley (1970) suggested the following equation for peat,

$$OC = 290.8/Gs - 107.7 \qquad [2]$$

From figure 3, it appears that Equation 1 for Urmia peat provides a better estimate for the percentage of organic matter for peat.

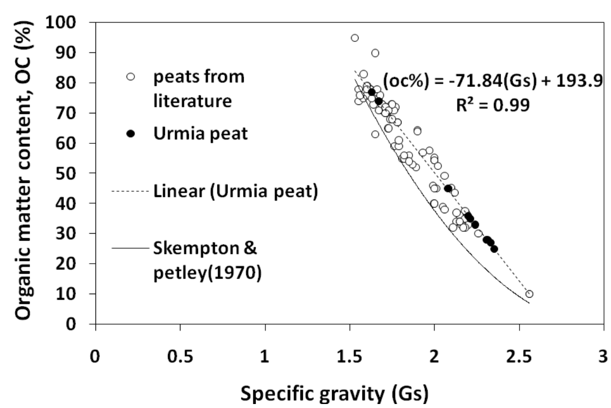

Figure 3. Change of percentage of organic matter content against specific gravity in Urmia peat

Figures 4 and 5 show the initial void ratio of Urmia peat versus the natural water content and the percentage of organic matter of peat, respectively.

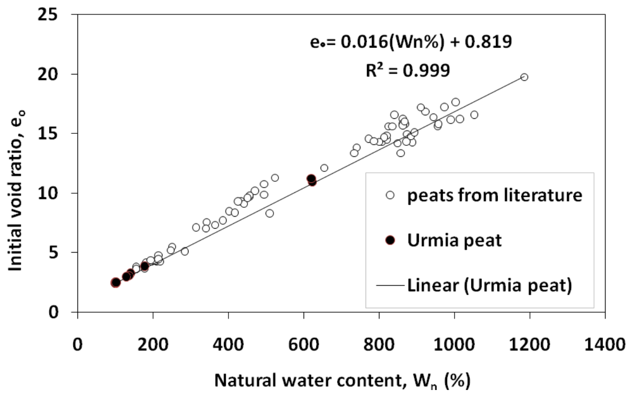

Figure 4. Change of initial void ratio against natural water content in Urmia peat

Since the organic matter has a porous and spongy structure, it is expected to be a close relationship between the initial void ratio of peat with its percentage of organic matter and natural water content. This could be verified from Figure 4 for the initial void ratio and natural water content. Equation 3 was derived from Figure 4 with a high correlation coefficient of R^2=99.9 %,

$$e_o = 0.016W_n + 0.819 \quad [3]$$

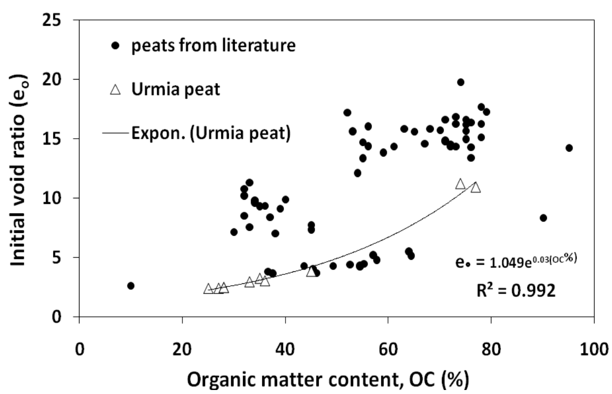

Figure 5. Change of initial void ratio against percentage of organic matter content in Urmia peat

in which e_o is the void ratio and W_n is the natural water content of peat. As could be verified from Figure 4, there is a good agreement between the data obtained for Urmia peat with other data from the literature.

As shown in Figure 5, although there is an exponential relationship between the initial void ratio of Urmia peat with the percentage of organic matter. As shown in Figure 5, there is relatively a wide scatter in other reported data. Consequently, care should be taken when one tries to predict OC from e_o.

5 ONE-DIMENSIONAL SETTLEMENT AND HYDRAULIC CONDUCTIVITY OF URMIA PEAT

The one dimensional settlement of peat results from primary and secondary consolidations. A relatively significant part of the settlement could result from secondary consolidation. Figure 6 shows the void ratios at the end of primary consolidation, e_p, versus the effective vertical stress, σ'_v, for different values of OC. As shown in Figure 6 for a constant value of σ'_v by increasing the OC value, the void ratio increases. Figure 6 also shows that when OC increases, the slope of e_p- σ'_v curve, which refers to the compression index, C_c, increases. Figure 7 shows the C_c values versus the initial void ratio (e_o). Regardless of the amount of OC of the peat, the C_c value increases linearly against e_o. Equation 4 has been derived from Figure 7 for Urmia peat as follows:

$$C_c = 0.644(e_o) - 0.954 \quad [4]$$

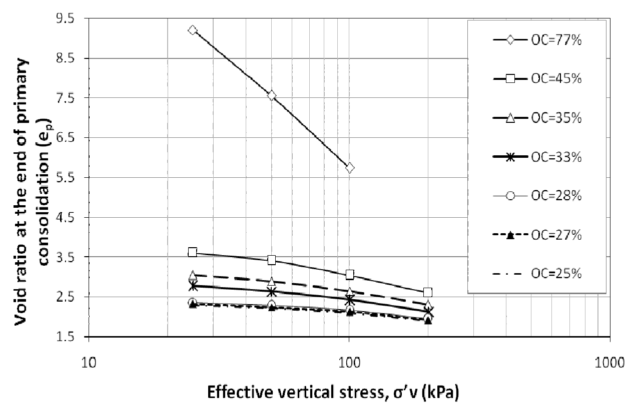

Figure 6. Change of void ratio at the end of primary consolidation against the effective vertical stress in Urmia peat

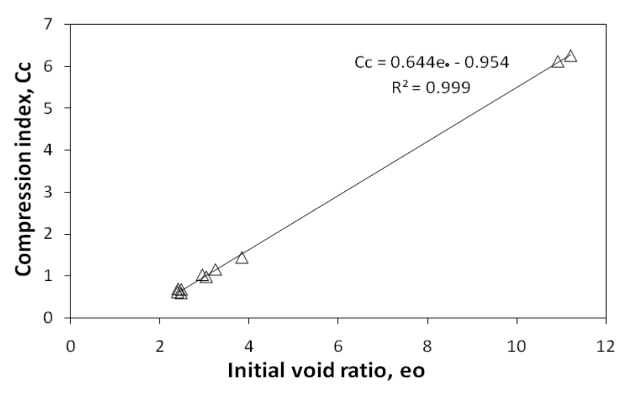

Figure 7. Change of initial void ratio against the compression index in Urmia peat

The importance of each of the primary and secondary consolidations on the total settlement of an embankment constructed on peat depends on the time required for primary consolidation and the service life of the project. The change in hydraulic conductivity of peat with time is an important controlling parameter on the speed and time required for primary consolidation of peat. Moreover, the hydraulic conductivity has a close relationship with the void ratio of peat. Hence, finding the relationship between the void ratio and the logarithm of vertical hydraulic conductivity of peat $\log(k_v)$ along with the e_p - $\log(\sigma'_v)$ relationship, could provide a useful information for settlement and hydraulic conductivity predictions of Urmia peat. In other words, by knowing the value of void ratio with respect to the applied vertical effective stress, the value of hydraulic conductivity of peat could be predicted. From the e – $\log(k_v)$ curve, the hydraulic conductivity index (C_k) could be calculated as follows:

$$c_k = \frac{\Delta e}{\Delta \log k_v} \qquad [5]$$

Figure 8 shows the change of void ratio of Urmia peat against $\log(k_v)$ values. As shown in the figure, despite the increase of the percentage of the organic matter content of Urmia peat (OC), there is a general trend in shifting the curves to the right, meaning that the there is trend for increase of the hydraulic conductivity. For a constant value of the void ratio, the increase of OC results in decrease of the hydraulic conductivity. It could be verified from Figure 8 that despite the low range of applied stresses in the consolidations tests, the range of change of the hydraulic conductivity of all tested Urmia peat samples is significant. This concludes that the hydraulic conductivity values of Urmia peat, like all other peats, are significantly variable. It could also be verified from Figure 8 that the slope of curves (the value of C_k) increases when OC increases. If the C_k values are plotted against the initial void ratio of each sample, as shown in Figure 9, the constant value of 0.235 is obtained for C_k/e_o . The values of 0.25 and 0.5 have been reported for peats and clays, respectively. The smaller the value of C_k/e_o, the more non-uniform will be the void sizes, and the more effective will be the role of bigger voids, on the hydraulic conductivity of peat. As shown in Figure 9, the data of the peat samples with higher degree of decomposition lies slightly above the C_k/e_o = 0.235 line. This concludes that when degree of decomposition increases, the size of voids decreases (decrease of void ratio) and becomes more uniform.

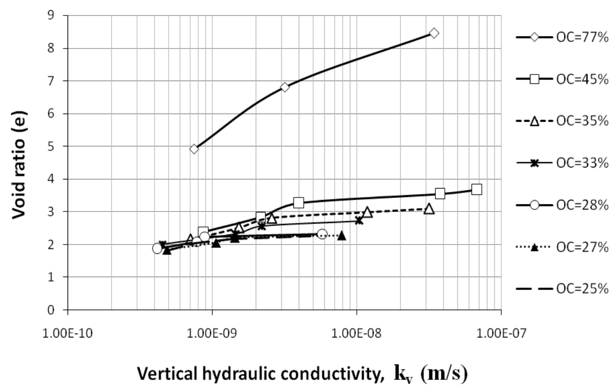

Figure 8. Change of void ratio against vertical hydraulic conductivity in Urmia peat

Figures 10 and 11 show the coefficient of volume change, m_v, and the coefficient of consolidation, C_v, against $\log(\sigma'_v)$, respectively. The m_v and C_v could be calculated from the following equations,

$$m_v = \frac{\Delta V}{V_o \Delta \sigma'_v} \qquad [6]$$

$$C_v = \frac{k_v}{m_v \gamma_w} \qquad [7]$$

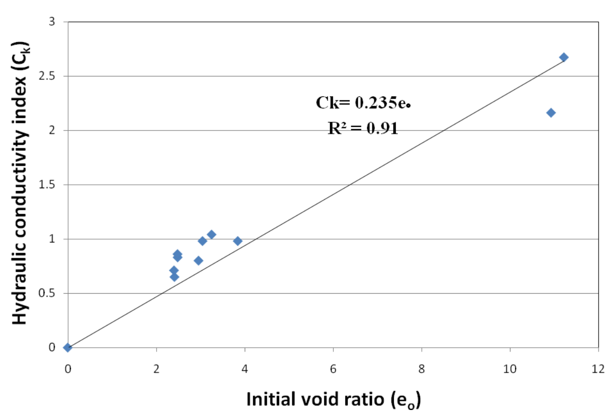

Figure 9. Change in initial void ratio against hydraulic conductivity index in Urmia peat

In Equation 6, Δv is the change of volume with respect to the initial volume V_o of soil, due to change in the effective vertical stress, $\Delta\sigma'_v$, and k_v and m_v in Equation 7 are as defined above.

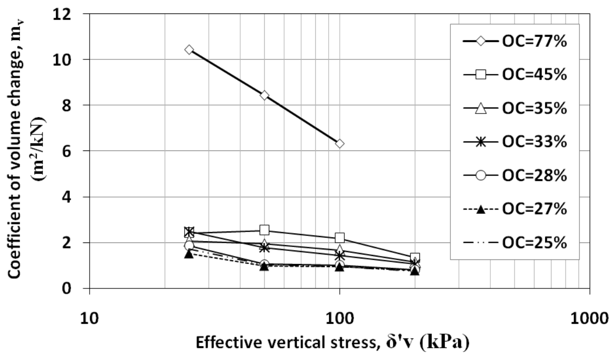

Figure 10. Change in effective vertical stress against coefficient of volume change in Urmia peat

Figure 10 shows that for a constant value of σ'_v , the m_v increases with OC. Moreover, the m_v decreases when σ'_v increases. This trend for organic soils with higher percentage of organic matter is higher. As shown in Figure 11, C_v decreases when σ'_v increases. Considering Figure 11 and Equation 11, it could be concluded that for Urmia peat with the percentage of organic matter content of more than 25 % (OC>25) and for the range of stresses applied, the slope of decrease of vertical hydraulic conductivity, k_v, is greater than the slope of decrease of the coefficient of volume change, m_v.

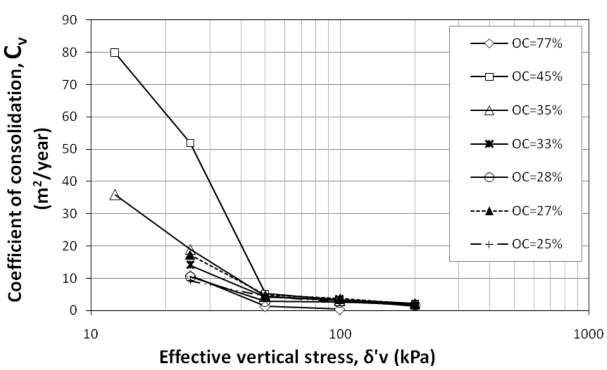

Figure 11. Change in effective vertical stress against coefficient of consolidation in Urmia peat

Urmia peat samples obtained from the above mentioned location have different percentages of organic matter content with high creep and volume change characteristics. Hence, the settlement resulting from the secondary consolidation is expected to be high. To calculate the settlement resulting from the secondary consolidation, the secondary compression index, C_α, is calculated as follows,

$$C_\alpha = \frac{\Delta e}{\Delta \log t} \qquad [8]$$

where Δe is the change in void ratio and Δlogt is the time span considered. Figure 12 shows the C_α values obtained after the primary consolidation, against the σ'_v values for different values of the percentage of organic matter content (OC) of Urmia peat. As could be verified from Figure 12, for a constant value of σ'_v , C_α increases when OC increases. Moreover, for all peat samples the C_α increases with the increase of σ'_v and the slope of curves for samples with higher OC values is higher (for example see curve with OC=77 % in Figure 12).

The C_α values obtained after the primary consolidation, were plotted against the C_c values obtained from the e_p – log σ'_v curve (Figure 6) as shown in Figure 13. The ratio of C_α/C_c = 0.058 is obtained from Figure 13 which has a good agreement with the ratios of 0.06 ± 0.01 reported for the fibrous peat (Mesri et al., 1997).

Using the unloading data of the consolidation test and the plot of e_p – log σ'_v, the recompression index, C_r, is determined as follows,

$$C_r = \frac{\Delta e}{\Delta \log \sigma'_v} \qquad [9]$$

in which Δe is the change in void ratio due to change (decrease) of Δlog σ'_v , due to unloading. By plotting C_r against C_c , as shown in Figure 14, it was verified that the ratio of C_r/C_c has a constant value of 0.143 and is independent of the percentage of the organic matter content of peat. This value for Urmia peat, agrees well with the reported values of 0.1-0.3 for other peats. The smaller value of the ratio of C_r/C_c for Urmia peat implies that the water in the voids is a free water (pore water) compared to clayey soils.

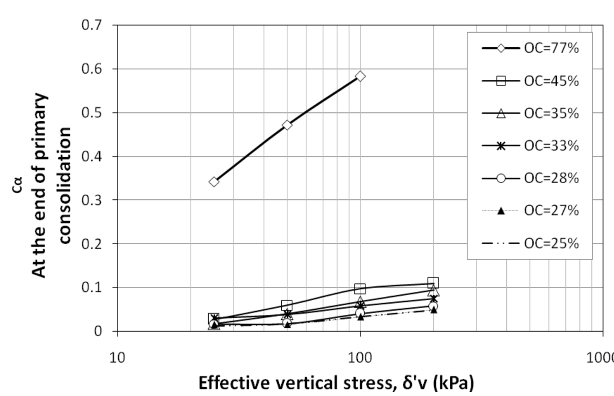

Figure 12. Change in effective vertical stress against C_α at the end of primary consolidation in Urmia peat

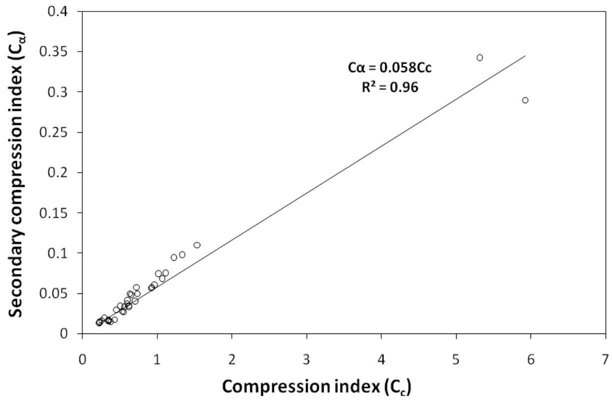

Figure 13. Change in compression index against the secondary compression index in Urmia peat

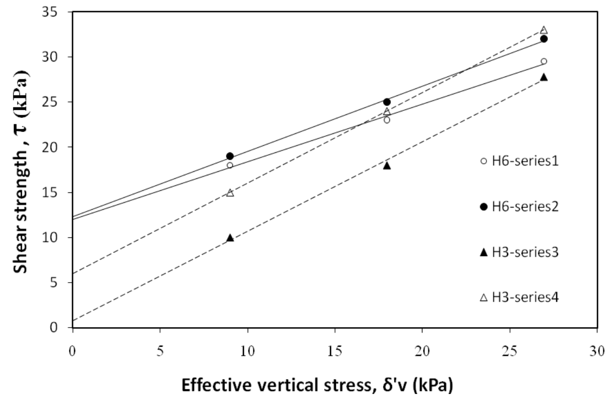

Figure 15. The effect of organic matter content on the shear strength characteristics of Urmia peat

6 SHEAR STRENGTH OF URMIA PEAT

A series of direct shear tests were conducted on Urmia peat samples. The results have been summarized in Table 2 and have been plotted in Figure 15.

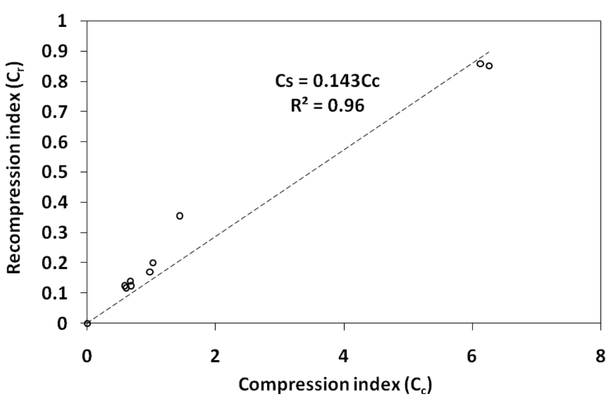

Figure 14. Change in compression index against recompression index in Urmia peat

Table 2. The results of direct shear tests on Urmia peat.

Test series No. and degree of decomposition based on Van Post system	Average percentage of organic matter (%)	Effective shear strength parameters	
		C'	Φ'
Series 1 (H6)	30	12	32
Series 2 (H6)	30	12.3	35
Series 3 (H3)	70	0.8	44
Series 4 (H3)	70	6	45

Since the samples were sheared after the end of primary consolidation, the shear strength parameters are based on the effective stress condition. The results show that the shear strength behaviour of the tested peat depends on its degree of decomposition and the percentage of organic matter. It is evident from the results that H3 samples with lower degree of decomposition (higher OC) show higher friction and lower cohesion compared to H6 samples with higher degree of decomposition (lower OC).

The relationship between the ratio of change of shear strength $\Delta\tau$ to change of effective vertical stress $\Delta\sigma'_v$, with the tangent of friction angle Φ' could be read as follows,

$$\tan\phi' = \frac{\Delta\tau}{\Delta\sigma'_v} \qquad [10]$$

From the test results shown above it could be concluded that the peat with lower degree of decomposition, although in lower effective stresses has lower shear strength compared to the peat with higher degree of decomposition, but due to higher friction angle, its shear strength increases significantly when σ'_v increases. It should be noticed that in peat layers close to the ground surface, due to the saturation and buoyancy effect, the peat unit weight is small and is close to the unit weight of water and the shear strength is low. Considering the Jaky equation for the coefficient of earth pressure at rest, $K_o = 1 - \sin\Phi'$ (Jaky, 1944), and the results shown above, it could be concluded that when the degree of decomposition of Urmia peat increases, the coefficient of earth pressure at rest increases. Similar conclusions have been made by other researchers by direct measurement of K_o for peat with different degrees of decomposition (Edil and Dhowian, 1981).

7 SUMMARY AND CONCLUSIONS

The physical and geotechnical properties of Urmia peat obtained from Shahid-Kalantari highway 7.8 Kilometres east of Urmia City, Iran, and its effect on the consolidation and settlement of overlying embankment were investigated. The tested samples were categorized into two groups of H3 and H6 based on the Van Post system. The linear relationships were obtained between the percentage of organic matter content and the specific gravity, and between the initial void ratio and natural water content. An exponential relationship was obtained between the initial void ratio of Urmia peat with the percentage of organic matter content.

A Series of consolidation and direct shear tests were conducted on samples of peat. The results showed that the degree of decomposition and the percentage of organic matter in Urmia peat play an important role on its physical, consolidation, and shear strength properties. A linear relationship was found between the compression index and the initial void ratio of Urmia peat which is independent of the amount of organic matter content of the peat. The results of consolidation tests showed that although the higher percentage of organic matter increases the compressibility and permeability, but this behaviour is significantly dependant on the stress level, so that, when the stress level is increased, the compressibility and permeability of peat decreases at a higher rate. A constant value of 0.235 is obtained for C_k/e_o ratio for Urmia peat which lies in the lower range of the reported values for peat. The smaller value of C_k/e_o, refers to a more non-uniform void sizes and the pronounced effect of the bigger voids on the hydraulic conductivity of Urmia peat. The results showed that for Urmia peat with the percentage of organic matter content of more than 25 % (OC>25) and for the range of stresses applied, the slope of decrease of vertical hydraulic conductivity, k_v, is greater than the slope of decrease of the coefficient of volume change, m_v.

It was found that for a constant value of effective vertical stress, the secondary compression index increases when organic matter content increases. Moreover, for all Urmia peat samples the secondary compression index increases with the increase of effective vertical stress. The ratio of $C_\alpha/C_c = 0.058$ is obtained for Urmia peat which is in good agreement with the ratios of 0.06 ± 0.01 reported for the fibrous peat. It was verified that the ratio of C_r/C_c has a constant value of 0.143 for Urmia peat and is independent of the percentage of the organic matter content of peat. This value is in good agreement with the reported values of 0.1-0.3 for other peats.

The shear strength parameters were obtained for Urmia peat by conducting a series of direct shear tests. The results showed that H3 samples with lower degree of decomposition (higher OC) show higher friction and lower cohesion characteristics compared to H6 samples with higher degree of decomposition (lower OC). It was found that Urmia peat with lower degree of decomposition, although in lower effective stresses has lower shear strength compared to the peat with higher degree of decomposition, but due to higher friction angle, its shear strength increases significantly when the effective vertical stress increases. It was concluded that when the degree of decomposition of Urmia peat increases, the coefficient of earth pressure at rest increases.

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