Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 9 (18): 3207-3218, 2009
ISSN 1812-5654

A Review on Hydraulic Conductivity and Compressibility of Peat

L.S. Wong, R. Hashim and F.H. Ali
Department of Civil Engineering, Faculty of Engineering, University of Malaya,
Kuala Lumpur, Malaysia

Abstract: This study reviews the results of several experimental and field investigations on the behavior of peat in hydraulic conductivity and compressibility. A study on the mechanical properties of peat is important in order to gather sufficient information on the response of the soil to preloading in terms of the soil permeability and deformation. Preloading technique is normally employed as a method to improve peat ground so that the improved ground can be used as a soil foundation to support road embankment. Findings on the initial hydraulic conductivity of peat revealed that the initial coefficient of vertical permeability (k_{v0}) of the soil ranged from 10^{-5} to 10^{-8} m sec^{-1} with the value was found to be lower in amorphous peat as compared to that of fibrous peat. Such findings indicated that the initial hydraulic conductivity of peat is influenced by the soil degree of decomposition. The higher is the soil degree of decomposition, the lower is its initial rate of hydraulic conductivity. Results from oedometer tests on Portage peat showed that while the soil coefficient of secondary compression ($c_{\alpha 1}$) ranged from 0.17 to 0.18, its coefficient of tertiary compression ($c_{\alpha 2}$) varied from 0.6 to 0.18. At high consolidation pressure, the soil $c_{\alpha 1}$ approached its $c_{\alpha 2}$ indicating the merging of secondary and tertiary compression components. It can be concluded that the behavior of peat is different from that of inorganic soil in that it exhibited high to moderate initial hydraulic conductivity, rapid primary consolidation and large secondary compression.

Key words: Peat, hydraulic conductivity, compressibility, experimental and field investigations

INTRODUCTION

Encountered extensively in wetlands, peat is subsurface materials considered to be among the poorest of foundation materials in terms of its engineering properties (Dhowian and Edil, 1980). Warburton *et al.* (2004) defined peat as a biogenic deposit which when saturated consists of about 90-95% water and about 5-10% solid material. According to Warburton *et al.* (2004) further, the organic content of the solid fraction is very high, often up to 95% and is made up of the partly decayed remains of vegetation which has accumulated in waterlogged areas over timescales of 10^2-10^3 years. This renders peat as an extremely soft organic soil with very low bearing capacity and high compressibility.

As a result, road embankments constructed on peat ground are often subjected to excessive total and differential settlements. Such excessive soil settlements often lead to serious cracks and damages of the road embankments. Gofar and Sutejo (2007) reported that excessive settlement of peat is attributed to unusual compression behavior of the soil with relatively short primary consolidation and significant secondary compression. The fact is supported by the finding of Berry and Vickers (1975) which stated that the deformation process of peat involves two separated but interlinked effects associated with primary pore pressure dissipation and secondary viscous creep. Such unusual compression behavior of the soil is attributed to several factors including the initial water content, void ratio, initial permeability, fiber content and arrangement and the condition in which the peat is deposited (Gofar and Sutejo, 2007).

Because of development in some parts of the world where peat deposits are extensive, preloading techniques through surcharging have been employed with some success as a means of *in situ* improvement of engineering properties (Lea and Barwner, 1963; Weber, 1969; Samson and La Rochelle, 1972). For roads of a high standard, where post-construction settlements are most undesirable, the technique of precompression of the peat has proved to be a very effective method to reduce the settlements to acceptable values; furthermore, the precompression of the peat has the advantage of resulting in an appreciable increase of its shear strength which makes the preloading technique extremely interesting for different engineering applications (Samson and La Rochelle, 1972). Improvement of peat ground by

Corresponding Author: Wong Leong Sing, Department of Civil Engineering, Faculty of Engineering, University of Malaya, Lembah Pantai, 50603 Kuala Lumpur, Malaysia Tel: +6016 981 8692 Fax: +603 7967 5318

preloading technique often leads to a satisfactory soil foundation to support road embankments. However, success in the implementation of such technique requires in depth understanding on the response of hydraulic conductivity and compression of peat to preloading. Quantification of the hydraulic conductivity and compression responses of peat to consolidation pressure require relevant soil parameters that must be acquired through experimental and field investigations in order to analyze, interpret and model the behavior of the soil. Recently, several laboratory studies were successful at developing consistent laboratory experimentation on the behavior of peat in hydraulic conductivity and compressibility (Robinson, 2003; Wong, 2005; Gofar and Sutejo, 2007). Emphasizing on such development, this study introduces the formation and structural arrangement of peat and reviews the previous investigations and findings on the hydraulic conductivity and compressibility of peat. Such findings are vital to layout the fundamental principles, to develop background and to provide justification on the capability of peat to allow water to pass through it and to deform as a result of the application of consolidation pressure.

FORMATION AND STRUCTURAL ARRANGEMENT OF PEAT

Peats are formed by the disintegration of plant and organic matter and are characterized by very high void ratios and very high water contents (Kulathilaka, 1999). Dhowian and Edil (1980) defined peat as a mixture of fragmented organic material formed in wetlands under appropriate climatic and topographic conditions and it is derived from vegetation that has been chemically changed and fossilized. The formation of peats occurs as a result of the decaying process of plant under acidic conditions in the absence of microbial process. At its initial state, peats are porous with high water holding capacity and low specific gravity. Eventually with the increasing period of time, peats are subjected to biodegradation.

The essence to the basic understanding of the mechanical properties of peat is the structural arrangement of the soil. The size, shape, fabric and packing of the soil particles influence the soil permeability, compressibility and shear strength. According to Mitchell (1993), the values of properties such as strength, permeability and compressibility are determined directly by the size and shape of soil particles, their arrangements and the forces between them and as such to understand the properties require knowledge of these factors.

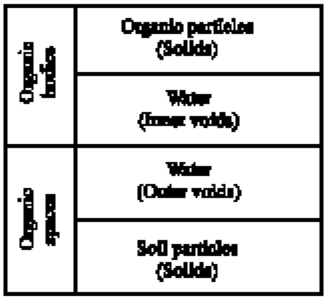

Fig. 1: Physical peat model (Kogure *et al*., 1993)

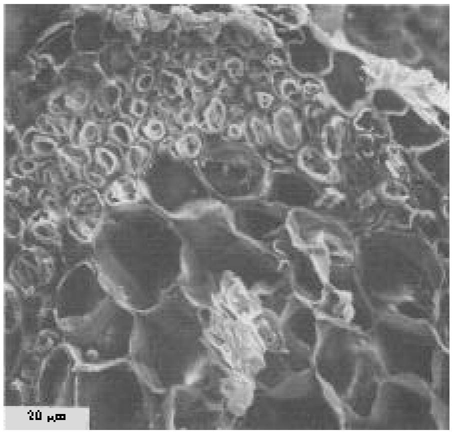

Fig. 2: Photomicrograph of a poriferous cellular peat particle (Terzaghi *et al*., 1996)

Kogure *et al*. (1993) introduced the concept of multi-phase system of peat and developed a physical peat soil model as shown in Fig. 1. Observation of the physical peat model indicates that the soil can be divided into two major components, namely organic bodies and organic spaces. The organic bodies consist of organic particles with its inner voids filled with water, whereas, the organic spaces of the soil model comprises of soil particles with its outer voids fill with water. The soil model gives a clear indication that at its initial state, peat can hold a considerable amount of water due to the hollow, spongy and coarse nature of the organic particles. The finding is supported by the fact that the photomicrograph of organic coarse particle of peat soil as shown in Fig. 2 gives a clear picture that the pore spaces within the particle are capable of holding water when fully saturated. Similar evidence of the presence of organic particle in peat can be observed from the scanning electron micrograph of peat in Fig. 3. The natural water content of the peat ranges from 610 to 830 % with its void ratio ranging from 11.1 to 14.2 (Terzaghi *et al*., 1996). However, the initial water content and void ratio of peat are dependent on its type (Bell, 2000). According to Bell (2000), amorphous

Fig. 3: Scanning electron micrograph of Banting peat (Alwi, 2008)

granular peat can have initial moisture content and void ratio as low as 500% and 9, respectively, whereas for fibrous peat, its initial moisture content and void ratio can be as high as 3000% and 25, respectively. Bell (2000) also claimed that amorphous peat tend to have higher bulk density if compared to that of fibrous peat with the former's bulk density can range up to 1.2 Mg m^{-3} whilst in woody fibrous peat, the bulk density maybe up to half to that of amorphous peat. While peats are normally acidic in character with its pH values varying between 5.5 and 6.5, the range of its specific gravity is between 1.1 and 1.8 (Bell, 2000).

The fiber content within peat has a major influence on the soil behavior. The term fiber includes all other fibrous structures, such as shrub rootlets, plant root hairs, rhizoids (root like filaments), etc. (Landva and Pheeney, 1980). According to Dhowian and Edil (1980), if peat has 20% fiber content or more, then it can be classified as fibrous peat. Otherwise, the peat is classified as amorphous peat. Karlsson and Hansbo (1981) further differentiated fibrous peat from amorphous peat with the description that fibrous peat has a low degree of decomposition, fibrous structures and easily recognized plant structure if compared to amorphous peat. A significant characteristic of amorphous peat is that it has a high degree of decomposition and thus it has lower water holding capacity if compared to that of fibrous peat. A more detail peat classification can be made using von Post classification system, which classifies peat according to its degree of humification. From an engineering point of view, the stronger the fibers and the greater their number, the more reinforced is the peat (Landva and Pheeney, 1980).

Amorphous peat: Based on the observation of micrographs of amorphous peat, Landva and Pheeney (1980) reported that the oven-dried amorphous-granular material in the soil (Fig. 4a) was practically solid. Further examination of the soil fabric under a consolidation pressure (Fig. 4b) indicated that there was little visual difference between the natural fabric and the fabric compressed under 7000 kPa (Landva and Pheeney, 1980). Clearly, there is not much void spaces observed from the micrographs in Fig. 4a and b and that gives a clear indication that amorphous peat has a lower hydraulic conductivity if compared to that of fibrous peat.

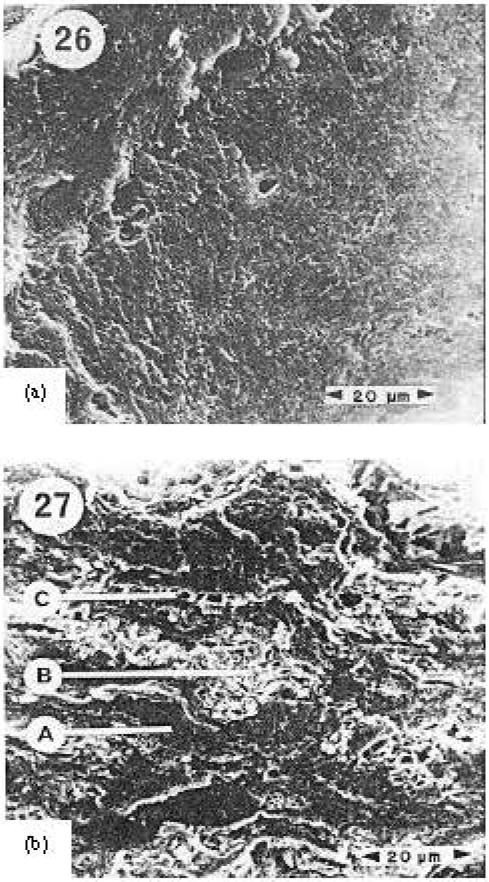

Fig. 4: Micrographs of amorphous peat (a) Amorphous-granular material in its natural state and (b) Amorphous-granular material compressed under a pressure of 7000 kPa (Landva and Pheeney, 1980)

Fibrous peat: Visual inspection on fibrous peat showed that the soil is dark brown in color, very soft, spongy and contains a large amount of fiber, organic and water content. Fox and Edil (1996) made detail observations of the fibrous peat microstructure using a scanning electron microscope. A sample of fibrous peat was loaded to

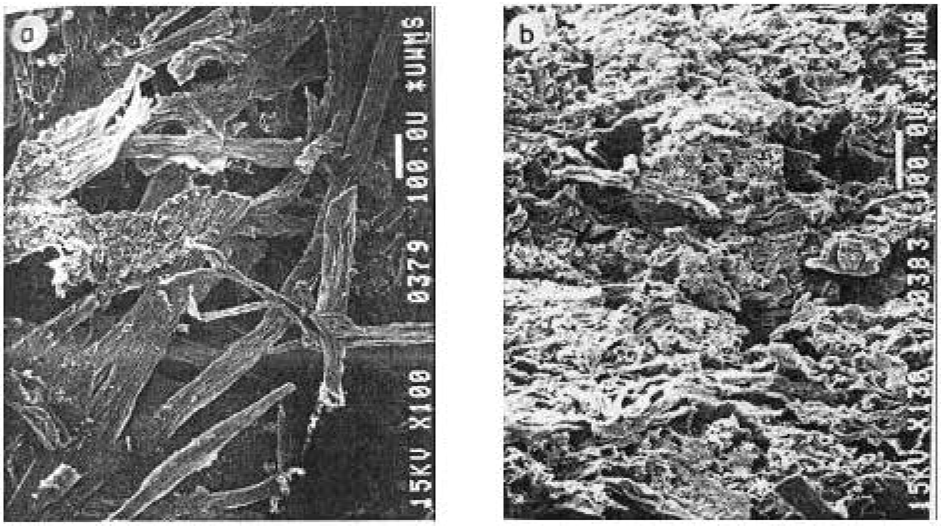

Fig. 5: Micrographs of Middleton fibrous peat (a) horizontal plane (b) and vertical plane (Fox and Edil, 1996)

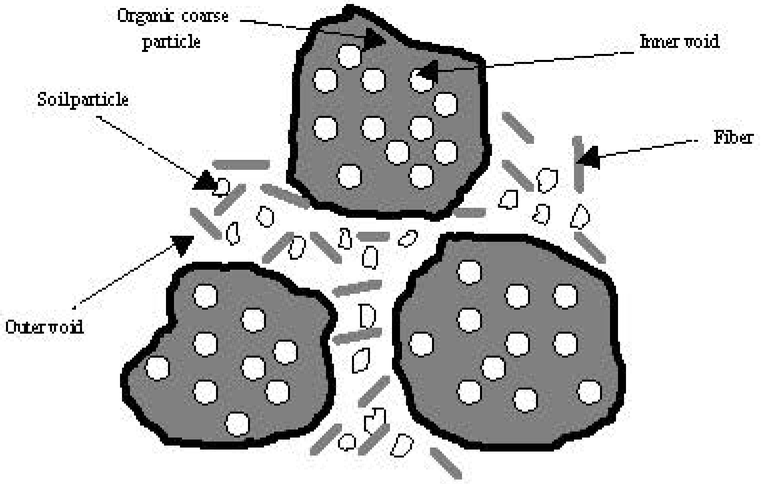

Fig. 6: Schematic diagram illustrating the composition of peat

400 kPa in one-dimensional compression and the corresponding photomicrographs with respect to vertical and horizontal planes were examined (Fig. 5). Revelation of a fabric of interwoven fibers from the photomicrograph in the horizontal plane proves that individual fibers tend to orient themselves horizontally as a consolidation pressure was applied to fibrous peat. This shows that under a consolidation pressure, the void spaces in the horizontal direction became larger than those in the vertical direction as a result of fiber orientation within the soil and this led to a pronounced structural anisotropy of the soil. This suggests that the horizontal hydraulic conductivity of the soil was greater than its vertical hydraulic conductivity when the soil was subjected to a consolidation pressure. Based on the findings of Kogure *et al*. (1993) and Dhowian and Edil (1980), a schematic diagram of peat indicating the soil composition is shown in Fig. 6.

HYDRAULIC CONDUCTIVITY OF PEAT

The capacity of a soil to allow water to pass through it is termed its permeability (hydraulic conductivity) (Whitlow, 2001). Earlier studies (Adams, 1965; Weber, 1969; Lefebvre *et al*., 1984) on hydraulic conductivity of peat indicated that in general, peat is averagely porous and has a medium degree of permeability with a good drainage characteristic in its natural state. A summary of

Table 1: Values of natural water content, w_0, initial coefficient of vertical permeability, k_{v0} and c_α/C_c for peat deposits (Mesri *et al.*, 1997)

Peat	w_0 (%)	k_{v0} (m sec^{-1})	c_α/C_c	References
Fibrous peat	850	4×10^{-6}	0.06-0.10	Hanrahan (1954)
Peat	520	-	0.061-0.078	Lewis (1956)
Amorphous and fibrous peat	500-1500	10^{-7}-10^{-6}	0.035-0.083	Lea and Brawner (1963)
Canadian muskeg	200-600	10^{-5}	0.09-0.10	Adams (1965)
Amorphous to fibrous peat	705	-	0.073-0.091	Keene and Zawodniak (1968)
Peat	400-750	10^{-6}	0.075-0.085	Weber (1969)
Fibrous peat	605-1290	10^{-6}-10^{-5}	0.052-0.072	Samson and La Rochelle (1972)
Fibrous peat	613-886	10^{-6}	0.06-0.085	Berry and Vickers (1975)
Amorphous to fibrous peat	600	10^{-6}	0.042-0.083	Dhowian and Edil (1980)
Fibrous peat	600-1590	5×10^{-7}-5×10^{-5}	0.06	Lefebvre *et al.* (1984)
Dutch peat	370	-	0.06	Den Hann (1994)
Fibrous peat	610-850	6×10^{-8}-10^{-7}	0.052	Mesri *et al.* (1997)

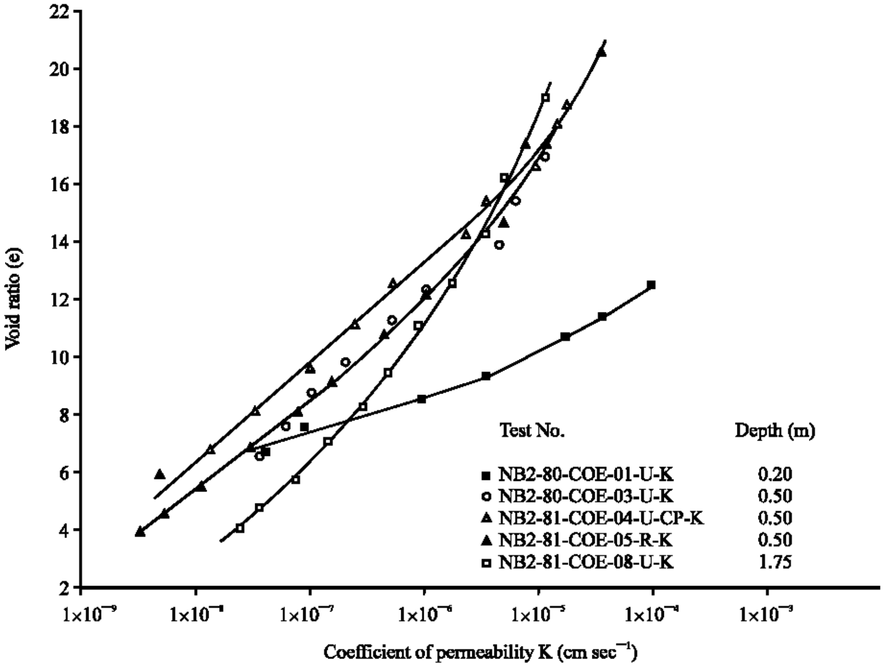

Fig. 7: Void ratio versus permeability, NBR-2 site (Lefebvre *et al.*, 1984)

the values of initial coefficient of vertical permeability of peat found by various researchers is shown on Table 1. The results indicate that their findings differ from one another due to the fact that soil fabric of peat varies from location to location. The physical and structural arrangement of constituent particles e.g., fibers and granules in peat greatly affect the size and continuity of pores resulting in a wide range of hydraulic conductivities (Edil, 2003). The results from Table 1 support the fact that amorphous peat has lower coefficient of permeability if compared to that of fibrous peat. This indicates that the permeability of peat is very much dependent on its degree of decomposition. In its initial state, fibrous peat undergoes decomposition with time to become amorphous peat and therefore, the initial permeability of fibrous peat reduces with increasing time depending on its degree of decomposition.

Results of falling-head tests conducted using oedometers on Canadian peat soils sampled from two different sites (NBR-2 and NBR-3 sites) show that Darcy's law is valid for the soils (Lefebvre *et al.*, 1984). Plots of logarithm of the soils coefficient of permeability versus its void ratio as shown in Fig. 7 and 8 indicate that the soils coefficient of permeability reduced rapidly with decreasing void ratio (Lefebvre *et al.*, 1984). Dhowian and Edil (1980) further stated that at a given void ratio of Portage peat, a typical fibrous peat, the soil coefficient of horizontal permeability (k_h) was about 300 times greater than its coefficient of vertical permeability (k_v) which proved that the fibrous peat was anisotropic (Fig. 9). This also implies that at a consolidation pressure, the soil coefficient of horizontal consolidation (c_h) was greater than its coefficient of vertical consolidation (c_v).

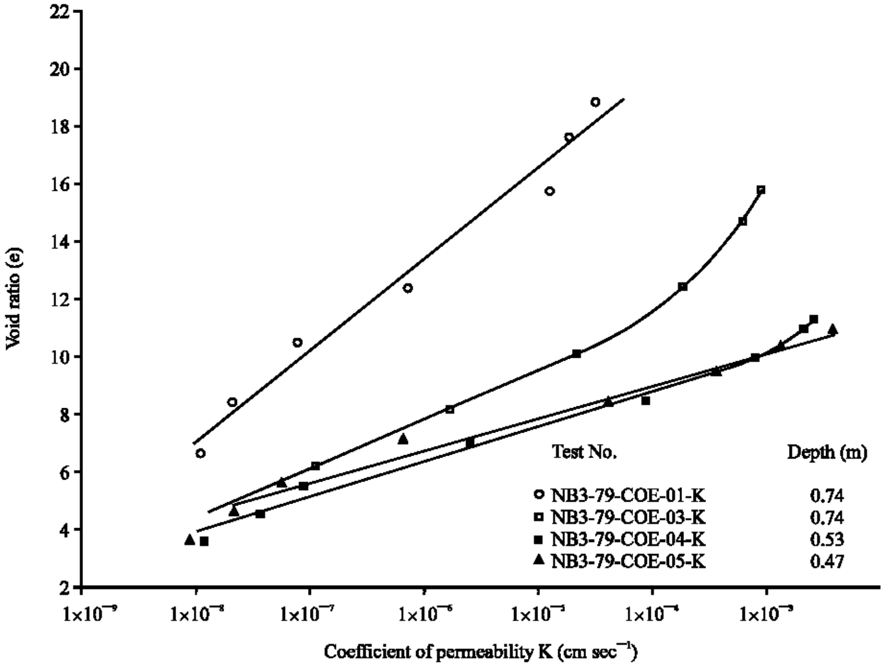

Fig. 8: Void ratio versus permeability, NBR-3 site (Lefebvre *et al*., 1984)

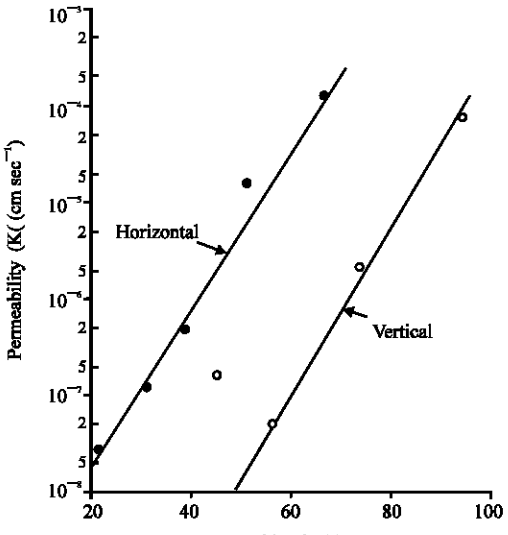

Fig. 9: Coefficient of permeability versus void ratio for vertical and horizontal specimens of Portage peat (Dhowian and Edil, 1980)

The change in permeability of peat as a result of compression is drastic (Dhowian and Edil, 1980). As shown in Fig. 7-9, the peat initially had a relatively high permeability comparable to that of fine sand or silty sand. However, as compression proceeded which resulted in rapid decrease in the soil void ratio, its coefficient of permeability was greatly reduced to a value comparable to that of soft intact clay.

COMPRESSIBILITY OF PEAT

Peats exhibit unusual compression behavior which is different from the conventional one of clay. Peats are often regarded as problematic soils with high rate of primary consolidation and a significant stage of secondary compression, which is not constant with logarithm of time in some cases (Colleselli *et al*., 2000). Due to its high to moderate initial permeability, peats have relatively short duration of primary consolidation and large secondary compression, even tertiary compression of peats can be observed. According to Colleselli *et al.* (2000), the initial permeability of peats is between 100 to 1000 times that of soft clays and silts and its coefficient of consolidation is between 10 to 100 times greater. The consolidation behavior of peats had been studied and presented by some researchers.

Colleselli *et al.* (2000) studied the compressibility characteristics of three types of Italian peat, namely Adria-1, Adria-2 and Correzzola peats using a 70.5 mm diameter standard oedometric consolidation cell and a 75.5 mm Rowe cell with pore water measurement at the base of the specimens. Figure 10 shows a log time-settlement curves of the peats for a single load increment from 10 to 100 kPa. The peats had quite similar amount of organic content ranging from 71 to 72% with Adria-2 peat had fiber content more than 75% which was much greater than those of 25% of both Adria-1 and Correzzola peats. Figure 10 shows that the primary consolidation and secondary compression of Adria-1 and Correzzola peats were clearly defined, with their tertiary compressions were relatively small. However, Adria-2 peat had low primary consolidation and both of its secondary and tertiary compressions are significantly observed in Fig. 10. With Adria-2 peat exhibited the greatest tertiary settlement than those of the other two peats, it can be explained that the different compression behavior is attributed to the different fiber content of the peats (Colleselli *et al.*, 2000). As such, it was found from the study that the higher the fiber content of peat, the larger was the tertiary compression of the soil.

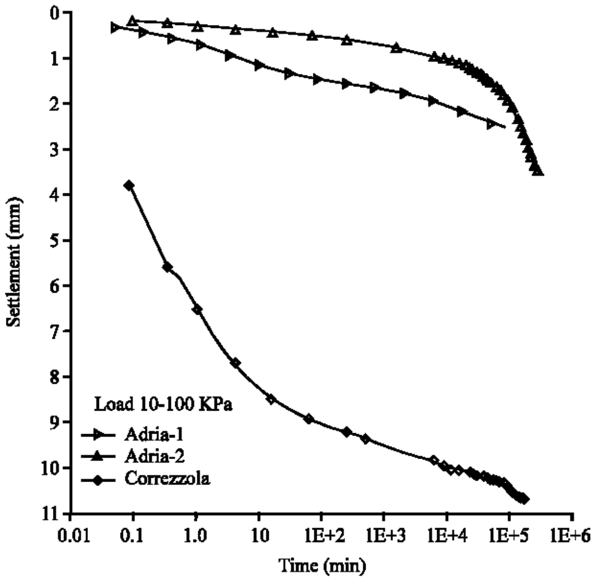

Fig. 10: Typical log time-settlement curves for Adria-1, Adria-2 and Correzola peats (Colleselli *et al.*, 2000)

Similar finding on the compression behavior of peat can be observed from the study of Dhowian and Edil (1980). The study evaluated the compression behavior of Portage peat, a typical fibrous peat with intermediate fiber content of about 31% using Anteus consolidometer with its specimen having a diameter of 73 mm and initial height of 228 mm. Different from the conventional apparatus, the Anteus consolidometer was modified to have two additional features: (1) a sensitive pressure transducer to measure the excess pore water pressure at the bottom of the specimen while the pore water is draining from the top and (2) burettes connected to the top and bottom of the specimen to measure the coefficient of permeability before the application of a stress increment during consolidation by the variable head method (Dhowian and Edil, 1980). Figure 11 shows a typical graphical plot from the study showing the vertical strain of the soil versus logarithm of time for the first increment of applied pressure of 50 kPa

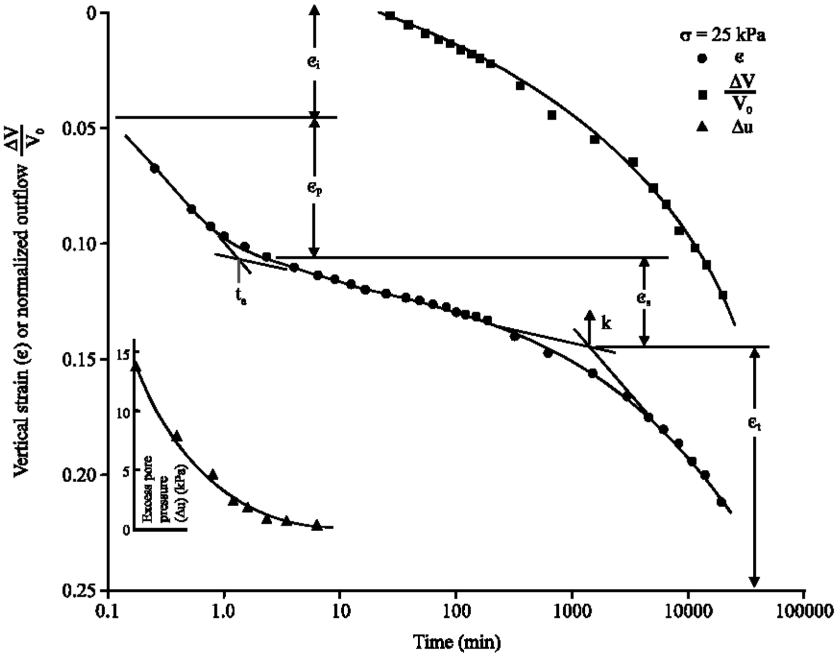

Fig. 11: Vertical strain, normalized effluent outflow and excess pore pressure versus logarithmic of time for a Portage peat specimen under the first stress increment (back pressure = 560 kPa) (Dhowian and Edil, 1980)

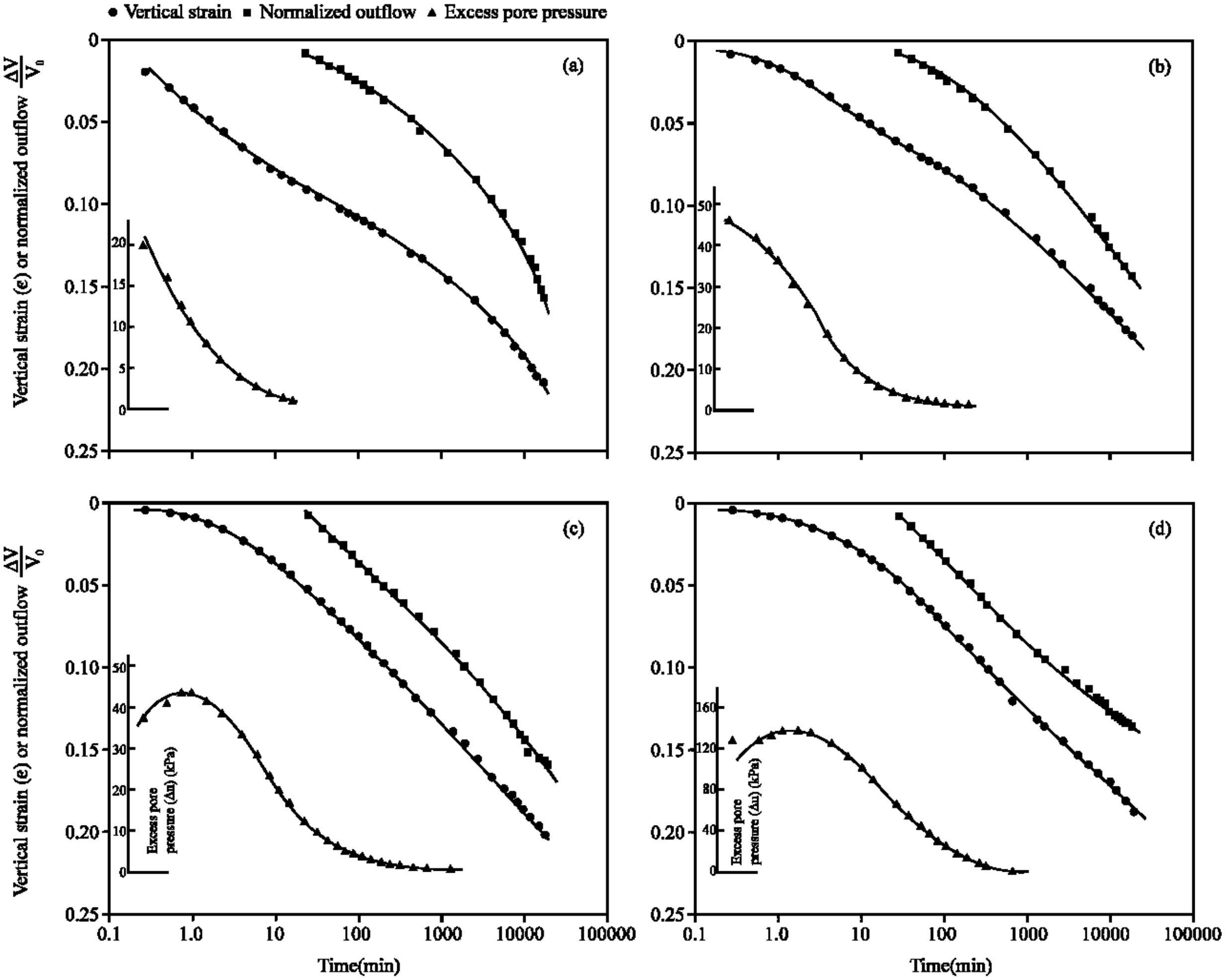

Fig. 12: Consolidation data for a Portage peat specimen (back pressure = 560 kPa), (a) σ = 50 kPa, (b) σ = 100 kPa, (c) σ = 200 kPa and (d) σ = 400 kPa (Dhowian and Edil, 1980)

under 560 kPa back pressure. According to Dhowian and Edil (1980), four components of strain can be clearly observed from the figure as detailed as follows:

- An instantaneous strain, which takes place immediately after the application of a pressure increment, possibly the result of the compression of air voids and the elastic compression of the peat
- A primary strain component, which occurs at a relatively high rate and continues for several minutes to a time, t_p
- A secondary strain component, which results from a linear increase of strain with the logarithm of time for a number of additional log cycles of time until a time, t_s, after which the time rate of compression increases substantially giving rise to a tertiary strain component
- A tertiary strain component, which continues indefinitely until the whole compression process ceases

The soil specimen was later subjected to consolidation pressures of 100, 200 and 400 kPa and the relationship between pore water pressure, strain and normalized outflow of the soil versus logarithm of time were graphically shown in Fig. 12. While Table 2 shows the time of end of primary consolidation (t_p) and time of end of secondary compression (t_s) for the soil specimen subjected to the consolidation pressures, Fig. 13 provides graphical illustrations of the relationship between compression parameters versus the consolidation pressures for the peat. As shown in Fig. 13a in relation to Fig. 12, about 10% strain for the first pressure increment was resulted from instantaneous and

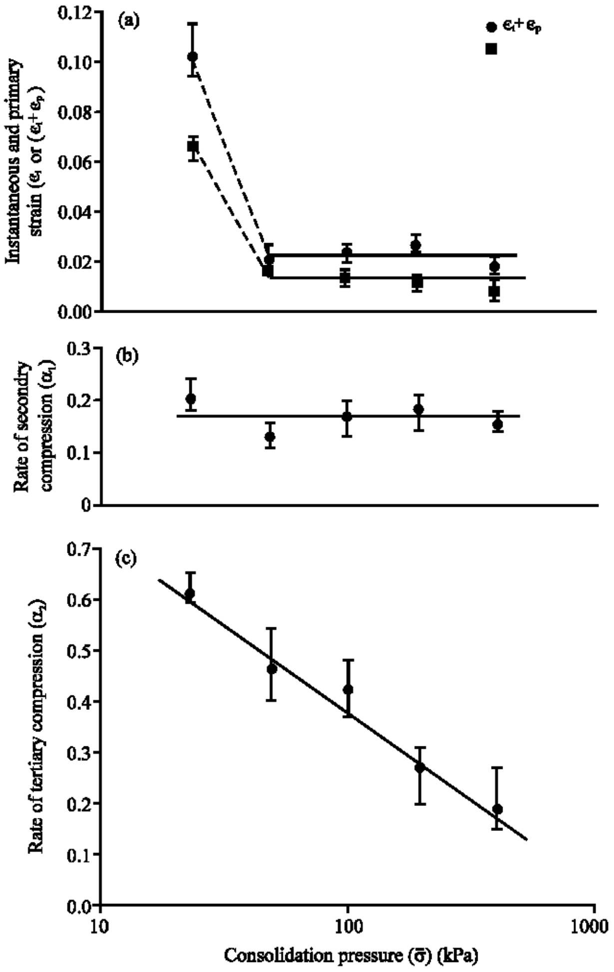

Fig. 13: (a-c) Compression parameters versus consolidation stress for Portage peat (Dhowian and Edil, 1980)

primary compression. However, the strain decreased to a constant value of 2% for the remaining pressure increments. This shows that the strain due to instantaneous and primary consolidation of the soil was relatively small due to its high initial permeability. As shown in Table 2, while the time of end of primary consolidation of the soil increased progressively from 1.35 to 2.68 min with increasing consolidation pressures, its time of end of secondary compression declined gradually from 2472 to 468 min with increasing consolidation pressures. Interestingly, as Fig. 13b shows that the rate of secondary compression was almost constant and lied within the range of 0.17 to 0.18, Fig. 13c indicates a steady decrease of rate of tertiary compression from 0.6 to nearly 0.18 at consolidation pressures of 25 and 400 kPa, respectively. The trend provides a clear indication that with increasing consolidation pressures, the rate of tertiary compression ($c_{\alpha 2}$), approached the rate of secondary compression ($c_{\alpha 1}$), which eventually resulted in the tertiary component of compression merged with secondary compression at high consolidation pressures (Dhowian and Edil, 1980). Despite of the finding that tertiary compression influences the long term compression behavior of peat, Hartlen and Wolski (1996) mentioned that there was no field evidence of tertiary compression of peat and it may therefore be considered a laboratory effect, which needs not to be included in the test evaluation. However, whether this is just a laboratory phenomenon or it also exists in the field remains unresolved (Dhowian and Edil, 1980).

Table 2: Change in t_p and t_s with pressure for Portage peat (average values for all tests) (Dhowian and Edil, 1980)

Pressure increment (kPa)	t_p (min)	t_s (min)
0-25	1.35	2472
25-50	0.48	1488
50-100	0.49	1284
100-200	1.49	468
200-400	2.68	NA

NA: Not available

The absence of tertiary compression of peat at field is evident in the field settlement observation of Samson and La Rochelle (1972) on a Canadian peat land. The peat land was preloaded by a sand embankment in three loading stages with the embankment heights of the first, second and third loading stages were 1.2 to 2.5, 0.3 and 1 to 1.5 m, respectively. Observations of the field settlement were made using 12 square settlement plates of 1×1 m size and 7.5 cm thick. Two typical log time-settlement curves of the peat subjected to the three loading stages measured at plates P-1 and P-3 are shown in Fig. 14 and 15. For analysis of the field settlement, the results of the second and third loading stages are shown in Fig. 16a and b (Samson and La Rochelle, 1972).

Analysis made on the graphs showed that the S-shaped primary consolidation curves are clearly defined with linear secondary compression. Settlement results from the settlement plates indicate that the time for the end of primary consolidation (t_p) for the first, second and third loading stages ranged from 5 to 10, 17 to 26 and 55 to 200 days, respectively. Such increase in the end of primary consolidation time can be attributed to the large and rapid decrease of the soil permeability as a result of staged preloading. Assuming constant values for the coefficient of secondary compression from the field investigation, it is expected that, 10 years after construction, the settlement will range from 0.7 to 2.5 in (1.8 to 6.4 cm). Such settlement is relatively small and therefore it can be stated that staged preloading is effective in reducing the long term settlement of peat

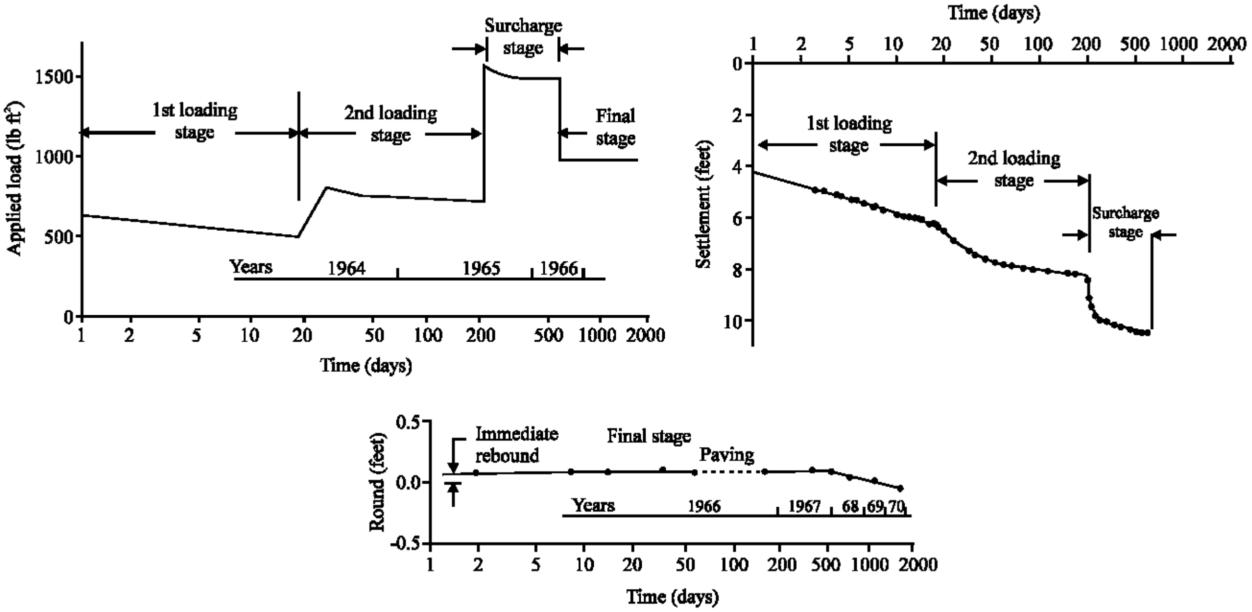

Fig. 14: Loading diagram, settlement and rebound curves at settlement plate P-1 (Samson and La Rochelle, 1972)

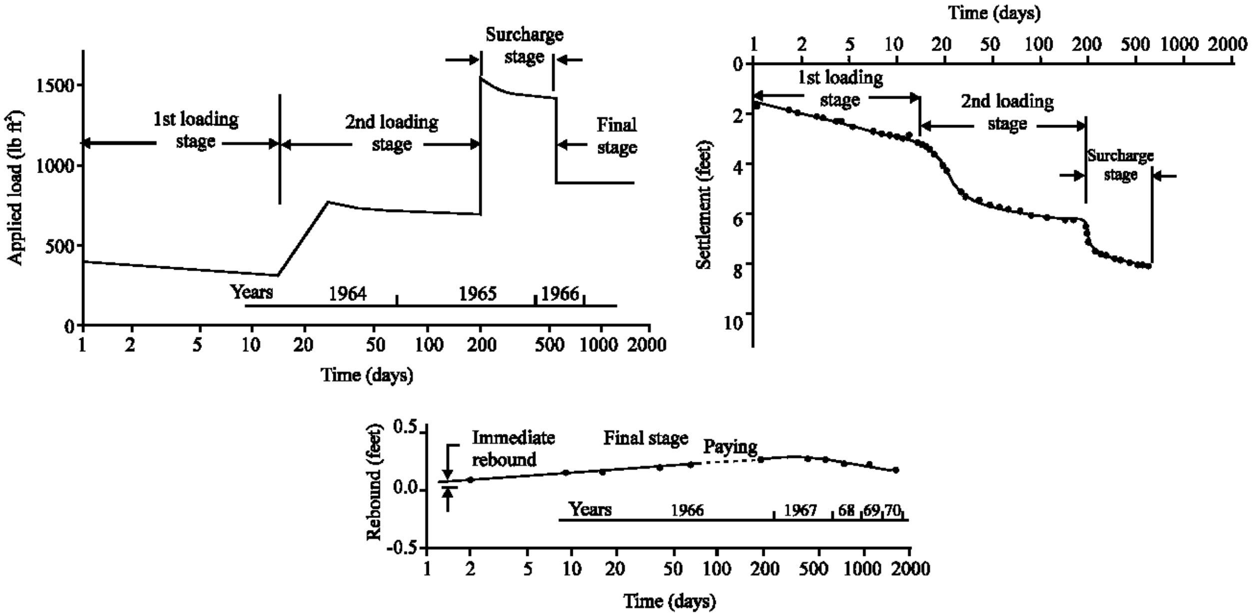

Fig. 15: Loading diagram, settlement and rebound curves at settlement plate P-3 (Samson and La Rochelle, 1972)

appreciably but it requires a significant amount of time before it can be ascertained that the long term settlement is reduced to within acceptable limits.

CONCLUSIONS

Based on the review of both experimental and field investigations on hydraulic conductivity and compressibility of peat, the following concluding remarks can be drawn:

- Peat is characterized by high to moderate initial hydraulic conductivity due to its porous nature. However, hydraulic conductivity of peat reduces drastically after compression due to its short duration of primary consolidation

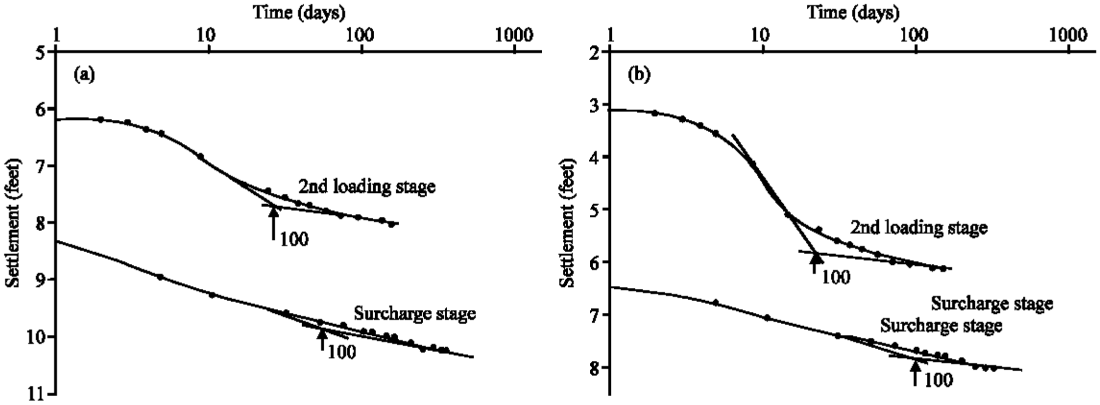

Fig. 16: Settlement versus log-time curves for two loading stages at settlement plates (a) P-1 and (b) P-3 (Samson and La Rochelle, 1972)

- The compression behavior of peat is quite distinct from that of inorganic soil. It is characterized by relatively short primary consolidation and is followed by large secondary compression which may not be constant with logarithm of time. The presence of tertiary compression in peat maybe considered as a laboratory effect since it is not evident in the results of field investigation on the soil
- High compressibility of peat is basically attributed to the presence of its multi-phase system, in which the soil consists of both macropores and micropores due to the coarse and spongy organic particles as evident in the photomicrographs of the soil
- Since, the properties of peat are very site specific due to the varying degree of peat decomposition, experimental and field investigations on hydraulic conductivity and compressibility of a typical peat are helpful to analyze and characterize the soil in response to preloading

ACKNOWLEDGMENTS

The authors wish to specially acknowledge Sadek Deboucha and Babak Kamali for giving constructive comments on the review article before it was sent for consideration to be published in the Journal of Applied Sciences.

REFERENCES

Adams, J.I., 1965. The engineering behavior of a Canadian Muskeg. Proceedings of the 6th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, 1965 Montreal, Canada, pp: 3-7.

Alwi, A., 2008. Ground improvement of Malaysian peat soils using stabilised peat-column techniques. Ph.D. Thesis, University of Malaya, Kuala Lumpur, Malaysia.

Bell, F.G., 2000. Engineering properties of soils and rocks. 4th Edn., Blackwell Science, Oxford, London, ISBN: 0-632-05205-8.

Berry, P.L. and B. Vickers, 1975. Consolidation of fibrous peat. J. Geotech. Eng. ASCE, 101: 741-753.

Colleselli, F., G. Cortellazzo and S. Cola, 2000. Laboratory Testing of Italian Peat Soils. In: Geotechnics of High Water Content Materials, ASTM STP 1374, Edil, T.B. and P.J. Fox (Eds.), American Society for Testing and Materials, West Conshohocken, PA.

Den Haan, E.J., 1994. Vertical compression of soils. Ph.D. Thesis, University of Technology, Delft, The Netherlands.

Dhowian, A.W. and T.B. Edil, 1980. Consolidation behavior of peats. Geotech. Test. J., 3: 105-114.

Edil, T.B., 2003. Recent advances in geotechnical characterization and construction over peats and organic soils. Proceedings of the 2nd International Conference in Soft Soil Engineering and Technology, Putrajaya, Malaysia.

Fox, P.J. and T.B. Edil, 1996. Effects of stress and temperature on secondary compression of peat. Can. Geotech. J., 33: 405-415.

Gofar, N. and Y. Sutejo, 2007. Long term compression behavior of fibrous peat. Malaysian J. Civil Eng., 19: 104-116.

Hanrahan, E.T., 1954. An investigation of some physical properties of peat. Geotechnique, 4: 108-123.

Hartlen, J. and W. Wolski, 1996. Embankments on Organic Soils. 1st Edn., Elsevier Science B.V., Amsterdam, ISBN: 0-444-88273-1.

Karlsson, R. and S. Hansbo, 1981. Soil Classification and Identification. 1st Edn., Swedish Council for Building Research, Stockholm, ISBN: 0-444-88549-8.

Keene, P. and C.D. Zawodniak, 1968. Embankment construction on peat utilizing hydraulic fill. Proceedings of the 3rd International Peat Conference, 1968 National Research Council of Canada, Ottawa, Canada, pp: 45-50.

Kogure, K., H. Yamaguchi and T. Shogaki, 1993. Physical and pore properties of fibrous peat deposit. Proceedings of the 11th Southeast Asian Geotechnical Conference, Singapore.

Kulathilaka, S.A.S., 1999. Improvement of engineering properties of peat by preconsolidation. Proceedings of the Asian Regional Conference of International Society of Soil Mechanics and Geotechnical Engineering, August, 1999, South Korea, pp: 97-100.

Landva A.O. and P.E. Pheeney, 1980. Peat fabric and structure. Geotechnique, 17: 416-435.

Lea, N.D. and C.O. Brawner, 1963. Highway design and construction over peat deposits in lower British Columbia. Highway Res. Record, 7: 1-32.

Lefebvre, G., P. Langlois, C. Lupien and J.G. Lavallee, 1984. Laboratory testing and *in situ* behaviour of peat as embankment foundation. Can. Geotech. J., 21: 322-337.

Lewis, W.A., 1956. The settlement of the approach embankments to a new road bridge at Lockford, West Suffolk. Geotechnique, 6: 106-114.

Mesri, G., T.D. Stark, M.A. Ajlouni and C.S. Chen, 1997. Secondary compression of peat with or without Surcharging. J. Geotech. Geoenviron. Eng., 123: 411-421.

Mitchell, J.K., 1993. Fundamentals of Soil Behavior. 2nd Edn., John Wiley and Sons, New York, ISBN: 0-471-85640-1.

Robinson, R.G., 2003. A study on the beginning of secondary compression of soils. J. Test. Eval., 31: 388-397.

Samson, L. and P. La Rochelle, 1972. Design and performance of an expressway constructed over peat by preloading. Can. Geotech. J., 9: 447-466.

Terzaghi, K., R.B. Peck and G. Mesri, 1996. Soil Mechanics in Engineering Practice. 3rd Edn., Wiley and Sons, New York, ISBN: 0-471-08658-4.

Warburton, J., J. Holden and A.J. Mills, 2004. Hydrological controls of surficial mass movements in peat. Earth-Sci. Rev., 67: 139-156.

Weber, W.G., 1969. Performance of embankments constructed over peat. J. Soil Mech. Found. Div., 95: 53-76.

Whitlow, R., 2001. Basic Soil Mechanics. 4th Edn., Pearson Education, London, ISBN: 0-582-38109-6.

Wong, L.S., 2005. Laboratory evaluation of horizontal coefficient of consolidation of fibrous peat soil. Master Project Report. Universiti Teknologi Malaysia, Skudai, Johor, Malaysia.