

AN INVESTIGATION INTO THE GEOTECHNICAL CHARACTERISTICS OF URMIA PEAT*

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Abstract– The Shahid-Kalantari highway between Urmia and Tabriz cities in Iran, has experienced more than one meter of settlement 7.8 Km east of Urmia city. The soil investigations revealed that the existence of a peaty foundation (Urmia peat) caused this settlement. This motivated a research to investigate the geotechnical characteristics of Urmia peat.

A series of consolidation and direct shear tests were conducted on samples of Urmia peat and the relationship between the key mechanical and physical properties was investigated. The results show that the amount of organic matter (degree of decomposition) and initial void ratio are two important factors which control the mechanical behaviour of this soil. It was also found that the C_u/C_c concept of compressibility is applicable for Urmia peat.

Keywords– Peat, organic content, initial void ratio, compressibility, shear behavior

1. INTRODUCTION

Peat forms in a landscape when the natural decay processes fail to keep up the amount of vegetation being produced. This usually happens on waterlogged land where the lack of oxygen prevents natural microorganisms from decomposing the dead plant material. Where these conditions occur, the dying vegetation does not decay at the end of the growing season as normal but instead accumulates year on year as a peat layer [1]. This different origin of peats compared to inorganic soils leads to completely different physical and mechanical properties such as very high compressibility, which makes it a difficult foundation material [2]. On the other hand, most peat deposits are highly variable [3]. This characteristic, related mainly to variable degree of decomposition within a peat deposit, has been a serious impediment to accurate interpretation of peat behavior from library measurements and field observations [4]. Some environmental conditions such as fluctuation of ground water level with respect to topography of an area may cause different degrees of degradation within a peat deposit like what is thought to have happened for a peat layer located 7.8 Km east of Urmia City, Iran [5].

Extra care should be taken during field sampling and test specimen preparation of peat. This is due to the peat fibrous structure and high compressibility, particularly when dealing with low decomposed peat. Peat physical properties can somehow represent its structure and engineering properties, in which inter-particle chemical bonding is not governing its mechanical behavior [6]. In this study, an attempt was made to investigate the relationship between some mechanical and physical properties of peat from Urmia City, Iran (Urmia peat), and using the data in the literature from other peats, some empirical correlations were derived [5]. Although the focus of this paper is on physical properties and one dimensional compression behavior, to compare the shear behavior of two peats with different degrees of decomposition, the results of some drained direct shear tests have also been discussed.

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2. FIELD SAMPLING

The sampling location was on the right side of Urmia-Tabriz Shahid-Kalantary highway, 7.8 Km east of Urmia City, Iran, where a layer of peat with an average depth of 5 m overlies a soft clay layer [7, 8]. During sampling the groundwater table was at its lowest level of 1 m below the ground surface, while at wet periods it rises above the ground surface. The cylindrical samples were taken using sharp edged steel tubes with 20 cm diameter, 30 cm height, and 0.3 cm thickness. For this purpose, 5 pits with a depth of 1 m were excavated. The average distance between pits was about 6 m.

For sampling, steel tubes were lubricated and then pushed into the ground in several stages while removing the surrounding soil to reduce the frictional resistance. The samples were waxed immediately after sampling and were stored in a humid environment.

3. CLASSIFICATION OF PEAT SAMPLES

For classification, the Von Post system in which the degree of decomposition is categorized into 10 groups of H1 to H10 was used; the higher the number, the higher the degree of decomposition [9]. According to this system, test samples are classified into H3 and H6 with an average organic content of 75% and 30%, respectively. H3 refers to very slightly decomposed peat, which releases very muddy brown water when being squeezed but no peat passes through the fingers. Its remaining plants are still identifiable and no amorphous material is present while H6 refers to moderately decomposed peat with a very indistinct plant structure. When it is squeezed, about one-third of the peat escapes between the fingers and the structure is more distinct compared to before squeezing [9].

Although the samples taken from a limited area and depth are classified into H3 and H6, it does not imply that peats with other degrees of decomposition do not exist in this sampling area.

4. OEDOMETER AND SHEAR TESTS

Ten oedometer tests were conducted on peat specimens having 7 cm diameter and 1.9 cm thickness. Also, four series of drained direct shear tests were performed on 10 cm square samples with 2 cm thickness. To prepare each test specimen, the lubricated specimen cutter, that is the oedometer ring for oedometer test and the shear box cutter for direct shear test was placed on the central part of the cylindrical samples, where it is expected to experience less sample disturbance during field sampling, and is pushed into the soil. While the cutter was in place, the peat sample was pushed out of the cylinder for about 5 cm using a hydraulic jack, the surrounding peat was removed, and the specimen was cut from the bottom. The peat specimen was placed on a glass plate for trimming. Figure 1 show the peat specimens inside the cutters when the surrounding peat has been removed.

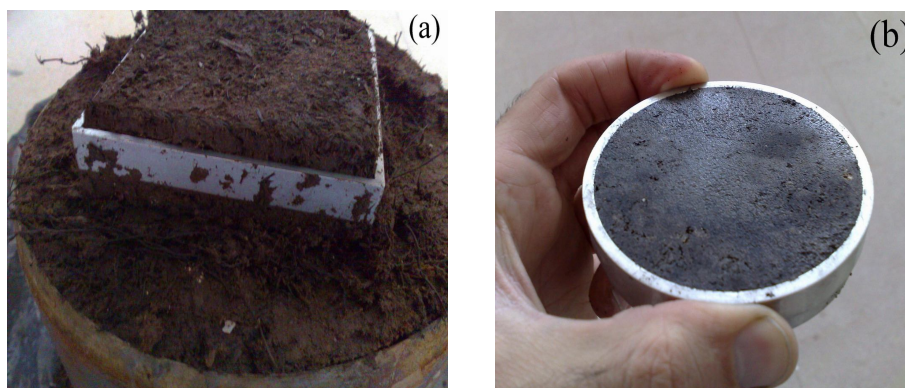


Fig. 1. Prepared specimens from (a) H3 peat sample, (b) H6 peat sample

In oedometer tests, the vertical stresses of 25, 50, 100 and 200 kPa were applied, each with a 24 hour duration. For two tests, an additional pressure increment of 12.5 kPa was also included. Because of the very high compressibility of H3 peat and the limitations of the apparatus, the last loading increment was not possible for this category of peat. In order to determine the swelling index, at the end of the last loading stage, the specimens were unloaded in two steps to 25 kPa.

Direct shear tests were conducted with vertical stresses of 8.98, 17.96, and 26.94 kPa. The adopted vertical stresses were chosen to be relatively low, because at this range of vertical stresses, the reinforcing effect of fibers is reduced [10]. Also, considering the high compressibility of peat at high vertical stresses, the upper perforated grid could get close enough to predefined shearing surface, which might affect the test results.

It should be noted that until now a specific shear test method has not been introduced for peat soils to determine their shear strength parameters. But among conventional shear tests, the ring shear and direct simple shear tests in which the effect of fibers on test procedure is low, were found to be more suitable [11]. Hence, the purpose of the conducted direct shear tests in this research was not the determination of shear strength parameters; rather the comparison between shear behaviour of two types of peat with different degrees of decomposition was desired.

5. PHYSICAL CHARACTERISTICS OF URMIA PEAT

Physical properties of peats are significantly different from those of inorganic soils. High values of void ratio and water content, and low values of specific gravity, bulk density, and dry density of peat are due to perforated organic particles with a low value of specific gravity, which are full of water [12].

Table 1 shows the range of physical characteristics of Urmia peat. As is obvious from this table, these properties can also be quite variable due to different degrees of decomposition. In order to find more independent properties which control the mechanical behaviour of Urmia peat, and to derive some empirical correlations between different physical properties, the relationship between the parameters was investigated.

Table 1. The range of characteristics of tested soils

Characteristics	Range of values
Organic content, OC, (%) ^a	25-77
Natural water content, W_n , (%)	102-671
Initial void ratio, e_0	2.4-11.2
Initial degree of saturation, (%)	95-100
Natural unit weight, γ_b , (kN/m ³)	10.33-13.7
Specific gravity, G_s	1.63-2.35
Pre-consolidation pressure, σ'_p , (kPa) ^b	10-60

^a Samples were heated to 800 °C

^b Obtained using Casagrande method

Figure 2 shows the variation of the percentage of the organic content of Urmia peat versus the specific gravity. In this figure other data from the literature is included for comparison [2, 12-15]. It could be verified from Fig. 2 that by increasing the specific gravity, the percentage of the organic content is decreased almost linearly. The following relationship was obtained for Urmia peat with a correlation coefficient of $R^2=99.0\%$.

$$OC = -71.84 (G_s) + 193.9 \quad (1)$$

In Eq. (1), the OC refers to the percentage of organic content and G_s refers to specific gravity. Skempton and Petley [16] suggested the following equation for peat,

$$OC = 290.8/G_s - 107.7 \quad (2)$$

From Fig. 2 it appears that Eq. (1) provides a better estimate for the percentage of organic content for peat.

Figures 3 and 4 show the initial void ratio of Urmia peat versus the natural water content and the percentage of organic content, respectively. Since the organic matter has a porous and spongy structure, a close relationship between the initial void ratio of peat with its percentage of organic matter and natural water content was expected, as shown in Fig. 3. The Eq. (3), with a high correlation coefficient of $R^2=99.9\%$ was derived from Fig. 3, and relates the initial void ratio of Urmia peat, e_o , to its natural water content, $W_n(\%)$.

$$e_o = 0.016W_n + 0.819 \quad (3)$$

However, in spite of an exponential relationship between the initial void ratio of Urmia peat with the percentage of organic content, as shown in Fig. 4, there is a relatively wide scatter in other reported data, which is probably due to different stress histories of peats. In other words, peats with identical organic content, but pre-compressed to different pressures and durations, would have different initial void ratios.

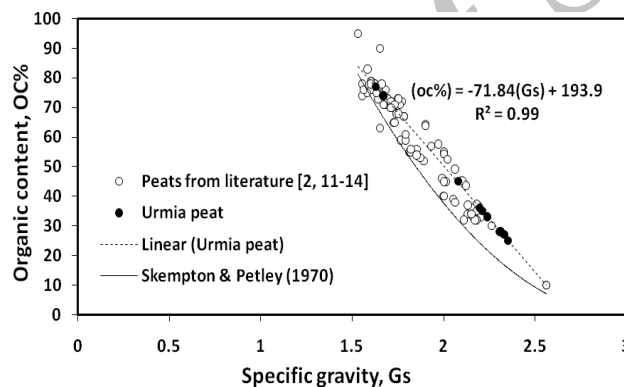


Fig. 2. Change of percentage of organic content against specific gravity

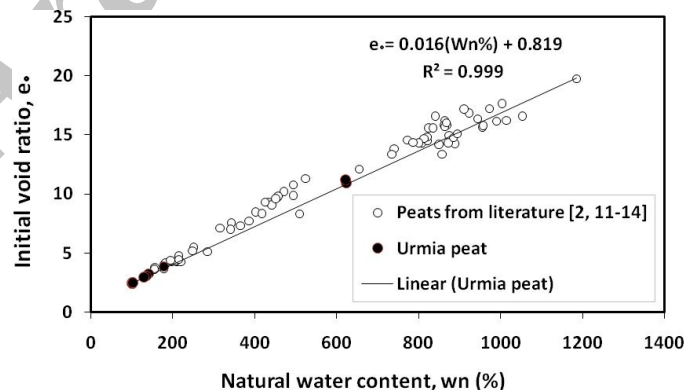


Fig. 3. Change of initial void ratio against natural water content

6. ONE-DIMENSIONAL COMPRESSION BEHAVIOR OF URMIA PEAT

Peat is considered as one of the undesirable foundation soils due to its high compressibility and long-term creep settlement. This soil often exhibits unusual one-dimensional time-compression curves compared to those for inorganic soils [14]. In Fig. 5, which corresponds to Urmia peat with 33% of organic content,

sample curves of void ratio versus logarithm of time are presented. As could be verified from Fig. 5, it is difficult to identify the exact time for the end of primary consolidation. Hence, Taylor's logarithm of time method was used for this purpose.

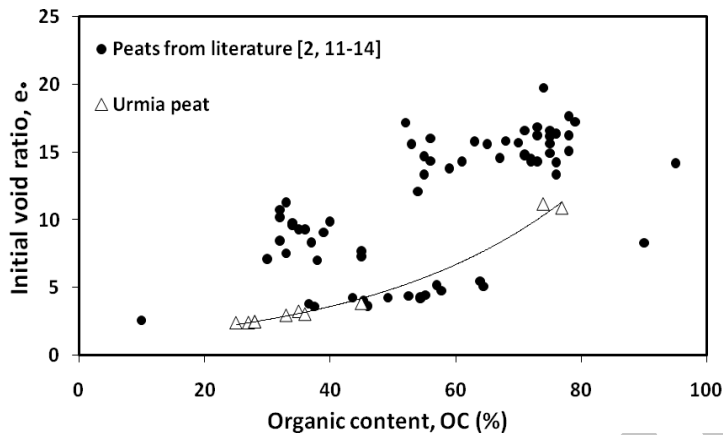


Fig. 4. Change of initial void ratio against organic content

A comparison between the obtained end of primary consolidation of peats with those measured has revealed that Taylor's logarithm of time method is applicable for peat soils [5].

In Fig. 5, the duration of primary consolidation, t_p , is relatively short in all loading stages, which implies that the primary consolidation takes place rapidly due to the high permeability of peat. But as can be seen, t_p increases when the applied stress level is increased. Also, from this figure, it can be verified that the secondary compression for the two first loading stages is not linear with logarithm of time. Similar nonlinear behaviour was also observed in some of the loading stages of other tested specimens.

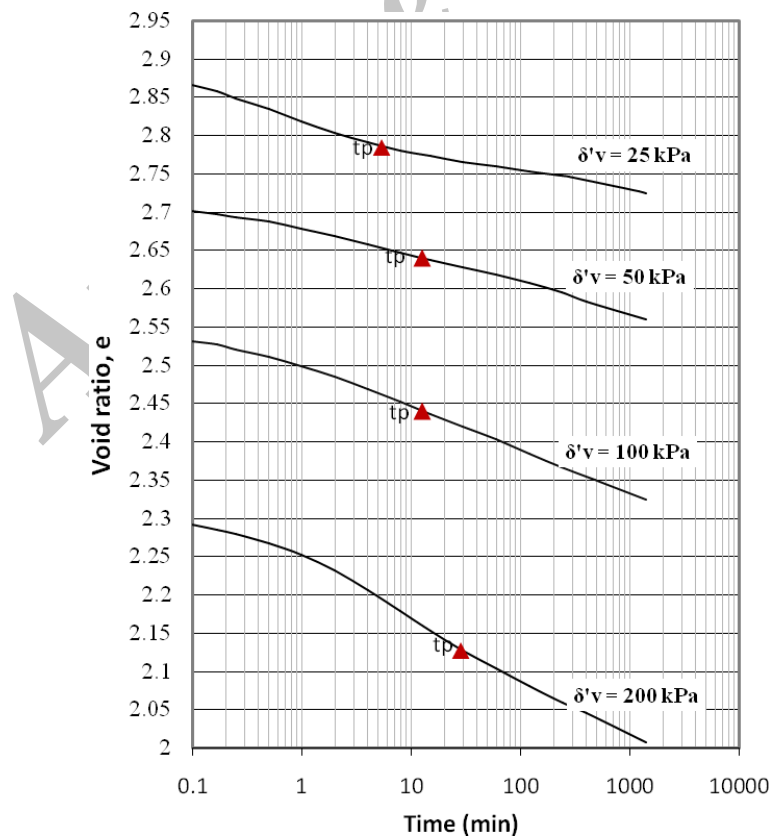


Fig. 5. Void ratio versus logarithm of time curves for Urmia peat with 33% of organic content

The variation of the coefficient of consolidation, c_v , and the coefficient of volume compressibility, m_v , with vertical effective stress, σ'_v , for tested specimens are shown in Fig. 6. c_v is a parameter that can be determined with Eq. (4); and as one can find from Eqs. (5) and (6), it relates the change in excess pore pressure with respect to time, to the amount of water draining out of the voids of a soil prism during the same time, due to consolidation

$$c_v = \frac{T_{90}}{t_{90}} h^2 \quad (4)$$

$$\frac{\partial u}{\partial t} = \frac{k}{m_v \gamma_w} \frac{\partial^2 u}{\partial z^2} \quad (5)$$

In Eq. (4), t_{90} is the time when 90% of primary consolidation takes place and can be obtained from Taylor's \sqrt{t} method, T_{90} is the theoretical time factor corresponding to 90% primary consolidation, and h is the length of the maximum drainage path. In Eq. (5), u is the excess pore water pressure at time t , at a point with a height of z , γ_w is the unit weight of water, k is the coefficient of permeability, and m_v is the coefficient of volume compressibility which is defined in Eq. (7),

$$c_v = \frac{k}{m_v \gamma_w} \quad (6)$$

$$m_v = \frac{1}{1 + e_1} \left(-\frac{\delta e}{\delta p} \right) \quad (7)$$

where e_1 is the void ratio at the start of the pressure increment δp , and δe is the change of void ratio for that increment.

From Fig. 6, one can find that the values of both m_v and c_v are considerably high compared to those of most inorganic silts and clays. However, their values decrease almost noticeably when the effective vertical stress, σ'_v , increases. It should be noted that for some tested specimens, the high value of c_v at low stresses may be due to their pre-consolidation. A comparison between the m_v - $\log \sigma'_v$ curves of Fig. 6, indicates that for a constant σ'_v in normally consolidated (NC) region, increasing the amount of organic content (OC) increases the value of m_v . Also, it can be seen that the slope of these curves in NC region, i.e., the decrease of m_v with an increase of σ'_v , is greater for peats with higher organic content. Hence, it can be concluded that a peat with high OC at a high stress level, might have the same m_v , compared to a peat with low OC at a low stress level.

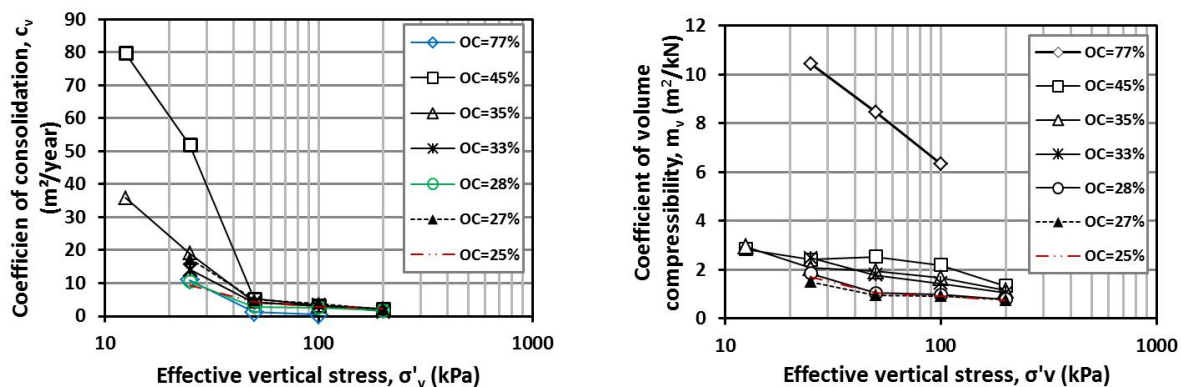


Fig. 6. Variation of the coefficient of consolidation (left), and the coefficient of volume compressibility (right), with effective vertical stress for Urmia peat

Substituting the values of m_v and c_v in Eq. (6), the coefficient of vertical permeability, k_v , for each test and loading stage was calculated. The relationship between the void ratio and logarithm of vertical permeability is shown in Fig. 7, where k_v is considered to be an average value of permeability during each loading step with a corresponding average value of void ratio for that step.

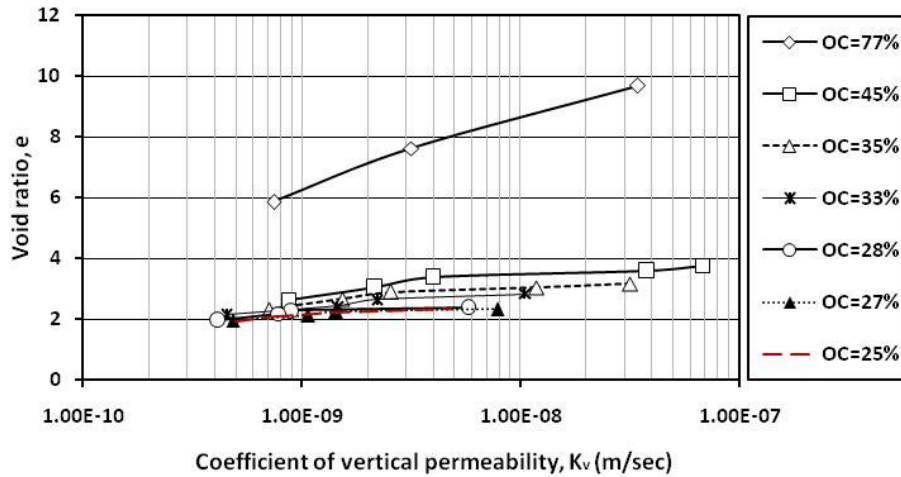


Fig. 7. Relationship between void ratio and coefficient of vertical permeability for Urmia peat with different percentages of organic content

From Fig. 7 it can be verified that the permeability of all tested specimens decreases significantly when the applied pressure increases from 25 kPa to 200 kPa (in the case of peat with 77% organic content, from 25 kPa to 100 kPa), which is consistent with reported characteristics of fibrous peats [12].

The slope of $e-\log k_v$ curves, known as permeability change index, C_k , is commonly used to characterize the decrease in permeability, $\Delta \log k_v$, with the decrease in void ratio, Δe (Eq. (8)),

$$C_k = \frac{\Delta e}{\Delta \log k_v} \tag{8}$$

As can be seen in Fig. 7, the permeability change index increases with increasing organic content. That is, for an identical decrease in permeability, a larger amount of void ratio decrease is required when the organic content of peat is higher. Also, comparing the $e-\log k_v$ curves of specimens with 25% to 45% of organic content (OC), one can conclude that for a given void ratio, k_v increases when OC increases.

Figure 8 is a plot of C_k obtained from the linear portion of the $e-\log k_v$ curves of Fig. 7 in the NC region, versus initial void ratio, e_o , where data on other peats from literature and a suggested empirical correlation [13] are also included. This figure shows that the data on tested specimens fall in the range of reported data, and the suggested correlation by Mesri et al. (1997) for fibrous peats, i.e.,

$$\frac{C_k}{e_o} = 0.25 \tag{9}$$

is also consistent for Urmia peat. The low value of this ratio compared to 0.5 for soft clays and silts, and 0.7 for sodium montmorillonite is interpreted to be due to very non-uniform pore-size distribution of peats. Moreover, considering the relatively high values of C_k for peats, it is concluded that only macropores between particles are serving as the flow channels [2, 13, 15].

Compression index, C_c , and swelling index, C_s , are also two important parameters which are widely used in settlement analysis, and can be determined from $e-\log \sigma'_v$ curves as shown in Fig. 9. In Fig. 9(left), e is the void ratio at the end of each loading stage for compression curve and unloading stage for swelling

curve; while in Fig. 9(right), the $(EOP)e$ is the void ratio at the end of primary consolidation in each loading step, including the primary and secondary compression of previous loading stages. For example, in Fig. 5, the value of e corresponding to each t_p has been used as $(EOP)e$ to plot the $(EOP)e-\log\sigma'_v$ curve of the specimen with 33% organic content in Fig. 9(right).

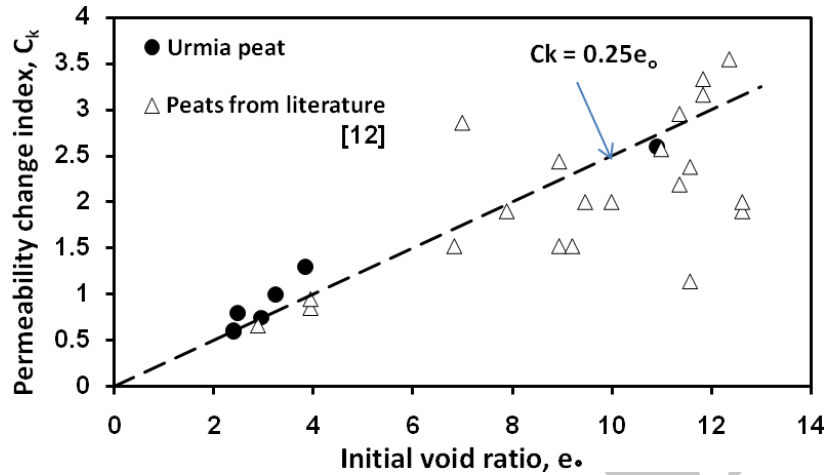


Fig. 8. Relationship between permeability change index and initial void ratio for Urmia peat and peats from literature

The value of C_c , i.e., the slope of the linear portion of $e-\log\sigma'_v$ curve in NC region, was obtained from both Fig. 9(left) and Fig. 9(right) for each tested specimen. Those determined from Fig. 9(right) were slightly higher. However, considering that the values reported for C_c in the literature are mostly obtained from $(EOP)e-\log\sigma'_v$ curves [13], and also higher values are more conservative, those obtained from Fig. 9(right) were used in the correlations. Also, the slopes of swelling curves in Fig. 9(left), which are almost linear, are used as C_s .

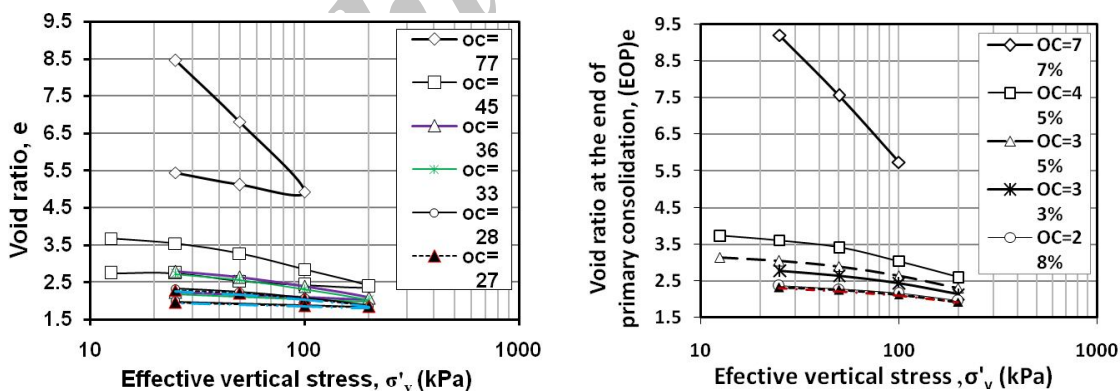


Fig. 9. Variation of void ratio with effective vertical stress during compression and swelling (left), and variation of void ratio at the end of primary consolidation versus effective vertical stress (right), in Urmia peat

In Fig. 9, according to definitions of C_c and C_s , it can be seen that the values of both compression and swelling indices increase with increasing organic content. The relationship between compression index and initial void ratio is shown in Fig. 10(left). Figure 10(right) is a plot of compression index versus natural water content of Urmia peat, where data on other peats from literature and a suggested empirical correlation are also included.

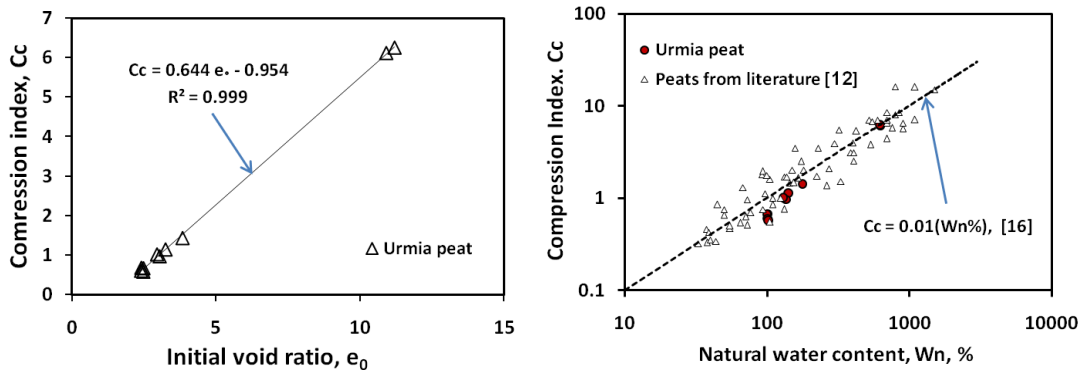


Fig. 10. Relationship between, (left) compression index and initial void ratio, (right) compression index and natural water content

It can be verified from Fig. 10(left) that by increasing the initial void ratio, e_0 , the value of compression index, C_c , increases linearly. The following equation defines their relationship.

$$C_c = 0.644e_0 - 0.954 \tag{10}$$

As described earlier, due to the linear relationship between initial void ratio and natural water content (Eq. (3)), it is expected that a linear relationship should also exist between the compression index, C_c , and the natural water content, w_n , of peat soils. Fig. 10(right) not only confirms this expectation, but also shows that the data obtained from the tested specimens of Urmia peat fall in the range of reported values, and the suggested correlation by Keene and Zawodniak [17], i.e.,

$$C_c = \frac{w_n(\%)}{100} \tag{11}$$

is also applicable for Urmia peat.

The relationship between the swelling index, C_s , and the initial void ratio, e_0 , of the tested specimens is shown in Fig. 11(left), which suggests that C_s increases linearly when e_0 increases. Equation (12) is derived from their correlation.

$$C_s = 0.075e_0 \tag{12}$$

From Eqs. (10) and (12) one can find that the ratio of C_s/C_c might also be constant. In Fig. 11(right), it is shown that the value of C_s/C_c for Urmia peat is 0.143 which falls in the range of 0.1-0.3 reported for peats [12].

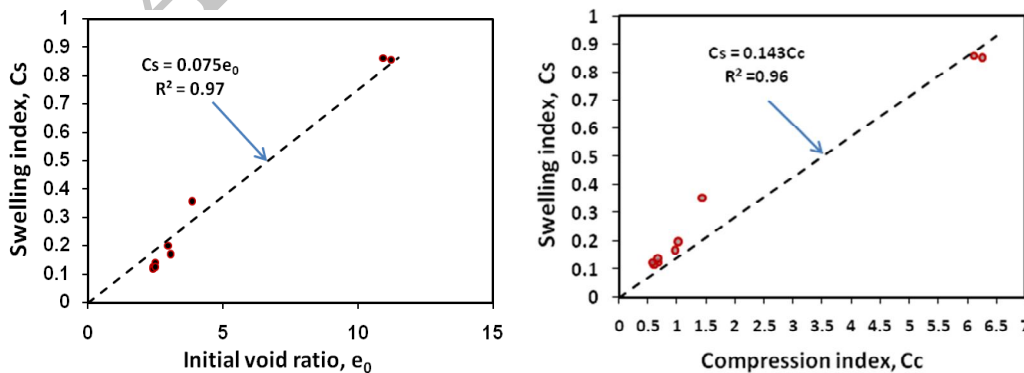


Fig. 11. Relationship between, (left) swelling index and initial void ratio, (right) swelling index and compression index, for Urmia peat

Another important parameter for this specific soil is the secondary compression index, C_{α} , which is widely used to characterize and evaluate the secondary compression behavior, and is defined by Eq. (13),

$$C_{\alpha} = \frac{\Delta e}{\Delta \log t} \tag{13}$$

where Δe is the change of void ratio occurring in a given time span of $\Delta \log t$ after the end of primary consolidation. In other words, C_{α} is the slope of an $e-\log t$ curve, similar to curves shown in Fig. 5, beyond t_p , where the primary consolidation ends. As could be verified from Fig. 5, the C_{α} is not only nonlinear in some loading stages, but it also varies from one loading step to another. The variation of C_{α} obtained from the linear segment of $e-\log t$ curves, immediately beyond the transition from primary to secondary compression against the effective vertical stress, is shown in Fig. 12. As can be verified, for a constant value of σ'_v , the value of C_{α} increases when the amount of organic content, OC, increases. Moreover, as shown in Fig. 12, the value of C_{α} increases with σ'_v , and the slope of the corresponding curve increases when the amount of organic content increases.

According to the C_{α}/C_c concept of compressibility, a single value of C_{α}/C_c together with $(EOP)e$ versus $\log \sigma'_v$ relationship define secondary compression behavior at all values of σ'_v in recompression and compression and throughout the secondary compression stage. Note specially that C_c denotes slopes of the e versus $\log \sigma'_v$ relationship throughout both recompression and compression ranges [13]. In Fig. 13, the values of C_{α} obtained right after the end of primary consolidation (data of Fig. 12), are plotted against the corresponding values of C_c obtained from $(EOP)e-\log \sigma'_v$ curves. As can be seen, the ratio of C_{α}/C_c is almost constant, which suggests that the C_{α}/C_c concept of compressibility is applicable for Urmia peat. Moreover, the value of 0.058 obtained for this ratio falls in the range of 0.06 ± 0.01 reported for peats [13].

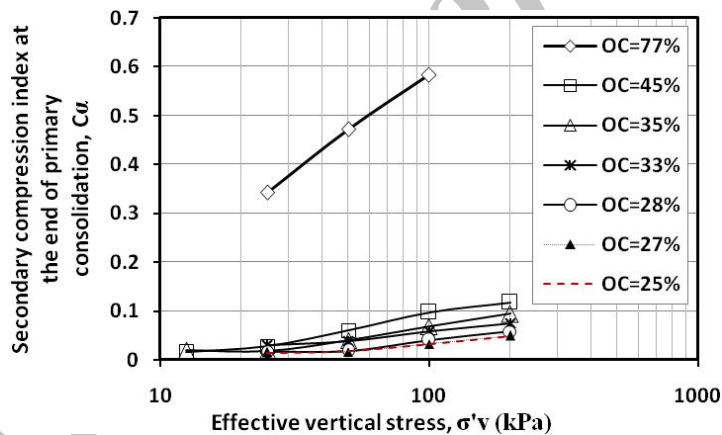


Fig. 12. Variation of secondary compression index, C_{α} , with effective vertical stress, σ'_v , for tested specimens of Urmia peat

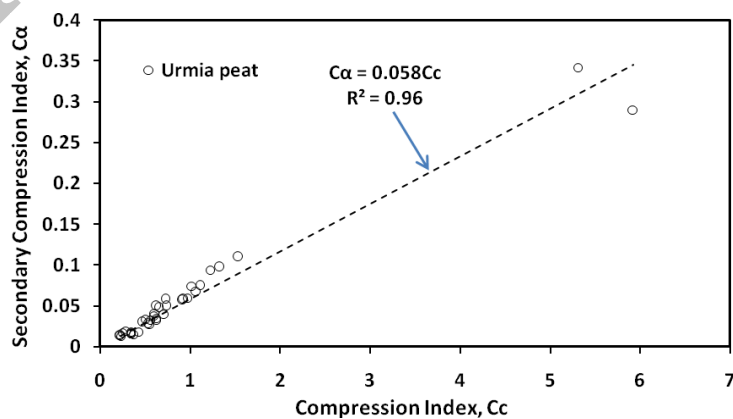


Fig. 13. Secondary compression index, C_{α} , versus compression index, C_c , for Urmia peat

The C_α/C_c concept of compressibility states that the magnitude and behavior of C_α with time is directly related to the magnitude and behavior of C_c with effective vertical stress, σ'_v . In general, C_α remains constant, decreases, or increases with time, in the range of σ'_v at which C_c remains constant, decreases, or increases with σ'_v , respectively [13]. In order to explain the observed secondary compression behavior in curves of Fig. 5 using this concept, void ratios at the end of primary consolidation and at the end of pressure increment duration of each test stage were plotted against logarithm of effective vertical stress as shown in Fig. 14.

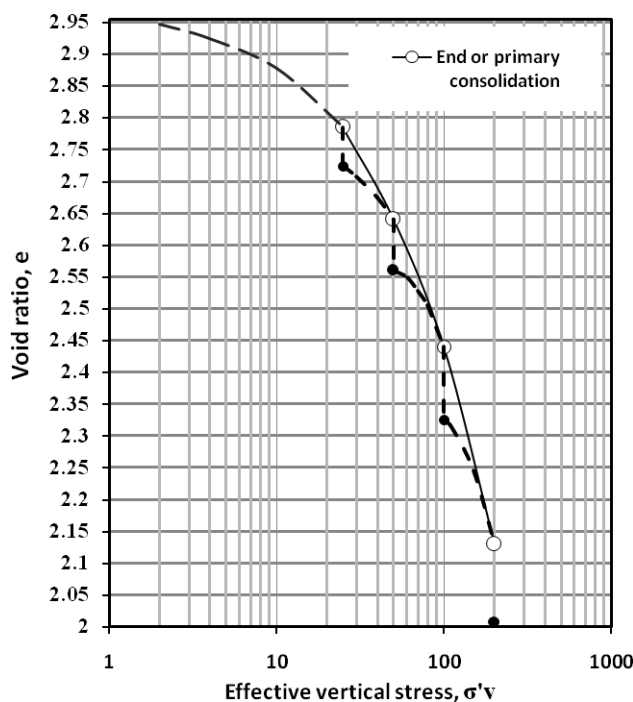


Fig. 14. Variation of void ratio with effective vertical stress for Urmia peat with 33% of organic content

In Fig. 14, each pressure increment and the resulting magnitude of primary compression followed by secondary compression is indicated with a dashed line. As can be seen, the first pressure increment ends near the pre-consolidation pressure, where the slope of $e-\log\sigma'_v$ curve, i.e., C_c , increases with the increase of σ'_v . According to the C_α/C_c concept of compressibility, since C_α/C_c is constant, C_α is expected to increase with time. The observed secondary compression behavior in first loading stage of Fig. 5 agrees with this prediction. In Fig. 14, it can be seen that the secondary compression during first loading stage, develops a pre-consolidation pressure, in the sense that upon reloading, the specimen displays a recompression to compression response. Hence, applied consolidation pressure increment from 25 kPa to 50 kPa, ends near the developed pre-consolidation pressure, where C_c again increases with the increase of σ'_v . Therefore C_α is also expected to increase with time. The observed secondary compression behavior in the second loading stage of Fig. 5 confirms this expectation. In Fig. 14, the last two pressure increments, despite the developed pre-compression in their previous loading stage, end almost in compression range, where the change of C_c with σ'_v is negligible. Accordingly, C_α is expected to be constant. In Fig. 5 it can be found that this prediction is also true.

7. SHEAR BEHAVIOR OF URMIA PEAT

In order to investigate the degree of decomposition on shear behavior of Urmia peat, a series of drained direct shear box tests were performed on two types of Urmia peat. Peat samples comprised of (1) over-

consolidated and more decomposed, categorized as H6 peat, and (2) normally consolidated with low degree of decomposition, categorized as H3 peat. An important feature encountered in shear tests was that a failure as defined by peak shear stress was not observed in any of the tested samples. Typical shear stress-displacement curves are shown in Fig. 15(left). As can be seen, shear resistance increases with displacement during the test, and the slope of the curves increases with the applied normal pressure, σ'_n , which is likely to be due to the fibers effect.

The results of extrapolated shear strengths from shear strength-displacement curves are summarized in Table 2 and are plotted in Fig. 15(right). The results show that the shear behavior of peat with low degree of decomposition is more frictional compared to that of highly decomposed peat, which seems to be more cohesive. As was described earlier, the inorganic portion of peat soil increases with its degree of decomposition. Moreover, the size and shape of organic matter are also a function of humification. Therefore, this different shear behavior stems from their different structure.

In peat samples of category H6, the soil grains and fibers are very small and due to pre-consolidation are densely packed. Hence, the surface tension of the water between grains and also the contact surface and traction between reinforcing fibers with adjacent soil particles are relatively large, leading to an apparent cohesion, c' , in soil. But the small number and short length reinforcing fibers in this relatively high decomposed peat cannot significantly affect its shear strength unless a large change in void ratio, entanglement of fibers, and consequently shear stress increase on the fiber-matrix interface occur. Since the applied normal pressures are relatively low and remain in the pre-consolidated region, the change in void ratio and accordingly the increase in shear strength are not large. Therefore, in applied range of stresses the angle of shear resistance, ϕ' , of this type of peat is relatively low. In contrast, the H3 peat is formed by large organic particles and long and rough fibers. The initial void ratio of this normally consolidated soil is very high, indicating that the contact surface and the traction between particles and fibers are very small. When the lowest normal pressure, i.e., 8.98 kPa is applied, the resulting decrease in void ratio is not enough to produce a significant traction between fibers and matrix. Hence, upon shearing, the soil particles and fibers slip easily on each other and no effect of reinforcement is evident. But, due to the presence of long fibers and high compressibility of H3 peat, even by applying the second normal pressure, i.e., 17.96 kPa, which is also a relatively low stress, the shear strength is increased significantly. In fact, the longer fibers of H3 peat are more effective compared to those of H6 peat. Since the normal force in the reinforcing fibers is equal to the integrated shear stress on the fiber-matrix interface, larger forces can be induced in longer fibers and then they can contribute more significantly in shear resistance even at low normal pressures. A low shear strength at low normal pressure, together with a sharp increase in shear strength by applied normal pressure, are the reasons that H3 peat has a low value of c' and a high value of ϕ' .

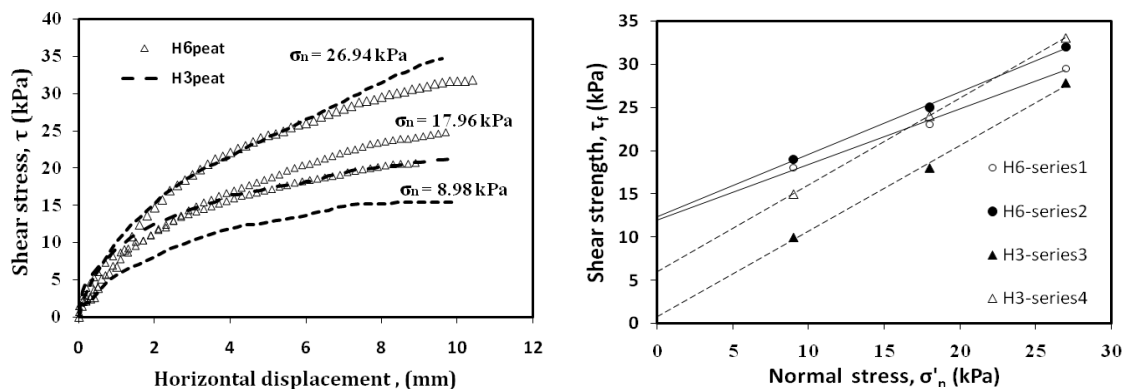


Fig. 15. Variation of shear stress with displacement (left), and shear strength with normal stress (right), in Urmia peat

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

8. SUMMARY AND CONCLUSIONS

A number of oedometer and direct shear box tests were conducted on undisturbed samples of Urmia peat with different degrees of decomposition. The relationship between various mechanical and physical properties of Urmia peat together with other peats from literature was investigated. Based on the results, some empirical correlations were derived for Urmia peat and were compared with the reported correlations for other peats. The following conclusions are made based on the results obtained from this study:

1. Physical properties of Urmia peat like other peats are significantly different from those of inorganic soils and vary in a wide range due to decomposition.
2. The amount of organic content, which is a function of degradation, decreases almost linearly when specific gravity increases. Although it is expected that the initial void ratio will increase with increasing the organic content, due to different stress histories, peats with identical organic content but pre-compressed to different pressures and durations would have different initial void ratios. Instead, it was found that the initial void ratio increases linearly when the natural water content increases.
3. Although the initial values of the coefficient of consolidation and coefficient of volume compressibility of peat are high, they decrease considerably with effective vertical stress. The decrease of volume compressibility is greater for peats with higher organic content. Moreover, at a constant effective vertical stress in the normally consolidated region, the value of volume compressibility increases when organic content increases.
4. The coefficient of vertical permeability decreases significantly due to compression and for a given void ratio, the coefficient of vertical permeability decreases when organic content increases. Moreover, the permeability change index, C_k , increases with organic content. Also the reported value of 0.25 for C_k/e_0 ratio of peats was consistent with that for Urmia peat.
5. The values of compression index, C_c , and swelling index, C_s , increase when the organic content increases. Moreover, both C_c and C_s increase linearly with e_0 . Also, a constant value of 0.143 was found for C_s/C_c ratio of Urmia peat, which is in the range of 0.1-0.3 reported for other peats.
6. For a constant value of σ'_v , the value of secondary compression index, C_α , increases when the amount of organic content increases. Moreover, the value of C_α increases with σ'_v , and the slope of the corresponding curve increases when the amount of organic content increases.
7. A constant value of 0.058 was found for C_α/C_c ratio in Urmia peat, which falls in the range of 0.06 ± 0.01 reported for other peats. Moreover, there is a good agreement between the secondary compression behavior of Urmia peat and the C_α/C_c concept of compressibility.
8. The reinforcing effect of fibers is significant in the shear behavior of Urmia peat. This is due to the shape, length, and size of fibers, as well as the organic content with respect to mineral content and their packing state. The results showed that the shear behavior of peat with low degree of decomposition is more frictional compared to that of highly decomposed peat, which seems to be more cohesive.

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