International Journal of the Physical Sciences Vol. 6(8), pp. 1974-1981, 18 April, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.396
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

A state of art review of peat: Geotechnical engineering perspective

Sina Kazemian[1]*, Bujang B.K. Huat[2], Arun Prasad[3] and Maassoumeh Barghchi[1]

[1]Department of Civil Engineering, Bojnourd Branch, Islamic Azad University, Bojnourd, Iran
[2]Department of Civil Engineering, University Putra Malaysia, Serdang, Selangor, Malaysia
[3]Department of Civil Engineering, Banaras Hindu University, Varanasi, India.

Accepted 24 March, 2011

Peat is a type of soft soil composed of high contents of fibrous organic matters and is produced by the partial decomposition and disintegration of mosses, sedges, trees, and other plants that grow in marshes and other wet place in the condition of lack of oxygen. These soils are geotechnically problematic as they show high compressibility and low shear strength. In this paper, the origin of peat and its different engineering properties (moisture content, bulk density, specific gravity, void ratio, permeability, compressibility, shear strength) are discussed in the perspective of a geotechnical engineer. The engineering behavior of peat can be improved by chemical stabilization using sodium silicate grout system, cement stabilization, cement stabilized columns, and fiber reinforcement to name a few.

Key words*:* Peat, compressibility, shear strength, chemical stabilization, fiber reinforcement.

INTRODUCTION

The review of peat, in context with general properties, has been presented in part-I of the paper. In this part, the review of peat in the perspective of geotechnical engineering has been presented.

Peat is a mixture of fragmented organic materials formed in wetlands under appropriate climatic and topographic conditions and it is derived from vegetation that has been chemically changed and fossilized (Edil and Dhowian, 1980). In natural state, peat consists of water and decomposed plant fragment with virtually no measurable strength (Munro, 2005). Peat is often referred as problematic soil due to its low shear strength, high compressibility and high water content.

Peat also contains high organic content, often more than 75%. The organic contents present in peat are the remains of partially decomposed and disintegrated plant. These take place in conditions where the rate of accumulation is more than the rate of decay. Peats are accumulated if the rate of decay is slower than the rate of addition (Bell, 2000). It accumulates whenever the conditions are suitable, that is, in areas where there is an excess of rainfall and the ground is fully undrained, irrespective of latitude or attitude.

Furthermore, the content of peat may differ from location to location due to factors such as origin of fiber, temperature and degree of humification. Decomposition or humification involves the loss of organic matter either in gas or in solution, the disappearance of physical structure and the change in chemical state. Breakdown of the plant remains is brought about by soil microflora, bacteria and fungi which are responsible for aerobic decay. Therefore, the end products of humification are carbon dioxide and water, the process being essentially one of biochemical oxidation. Immersion in water reduces the oxygen supply enormously which, in turn, reduces aerobic microbial activity and encourages anaerobic decay which is much less rapid. Consequently, it has been said that peat shows unique geotechnical properties in comparison with those of inorganic soils such as clay and sandy soils which are made up of only soil particles (Hashim and Islam, 2008). The content of peat differs from location to location due to the factors such as the origin of fibre, temperature, climate, and humidity (Huat, 2004). Decomposition (humification) is the loss of organic matter that causes the disappearance of the peat structure and changing the primary chemical composition

---

*Corresponding author. E-mail: sina.kazemian@gmail.com.

of peat. Table 1 shows the variation in physical and chemical properties of peat.

The organic contents are essentially remains of plants whose rate of accumulation is faster than the rate of decay. Generally, the deposit is found in thick layers on limited areas. Basically, peat is predominantly made up entirely of plant remains such as leaves and stem. It is produced by the partial decomposition and disintegration of mosses, sedges, trees, and other plants that grow in marshes and other wet place in the condition of lack of oxygen. Therefore, the color of peat usually is dark brown or black and with a distinctive odor (Craig, 1992). Since the main component is organic matter, peat is very spongy, highly compressible and combustible in characteristic (Roy, 2004). This characteristic also made the peat pose its own distinctive geotechnical properties compared with other inorganic soils like the clay and sandy soils which are made up by the soil particle only (Deboucha et al., 2008).

Sometimes the plant fibers are visible but in the advantages stages of decomposition, they may not be evident. Peat will turn into lignite coal over geologic periods of time under proper conditions. Also, the fresher the peat, the more fibrous material it contains, and as far as engineering is concerned, the more fibrous the peat, the higher is the shear strength, voids ratio and water content. In fact, the properties of peat are greatly dependent on the formation of its deposits. This means that peat at different location will have different properties. Commonly, the classification of peat is developed based on fiber content, organic content, and ash content. Decomposition is the breakdown process of the plant remains by the soil micro flora, bacteria and fungi in the aerobic decay. In this procedure, as mentioned earlier, there is a disappearance of the peat structure and changes in the primary chemical composition of peat. At the end, carbon dioxide and water are the products of the decomposition process. The degree of decomposition varies throughout peat since some plants or some parts of the plants are more resistant than others. Also, the degree of decomposition of peat depends on a combination of conditions, such as the chemistry of the water supply, the temperature of the region, aeration and the biochemical stability of the peat-forming plant (Lishtvan et al., 1985).

Compressibility of peat

The compressibility of soil generally consists of three stages namely initial compression, primary consolidation, and secondary compression. Initial compression occurs instantaneously after the load is applied; whereas primary and secondary compressions depend upon the length of time the load is applied. The initial compression occurs mainly due to the compression of gas within the pore spaces and also due to the elastic compression of soil grains. Primary consolidation observed during the increase in effective vertical stress caused the dissipation of excess pore water pressure. After the completion of dissipation of excess pore water pressure, the secondary compression would take place at constant effective vertical stress.

The compression behavior of peat varies from the compression behavior of other types of soils in two ways. First, the compression of peat is much larger than that of other soils. Secondly, the creep portion of settlement plays a more significant role in determining the total settlement of peat than of other soil types. The primary consolidation of fibrous peat takes place very rapidly. A large secondary compression, even tertiary compression is also observed to take place (Kazemian and Huat, 2009a).

The dominant factors controlling the compressibility characteristics of peat include the fiber content, natural water content, void ratio, initial permeability, nature and arrangement of soil particles, and inter-particle chemical bonding in some of the soils (Mesri and Ajlouni, 2007). Determination of compressibility of fibrous peat is usually based on the standard consolidation test.

The *in situ* void ratio of fibrous peats is very high because of the fact that very compressible and bendable hollow cellular fibers form an open entangled network of particles and the high initial water content. During both primary and secondary compression, water is expelled simultaneously from within and among the peat particles (Mesri and Ajlouni, 2007). Therefore, the e-log p′ curves show a steep slope indicating a high value of compression index (C_c). The compression index of peat soil ranges from 2 to 15. Furthermore, there is a possibility that secondary compression starts before the dissipation of excess pore water pressure is completed (Leonards and Girault, 1961).

As mentioned earlier, the unit weight of peat is close to that of water, thus the *in situ* effective stress (σ'_c) is very small and sometimes cannot be detected from the results of consolidation test (Mesri et al., 1997). It is also very difficult to obtain the beginning of secondary compression (t_p) from the consolidation curve because the preliminary consolidation occurs rapidly (Yulindasari, 2006).

Compression of fibrous peat continues at a gradually decreasing rate under constant effective stress, called secondary compression. The secondary compression of peat is due to the further decomposition of fibers which is assumed to occur at a slower rate after the primary consolidation is over (Mesri et al., 1997). The slope at final part of the graph of void ratio versus logarithmic of time curve (C_α) is definite as the rate of secondary compression. This estimate is based on the assumptions that C_α is independent of time, thickness of compressible layer, and applied pressure. Ratio of C_α/C_c has been used widely to study the behavior of peat (Dhowian and Edil, 1980) and a range between 0.05 and 0.07 for C_α/C_c is reported by Mesri et al. (1994).

Although the rate of primary consolidation of fibrous peat

Table 1. Physical and chemical properties of peat.

Peat type	Natural water content (w, %)	Bulk density (Mg/m^3)	Specific gravity (G_s)	Acidity (pH)	Ash content (%)	Reference
Fibrous-woody	484-909	-	-	-	17	Colley (1950)
Fibrous	850	0.95-1.03	1.1-1.8	-	-	Hanrahan (1954), Asadi et al., 2009, 2010
Peat	520	-	-	-	-	Lewis (1956)
Amorphous and fibrous	500-1500	0.88-1.22	1.5-1.6	-	-	Lea and Browner (1963)
	200-600	-	1.62	4.8-6.3	12.2-22.5	Adams (1965)
	355-425	-	1.73	6.7	15.9	
Amorphous to fibrous	850	-	1.5	-	14	Keene and Zawodniak (1968)
Fibrous	605-1290	0.87-1.04	1.41-1.7	-	4.6-15.8	Samson and LaRochell (1972), Moayedi et al.(2011a, b)
Coarse fibrous	613-886	1.04	1.5	4.1	9.4	Berry and Vickers (1975)
Fibrous sedge	350	-	-	4.3	4.8	Levesque et al. (1980)
Fibrous sphagnum	778	-	-	3.3	1	
Coarse fibrous	202-1159	1.05	1.5	4.17	14.3	Berry (1983)
Fine fibrous	660	1.05	1.58	6.9	23.9	NG and Eischen (1983)
Fine fibrous	418	1.05	1.73	6.9	9.4	
Amorphous granular	336	1.05	1.72	7.3	19.5	
Peat portage	600	0.96	1.72	7.3	19.5	Edil and Mochtar (1984)
Peat waupaca	460	0.96	1.68	6.2	15	
Fibrous peat (Middleton)	510	0.91	1.41	7	12	
Fibrous peat (Noblesville)	173-757	0.84	1.56	6.4	6.9-8.4	
Fibrous	660-1590	-	1.53-1.68	-	0.1-32.0	Lefebvre et al. (1984)
Fibrous peat	660-890	0.94-1.15	-	-	-	Olson and Mesri (1970)
Amorphous peat	200-875	1.04-1.23	-	-	-	
Peat	125-375	0	1.55-1.63	5-7	22-45	Yamaguchi et al. (1985)
Peat	419	1	1.61	-	22-45	Jones et al. (1986)
Peat	490-1250	-	1.45	-	20-33	Yamaguchi et al. (1987)
Peat	630-1200	-	1.58-1.71	-	22-35	Nakayama et al. (1990)
Peat	400-1100	0.99-1.1	1.47	4.2	5-15	Yamaguchi 1990
Fibrous	700-800	~1.00	-	-	-	Hansbo (1991)
Peat (Netherlands)	669	0.97	1.52	-	20.8	Termatt and Topolnicki (1994)
Fibrous (Middleton)	510-850	0.99-1.1	1.47-1.64	4.2	5-7	Ajlouni (2000)
Fibrous (James Bay)	1000-1340	0.85-1.02	1.37-1.55	5.3	4.1	

is very high, it decreases with the application of consolidation pressure. According to Lea and Brawner (1963), there will be a significant decrease in the rate of coefficient of consolidation (C_v) during application of pressure from 10 to 100 kPa. The significant reduction factor of 5–100 is attributed to the reduction of permeability due to the appreciation of pressure.

Shear strength of peat

Shear strength is considered as one of the most important parameters in engineering design and decision when dealing with soil especially during pre and post-construction since it is used to evaluate the foundation and slope stability of soil. When the ultimate shear strength is exceeded, the soil will fail or deform. The failure criteria is developed using the stress-strain relationship and the concept of elasticity theory is applied too. The magnitude of the strain in soil depends on the parameters such as the magnitude of applied load, the composition of the soil, past stress history, void ratio, and also on the manner in which the stress is applied (Anggraini, 2006).

Peat usually has very low shear strength and the determination of shear strength is somehow a difficult job in geotechnical engineering because the difficulties will depend on factors such as the origin of the soil, its water content, organic matters and also on the degree of humification. During the sampling stage, the sample disturbance will also affect the evaluation of shear strength of peat.

Peat is a type of soil that has very low shear strength but the increase in strength upon consolidation could be significant. The shear strength of peat is dependent on some factors such as moisture content, degree of decomposition and mineral content. According to Munro (2005), higher the moisture content and decomposition, the lower is the shear strength; in addition, the higher mineral content causes higher shear strength. In general, shallow peat, due to its more fibrous nature, is likely to have greater strength than more humified peat at depth (Culloch, 2006).

Mostly, peat is considered a frictional or non-cohesive material due to the fiber content and the spatial orientation of the fibers. The high friction angle of peat will not actually reflect high shear strength due to the fact that the fibers are not always solid and may be filled with water and gas. The presence of fibers will modify the strength behavior of peat since the fibers can be considered as reinforcement and the fibers can provide effective stress where there is none and it induces anisotropy.

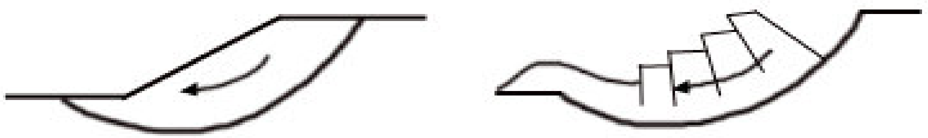
The shear strength of peat generally can be found out in many ways. *In-situ* methods such as field vane shear test and cone penetration test are very useful and these tests can be used to avoid many of the problems associated with the soil sampling. However, these methods have some inherent limitation since the shear strength can only be determined indirectly through correlations with laboratory results and also from the back calculation from the results of actual failures. Further, the variable nature of peat and the difficulties in obtaining good representative samples from the field, laboratory testing can only give indicative results (Culloch, 2006).

The most common laboratory test is direct shear test in determining the drained shear strength of fibrous peat, while triaxial test is frequently used for evaluation of shear strength of peat in the laboratory under consolidated-undrained (CU) conditions. This is due to the fact that the results of triaxial test on fibrous peats are difficult to interpret because fiber often act as horizontal reinforcement, so failure is seldom obtained in a drained test. The reason being the triaxial test for peat with low permeability, if performed under a drained condition, may take several days to complete.

Edil and Dhowian (1981) and Landva and LaRochelle (1983) showed that the effective internal friction φ' of peat is generally higher than inorganic soil (e.g. undrained friction angle of amorphous peat and fibrous peat is in the range of 27 – 32° under a normal pressure of 3–50 kPa; on the other hand, for amorphous granular peat effective internal friction is 50° and for fibrous peat is in the range of 53- 57°). Whereas, the undrained friction angle of peat, in West Malaysia, is in the range of 3- 25° (Huat, 2004).

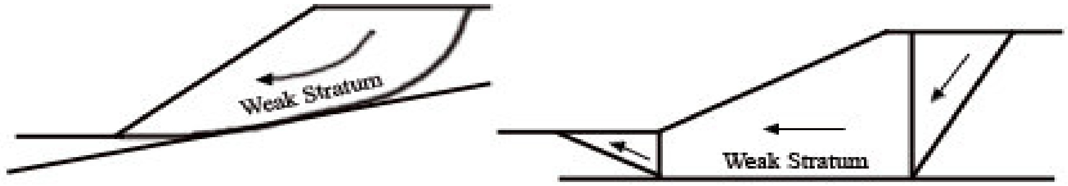
The determination of undrained shear strength is also important because of the presence of peat is always below the groundwater level. This is usually done *in situ* because sampling of fibrous peat for laboratory evaluation of undrained shear strength is almost impossible. Some approaches that were used for *in situ* testing for peat are: cone penetration test, dilatometer test, vane shear test, pressure-meter test, plate load test, and screw plate load test (Edil, 2001). Vane shear test is the most commonly used among others; however, the interpretation of the test results must be handled with caution. The range of 3-15 kPa is obtained for the undrained shear strength of peat, which is much lower than that of the mineral soils. A correction factor of 0.5 is suggested by Noto (1991) and Hartlen and Wolsky (1996) for the test results on organic soil for which the liquid limit is more than 200%.

The evaluation of shear strength of peat under undrained condition is greatly affected by the disturbance of the soil sample. Shogaki and Kaneko, (1994) stated that to obtain and minimize the effect of sample disturbance, there is no need of sampling required if the undrained shear strength is obtained by field tests. The undrained shear strength of the soil can also be measured by performing laboratory tests on specimen trimmed from blocks or undisturbed samples of large size (Kazemian et al. 2009a, b, c; 2010b). In this condition, there could be nearly zero effective confining pressure or



Circular Failure Surface

After Failure



Non-Circular Failure Surface

Sliding Block Failure

Figure 1. Bearing capacity failure.

even tension at failure in fibrous peat (Edil, 1997).

In fibrous peat, the force is taken by the fibres as it acts as reinforcement if the direction of the load is in the same direction as the fibres. As a result of the sedimentation process and compaction, the main direction is usually horizontal however it is possible that a section of peat has a vertical orientation. The effect of organic matter and stiffness of soils depends largely on whether the organic matter is decomposed or consists of fibres which can act as reinforcement (Arman, 1969; Landva and LaRochelle, 1983). In general, fibrous peat has higher shear strength than other group of peat such as hemic and sapric peats. The shear strength behaviour of peat is observed to be highly anisotropic (Hanzawa et al., 1994). The shear strength of a soil is not only a function of the material itself, but also of the stress applied, and the manner in which it is applied.

Problems with peat from geotechnical engineering view point

Peat is considered as problematic soils in the view of design parameter by the geotechnical engineers becauseits engineering characteristic are inferior to those of the other soft soils which make it unsuitable for construction in its natural stage. Peats are found to contain high organic matter and are generally associated with poor strength characteristics, large deformation, high compressibility, and high magnitude and rates of creep (Haan and Kruse, 2006).

Peat is subjected to problems of instability such as local sinking and development of slip failure. It is also subjected to very large primary and long term settlement under an even moderate increase in load. There is also some difficulty in accessing the sites, a large variation in material properties coupled with difficulty in sampling. There is also some possibility of chemical and biological changes in these materials with time. As an example, the organic constituents upon further humification may change the mechanical properties of peat such as shear strength, compressibility, and hydraulic conductivity (Huat, 2004).

Therefore, pile foundation is often recommended for the buildings on peat. However, the ground may still settle around the building. Also, sometimes the construction line such as road embankment is not only just subjected to only localized sink and development of the slip failure, but also large magnitude of primary and long term settlement.

Andriesse (1988) and Islam and Hashim (2008a and b) stated that the bearing capacity of peat is very low and it fails in different ways as shown in Figure 1. The bearing capacity was affected by the high water table and the presence of woody debris in the soil. A lowering of the ground water level may result in shrinkage and oxidation of peat; thus leading to its humification with an increase in compressibility and permeability.

Even if the failure can be avoided, it is also inevitable that soft water logged soil and peat takes a long time to settle when loaded due to embankment or soil fill. Under these conditions, the embankment will settle continually into the ground below, even if the soils do not fail by displacement. This is illustrated in Figure 2. If an additional fill is made up, the depression into the embankment will ensure more settlement and make the condition even worse (Huat, 2004). Hence, it can be concluded that peat is very unsuitable for construction since it is unable to provide support to the foundations.

Ground improvement

All ground improvement methods mainly improve those

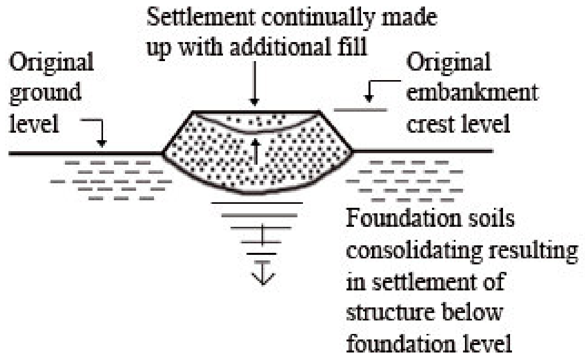


Figure 2. Settlement problem in peat (Huat, 2004).

soil characteristics that match the desired results of the success of the project. The characteristics targeted are density and shear strength to improve the problems of stability of soil, the reduction in compressibility, reducing the permeability to control ground water flow or to increase the rate of consolidation to reduce consolidation time.

Peat or organic soils are often excavated and refilled with a good construction material which is an economical solution if the thickness of these layers is marginal. Long term settlements of these deposits can be minimized by preloading method but this option is time consuming. Geosynthetics can also be used to increase the stability of structures constructed over these deposits, however, this method does not address the problems associated with the construction due to high water content and long term settlement potential of these deposits. If the thickness of such soft layers is high, alternate solutionsare constantly looked for. Several different methods to stabilize the organic soils/peats are currently used in practice and they are discussed below.

Soil improvement for construction on peat

Soil improvement plays a vital role in geotechnical engineering because it is the only way to stabilize and enhance the properties of soils. Most of the time, the improvement is focused on modifying and stabilizing the soil. This is because stabilization of soil is one of the most important criteria that should be considered for construction on soft soil. Stability of ground will affect the stability of the structure above it. If structures are placed without any proper ground improvement to provide adequate stability to the ground, failure of structures may happen and this will cause death, loss of money and energy. Hence, a proper ground improvement work is essential before starting construction works over peat.

Since peat is extremely soft soil and is unable to reach the required specification at construction sites due to its properties of low shear strength or low bearing capacity and highly compressibility, therefore, the characteristics targeted are density and shear strength to improve the problems of stability of soil, the reduction in compressibility, reducing the permeability to control ground water flow or to increase the rate of consolidation to reduce consolidation time. The site investigation is always carried out before deciding the type of ground improvement method to be used.

There are various methods for ground improvement such as soil replacement, reinforcement to enhance soil strength and stiffness (preloading and stage construction), ground improvement, stone columns, piles, thermal pre-compression and preload piers; or by reducing driving forces by light-weight fill; and chemical admixture such as cement and lime (Edil, 2003; Kazemian and Huat, 2009b). The chemical admixtures can be applied either as deep *in situ* mixing method (lime-cement columns), or as surface stabilizer (Kazemian et al., 2010a, b). Compared to other methods, the chemical admixtures are more economical and time saving option (Kazemian et al., 2011a,b,c). Ahnberg et al. (1995), Ding (2000), Hebib and Farell (2003), Hashim and Islam (2008), Kazemian and Huat (2009a), and Kazemian et al. (2009a,b,c,) and Huat et al. (2011) performed studies to obtain the various engineering properties of peat. It was observed that the strength of peat increased after stabilization by soil-cement column technique. In this study, cement was used as binder and bentonite and well graded sand were used as filler.

Conclusions

Peat contains organic materials and is formed in wetlands when the climatic and topographic conditions are appropriate. It is derived from vegetation that has been chemically changed and fossilized. The content of peat normally differs from location to location due to the variables such as origin fiber, degree of humification, and temperature. The process of decomposition or humification of peat is the loss of organic materials either in gas or in solution, the disappearance of physical structure or the texture and also some changes in the chemical state. It has been reported that peat shows some unique geotechnical properties in comparison with those of inorganic soils such as clay and sandy soils which consist only of inorganic soil particles. The compression behavior of peat varies from the compression behavior of other types of soils in two ways. First, the compression of peat is much larger than of other soils. Secondly, the creep portion of settlement plays a more significant role in determining the total settlement of peat than of other soil types. The dominant factors controlling the compressibility characteristics of peat include the fiber content, natural water content, void ratio, initial permeability, nature and arrangement of soil particles, and inter-particle chemical bonding in some of the soils. Peat usually has very low shear strength and the determination of shear strength is somehow a difficult job in geotechnical engineering because the difficulties consist of organic content and degree of humification, origin of soil, and water content. The evaluation of shear strength of peat under undrained condition is greatly affected by disturbance to the samples. It has been stated that to obtain and minimize the effect of sample disturbance, where there is no need of sampling required, the shear strength under undrained condition may be obtained by field tests. Peat is subjected to problems of instability such as local sinking and the development of slip failure, and massive primary and long term settlement when load increases even by a moderate amount. Also, there is the discomfort and difficulty to access the sites, coupled with a large variation in the material properties and including sampling difficulty. There are various methods for ground improvement such as soil replacement, reinforcement to enhance soil strength and stiffness (preloading and stage construction), ground improvement, stone columns, piles, thermal pre-compression and preload piers; or by reducing driving forces by light-weight fill; and chemical admixture such as cement and lime. The chemical admixtures can be applied either at a deeper locations as deep in-situ mixing method (lime-cement columns), or as on the surface as stabilizer. Compared to other methods, the chemical admixtures are more economical and time saving option. Studies have been carried out to determine the various engineering properties of peat and it has been observed that the strength increases after stabilization using the soil-cement column technique. Cement can be used as binder and bentonite and well graded sand can be used as fillers.

ACKNOWLEDGMENT

The authors wish to express their gratitude to the Ministry of Science, Technology and Innovation, Malaysia (Project No. 03-01-04-SF0889) for the financial support to the research group.

REFERENCES

Adams JI (1965). The engineering behavior of a Canadian Muskeg. Proc. Of the 6th Int. Conf. Soil Mech. Found. Eng. Montrael, Canada, 1: 3-7.

Ahnberg H, Johansson SE, Retelius A, Ljungkrantz C, Holmqvist L, Holm G (1995). Cement och kalkk for djupstabilisering av jord. En Kemisk-Fysikalisk Studie Av Stabiliseringseffekter. Swedish Geotechnical Institute. Report No. 48 (in Swedish with English summary).

Aljouni MA (2000). Geotechnical properties of peat and related engineering problems. PhD Dissertation, University of Illinois at Urbana-Champaign.

Andriesse JP (1988). Nature and Management of Tropical Peat Soils. 1st ed. Rome: FAO.

Anggraini V (2006). Shear strength improvement of peat soil due to consolidation. Master Dissertation, Universiti Teknologi Malaysia.

Arman A (1969). A definition of organic soils (an engineering identification). Engineering Research Bulletin No. 101, Louisina State University, Division of Engineering Research, for Louisiana Department of Highways.

Asadi A, Huat B, Hanafi M, Mohamed TA, Shariatmadari N (2010). Physicochemical sensitivities of tropical peat to electrokinetic environment, Geosci. J., 14 (1): 67-75.

Asadi A, Huat B, Hanafi M, Mohamed T, Shariatmadari N (2009). Role of organic matter on electroosmotic properties and ionic modification of organic soils, Geosci. J., 13(2): 175-181.

Bell FG (2000). Engineering Properties of Soils and Rocks. Malden, MA, Blackwell Sci., pp. 202-221.

Berry PL, Vickers B (1975). Consolidation of fibrous peat. J. Geotech. Eng., ASCE, 101: 741-753.

Berry PL (1983). Application of consolidation theory for peat to the design of a reclamation scheme by preloading. Q. J. Eng. Geol., London, 16(9): 103-112.

Colley BE (1950). Construction of highways over peat and muck areas. Am. Highway, 29(1): 3-7.

Craig RF (1992). Soil Mechanics. 5th Edition. London: Chapman & Hall.

Culloch FM (2006). Guidelines for the Risk Management of Peat Slips on the Construction of Low Volume/ Low Cost Road Over Peat. Scotland: For. Civ. Eng. For. Comm., pp. 1-46.

Deboucha S, Hashim R, Alwi A (2008). Engineering properties of stabilized tropical peat soils. Electron. J. Geotechn. Eng., 13E.

den Haan EJ, Kruse GAM (2006). Characterisation and engineering properties of Dutch peats. Characterisation and Engineering Properties of Natural Soils. Proceedings of 2nd Int. Workshop, Singapore, Taylor & Francis, London, 2007, 3: 2101–2133.

Dhowian AW, Edil TB (1980). Consolidation behavior of peats. Geotech. Testing J., 3(3): 105-114.

Ding M (2000). Improvement of engineering properties of tropical soils using admixtures. PhD Dissertation, University of Hawaii, Manoa, US.

Edil TB (2001). Site characterization in peat and organic soils. Proc. Int. Conf. *In-situ* Meas. Soil Properties and Case Histories, Bali, Indonesia, pp. 49-59.

Edil TB, Dhowian AW (1981). At-rest lateral pressure of peat soils. Proc. Conf. Sediment. Consolidation Model, ASCE, San Fransisco, pp. 411-424.

Edil TB, Mochtar NE (1984). Prediction of peat settlement. Proc. Sediment. Consolidation Models Symp. Prediction Validation, ASCE, San Fransisco, California, pp. 411-424.

Edil TB (2003). Recent advances in geotechnical characterization and construction over peats and organic soils. Proceedings of the 2nd International Conferences in Soft Soil Engineering and Technology, Putrajaya (Malaysia), pp. 3-26.

Hanrahan ET (1954). An investigation of some physical properties of peat. Géotechnique, London, England, 4(2): 108-123.

Hansbo S (1991). Full-scale investigations of the effect of vertical drains on the consolidation of a peat deposit overlying Clay. De Mello Volume, Published by Editoria Edgard Bldcher LTDA, Caixa, Sao Paolo, Brasil, pp. 1-15.

Hanzawa H, Kishida T, Fukusawa, T, Asada H (1994). A case study of the application of direct shear and cone penetration tests to soil investigation, design and quality control for peaty soils. Soils and Foundations, Jap. Soc. Soil Mechan. Found. Eng., 4: 13-22.

Hartlen J, Wolsky W (1996). Embankments on Organic Soils. Netherlands: Elsevier Sci., 80: 4-20.

Hashim R, Islam MS (2008). Properties of stabilized peat by soil-cement column method. EJGE. Electronic J. Geotechn. Eng., p.1-9.

Huat BBK, Kazemian S, Prasad A, Barghchi M (2011). "A Study of the Engineering Behavior of Peat Stabilized by DMM: Lab Model and FE Analysis," Sci. Res. Essays J., 6(1): 196-204.

Hebib S, Farell ER (2003). Some experiences on the stabilisations of Irish peats. Can.Geotech. J., 40: 107-120.

Huat BBK (2004). Organic and Peat Soils Engineering. University Putra Malaysia Press, Serdang, Malaysia, pp. 20-80.

Islam MS, Hashim R (2008a). Use of Machintosh probe test for field investigation in peat soil. Proceeding of the International Conference, May 26-27, Best Western Premeier Seri Pacific Kuala Lumpur, Malaysia, pp. 27.

Islam S, Hashim R (2008b). Engineering properties of peat soils in peninsular Malaysia. J. Appl. Sci., 8 (22).

Jones DB, Beasley DH, Pollock DJ (1986). Ground treatment by surcharging on deposits of soft clays and peat. Proceedings of the Conf. on Building on Marginal and derelict land, L. C. E., Glasgow, 679-695.

Kazemian S, Huat BBK (2009a). Assement and comparison of grouting and injection method in geotechnical engineering. Euro. J. Sci. Res., 234-247.

Kazemian S, Huat BBK (2009b). Compressibility characteristics of fibrous tropical peat reinforced with cement column, Electronic J. Geotechn. Eng., 14C.

Kazemian S, Asadi A, Huat BBK (2009c). Laboratory study on geotechnical properties of tropical peat soils. Int. J. Geotechn. Environ., 1: 69-79**.**

Kazemian S, Prasad A, Huat BBK, Ali TAM, Aznieta FN (2010a). Effect of cement, sodium silicate, kaolinite and water on the viscosity of the grout, Sci. Res. Essays J., 5(22): 3434-3442.

Kazemian S, Huat BBK, Prasad A, Barghchi M (2010b). A review of stabilization of soft soils by injection of chemical grouting. Australian J. Basic Appl. Sci., 4(12): 5862-5868.

Kazemian S, Prasad A, Huat BBK, Bolouri BJ, Farah NAA, Thamer AM (2011a). “Effect of Aggressive pH Media on Peat Treated by Cement and Sodium Silicate Grout.," J. Central South University of Technol., (In press).

Kazemian S, Huat BBK, Prasad A (2011b). "Study of Peat Media on Stabilization of Peat by Traditional Binders," Int. J. Phys. Sci., 6(3): 476-481.

Kazemian S, Huat BBK, Barghchi M (2011c). "Effect of calcium chloride and kaolinite on shear strength and shrinkage of cement grout," Int. J. Phys. Sci., 6(4): 707-713.

Keene P, Zawodniak CD (1968). Embankment construction on peat utilizing hydraulic fill. Proceedings of the 3rd Int Peat Conference, National Research Council of Canada, Ottawa, pp. 45-50.

Landva AO, LaRochelle P (1983). Compressibility and shear characteristics of radforth peats. Testing Peat Organic Soils, ASTV STP, 820: 157-191.

Lea N, Brawner CO (1963). Highway design and construction over peat deposits in the lower British Colombia. Highw. Res. Rec., 7: 1–32.

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

Leonards GA, Girault P (1961). A study of the one-dimensional consolidation test. Proceeding 9th ICSMFE, Paris, 1: 116-130.

Levesqe M, Jacquin F, Polo A (1980). Comparative biodegradability of shagnum and sedge peat from France. Proc., 6th Int. Peat Congress, Duluth, Minnesota, pp. 584-590.

Lishtvan II, Bazin ET, Kosov BI (1985). Physical properties of peat and peat deposits (in Russia). Nauka I Technika Press, Miñsk. 134-145.

Mesri G, Ajlouni M (2007). Engineering properties of fibrous peats. J. Geotech. Geoenv. Eng., 133(7): 851-866.

Mesri G, Stark TD, Chen CS (1994). C_c/C_α concept applied to compression of peat. discussion. J. Geotech. Geoenv. Eng., 120: 764-766.

Mesri G, Stark TD, Ajlouni MA, Chen CS (1997). Secondary Compression of Peat With or Without Surcharging. J. Geotech. Geoeviron. Eng., 123(5): 411-421.

Moayedi H, Asadi A, Huat BBK, Moayedi F (2011a). Zeta Potential of Tropical Soil in Presence of Polyvinyl Alcohol, Int. J. ElectrochemSci., 6 (5): 1294-1306.

Moayedi H, Asadi A, Huat BBK, Moayedi F (2011b). Optimizing Stabilizers Enhanced Electrokinetic Environment to Improve Physicochemical Properties of Highly Organic Soil, Int. J. Electrochem. Sci., 6 (5): 1277-1293.

Munro N (2005). Dealing With Bearing Capacity Problems on Low Volume Roads Constructed on Peat. ROADEX II Northern Periphery.

Nakayama M, Yamaguchi H, Kougra K (1990). Change in pore size distribution of fibrous peat under various one-dimensional consolidation conditions. Mem. Defense Acad., 30(1): 1-27.

NG SY, Eischens GR (1983). Repeated short-term consolidation of peats. Testing of Peat and Organic Soi*ls,* ASTM STP 820: 192-206.

Noto S (1991). Peat Engineering Handbook. Civil Engineering Research Institute, Hokkaido Development Agency, Prime Minister’s Office, Japan. 1-35.

Olson RE, Mesri G (1970). Mechanisms controlling compressibility of clays. J. Soil Mech. Found. Div., 96(SM6): 1863-1878.

Samson L, LaRochelle P (1972). Design and performance of an expressway constructed over peat by preloading. Can. Geotech. J., 9(4): 447-466.

Shogaki T, Kaneko M (1994). Effects of sample disturbance on strength and consolidation parameters of soft clay. Soils Found., 34(3): 1-10.

Termatt R, Topolnicki M (1994). Biaxial tests with natural and artificial peat. Proceedings of the International Workshop on Advances in Understanding and Modeling the Mechanical Behavior of Peat, Delft, Netherlands, pp. 241-251.

Yamaguchi H (1990). Physicochemical and mechanical properties of peats and peaty ground. Proc. 6th Int. Congress Int. Assoc. Eng. Geol., Balkema, Rotterdam, pp. 521-526.

Yamaguchi H, Ohira Y, Kogure K, Mori S (1985). Deformation and strength properties of peat. Proc. 11th Int. Conf. Soil Mech. Found Eng., San Francisco, 2: 2461-2464.

Yamaguchi H, Yamauchi K, Kawano K (1987). Simple shear properties of peat. Proc. 6th Int. Symp. Geotech. Eng. Soft Soils, Ciudad, Mexico, pp. 163-170.

Yulindasari (2006). Compressibility characteristics of fibrous peat soil. Master Dissertation, Universiti Teknologi Malaysia, Malaysia. pp. 1-239.