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ASSESSMENT AND VERIFICATION OF GEOTECHNICAL PARAMETERS OF RECONSTITUTED ORGANIC SOIL AT SOUTH WESTERN REGION IN BANGLADESH

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ABSTRACT

This study reveals the assessment and verification of geotechnical parameters of reconstituted soils (RCS) at varying organic content (OC) of the selected site in Khulna region of Bangladesh. To these endeavors, eight different samples of RCS for the OC of about 5, 6, 13, 19, 25, 30, 35 and 42 % were prepared in the laboratory by adjusting the different proportions of inorganic and organic soil, collected from two selected locations of Khulna region, with a water content equal to 1.25 times of liquid limit. The usual procedure of preparation of soil slurry, deposition in a mold and application of surcharge were used to reconstitute the soil. The mold diameter was 152 mm, height 222 mm and applied ultimate surcharge was 100 kN/m^2. In the laboratory, the ASTM (2004) methods were followed for the determination of geotechnical properties in terms of physical, compaction, compressibility and strength of RCS at varying OC. Based on the evaluated results, it can be depicted that the geotechnical properties have been influenced significantly with the increase of OC in RCS. Moreover, the statistical analysis of data for OC with the geotechnical properties gave good empirical correlations. Then, the developed correlations were compared with the findings of other researchers and results from undisturbed soils, collected from four selected locations of Khulna region, to depict the validity in this study. Here it is interesting to note that these correlations can be expressed in terms of equations that may be proposed to estimate the various properties of organic soil of Khulna region using its organic content.

Keywords: *Geotechnical behavior, Organic content, Overburden pressure, Reconstituted soil, Soil slurry.*

1. INTRODUCTION

The soils will be called 'organic soil' once their organic content exceeds 20% of their dry mass. Organic soil is comprised of peat or fine, coarse, or very coarse soil with an organic content (Edil, 2003; Wong *et al.,* 2008). Organic soils can be distinguished from inorganic soil by their grey, dark grey or black colour and their distinctive odor which can be enhanced by gentle heating. This soil commonly occurs by the coastline, lakes, bays, estuaries, harbours and reservoirs. The presence of organic matter tends to make the soil smoother to the touch (Soper *et al*., 1922; Radforth, 1969; Babel, 1975; Stanek *et al.,* 1983; Moore, 1989; Van der Heijden *et al.,* 1994). Moreover, organic soils present a problematic and poor quality soil due to it's excessive compressibility, poor drainage on site (Rafizul *et al.,* 2012). It is very difficult to stabilize peat or organic soil due to it's very high water content and as it consists of decomposed plant fragment, lower pH and as a result it's potential to interfere chemically and biologically with time and environmental condition (Magnan, 1993; Hernandez *et al*., 2009). These unfavourable characteristics of organic soil deposits make them unsuitable for supporting most engineering projects or infrastructure development. Furthermore, such ground presents failure due to ground instability such as localised sinking and extreme settlement over extended time periods when subjected to a increase in loading (Jarret, 1995; Huat *et al.,* 2004).

Khulna region is situated in the southwestern part of Bangladesh near the world largest mangrove forest, Sundarban shown in Figure 1. The sub-soil of this region consists of fine-grained soils with a considerable amount of decomposed and semi-decomposed organic matter (Rafizul *et al.,* 2012; Alamgir *et al.,* 2006). In this region, the soft soil deposit extends up to a considerable depth, as a result the recent alluvial deposits with organic composition creates problem to geotechnical engineers in designing economic foundations to construct the required infrastructure (Mahamud *et al.,* 2007; Rafizul *et al*,. 2007; Alamgir *et al.,* 2001). Due to presence of thick organic soil layer, the civil engineering constructions in such sites need special attention to the against of possible shear failure as well as total and differential settlement (Tahia *et al*., 2012). To quantify the effects of such organic deposits on the adopted foundation systems, it is required to establish the behavior of OC with the soil parameters. In Khulna region, organic soil layer exists in most of the places within a depth of 10 to 25 ft below the existing ground surface (Rafizul *et al.,* 2009). Moreover, the nature and pattern of OC and geotechnical properties of this

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soil are found to vary from place to place. The soil is also erratic in nature both in the vertical and horizontal directions (Tahia *et al.,* 2012). The bearing capacity of this soil is very low and always leads to adopt a costly foundation for the construction of infra-structures. To understand the characteristics of such organic soil deposits, detailed information about the soil formation, composition and geotechnical characteristics are required to evaluate (Fauziah *et al.,* 2006). Furthermore, the in situ behavior of organic soils is complex because it is heavily dependent on numerous factors. To acquire appropriate understanding, it is necessary to analyze them not only through geotechnical engineering skills but also through other associated disciplines like soil types, composition, fabrics and structures, depositional environment, stress history and physical and mechanical properties, geomorphology, climatology and other earth and atmosphere related sciences (Rafizul *et al*., 2006; Rakmi *et al.*,1995; Soon *et al.,* 2003).

To these attempts, it is essential to conduct a comprehensive study for understanding the characteristics of soil deposits in this region as well as to establish correlations among the geotechnical parameters with the variation of OC. In this study, disturbed soil samples from two selected locations of Khulna region were collected to prepare RCS of various percentages of OC. One sample has 70% of OC and another one contains 8% OC. Then, eight different samples of RCS for the OC of about 5 to 42% were prepared in the laboratory by adjusting the different proportions of low and high OC samples to obtain the wide range of OC. The RCS at each designed OC stated earlier, were prepared in the laboratory based on the procedure followed by Burland (1990). In the laboratory, the required ASTM (2004) methods were followed to conduct the tests such as Atterberg limit, organic content, unit weight, specific gravity, compaction, unconfined compression, permeability, sieve and hydrometer analysis as well as consolidation test to evaluate the variation of geotechnical parameters with OC. Based on the experimental results, some important empirical correlations were established and then compared with the available results from literature and results of undisturbed soil samples collected from four locations of Khulna region, namely, KUET campus, Boyra, Fulbarigate and Circuit House.

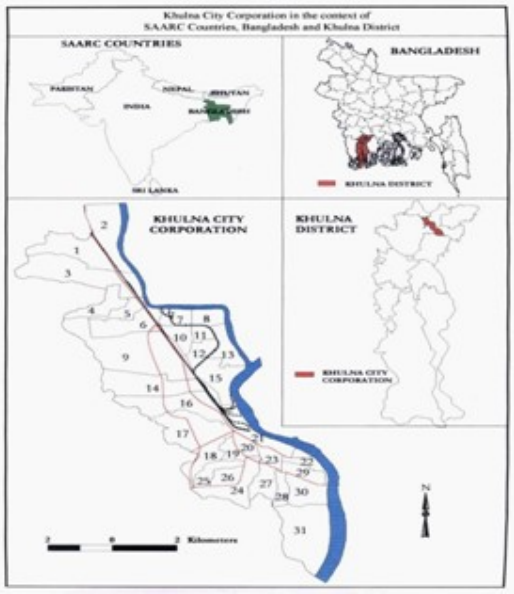

Figure 1: KCC in the context of SAARC countries, Bangladesh and Khulna Division.

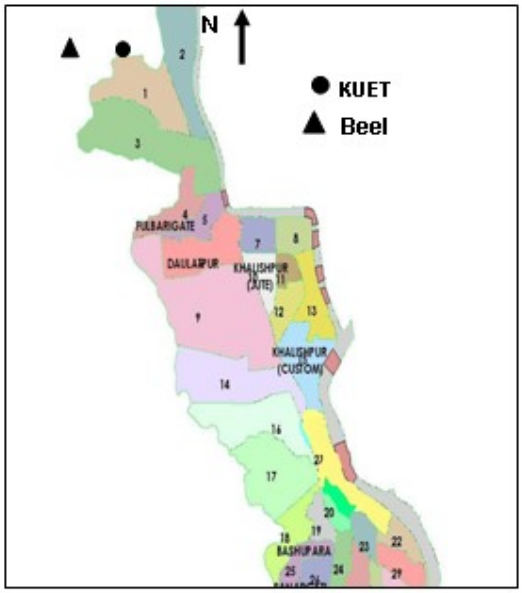

Figure 2: Location of disturbed soil sample used to prepare reconstituted soils in Khulna city.

2. LABORATORY INVESTIGATIONS

For laboratory investigations, disturbed soil samples were collected from two selected locations of Khulna region. One from Beel Dakatia, 2 km away from KUET campus, at a depth of 5 meter and another from KUET campus at a depth of 1.5 meter from the existing ground surface depicts in Figure 2. The methodology followed for the laboratory investigations is presented in Figure 3. However, the details of laboratory investigations and the preparation and consolidation of soil slurry as well as selection of overburden pressure can be obtained in Rafizul *et al.* (2009) and Rafizul (2006) and also described in the following articles. The summary of physical and index properties of soil used to prepare RCS depicts in Table 1.

Table1: Summary of physical and index properties of soil used to prepare RCS

Property Name	Locations	
	Beel Dakatia	KUET Campus
Organic content, OC (%)	70	8
Moisture content, w (%)	250	36
Liquid limit, w_L (%)	78	40
Plastic limit, w_P (%)	63	27
Specific gravity, G_s	2	2.75
Maximum dry density, γ_d (kN/m^3)	7.10	16.0
Sand % (4.75-0.076 mm)	30.5	2.80
Silt % (0.076-0.002 mm)	49.50	53.80
Clay % (<0.002->0.001 mm)	20.0	43.40

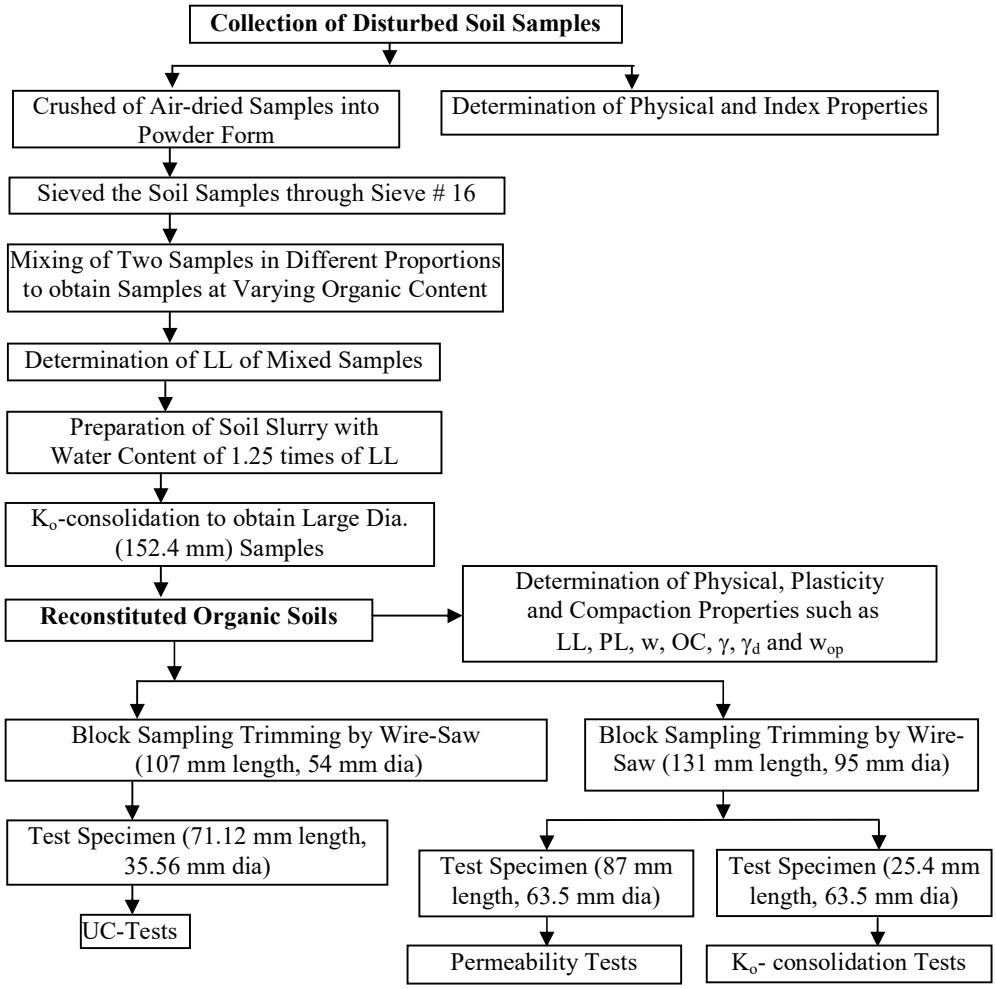

Figure 3: Flow chart of laboratory investigation.

In addition, undisturbed soil samples were collected from four selected locations within the Khulna region, namely KUET campus, Boyra, Fulbari gate and Circuit House. The range and mean physical and index properties of this collected soil samples are presented in Table 2. However, it is interesting to note that the evaluated parameters of this undisturbed soil were exploited to depict the validity of proposed behavior of RCS in this study.

Table 2: Summary of physical and index properties of undisturbed soil samples collected from Khulna region

Property name	Locations							
	KUET campus		Boyra		Fulbarigate		Circuit House	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
OC (%)	5-28	12	4-18	11	7-17	12	8-15	11
w (%)	45-87	65	41-71	60	67-75	70	52-103	68
w_L (%)	40-65	49	41-91	59	43-65	71	31-65	45
w_p (%)	31-57	39	37-70	49	57-87	52	20-37	28
I_p	8-11	10	4-22	10	4-23	16	11-29	11
C_c	0.25-0.81	0.5	0.31-0.62	0.4	0.44-0.68	0.6	0.47-0.64	0.6
e_o	0.77-1.73	1.3	0.76-2.13	1.4	0.96-2.82	1.8	0.73-2.13	1.4
q_u (kPa)	18-71	46	63-91	74	36-60	50	17-73	42
γ (kN/m^3)	4.91-7.67	6.1	4.81-6.92	5.8	5.17-5.96	5.6	4.85-7.10	5.8
G_s	1.80-2.79	2.2	2.40-2.80	2.6	2.10-2.95	2.6	2.60-2.65	2.6

Note: OC=organic content (%), w=water content (%), w_L=liquid limit (%),w_p=plastic limit (%), I_p=plasticity index, C_c=compression index, e_0=initial void ratio, q_u=unconfined compressive strength (kPa), γ=unit weight (kN/m^3) and G_s= specific gravity.

2.1 Preparation of Soil slurry

A RCS has been defined as one that has been thoroughly mixed at moisture content equal to or greater than liquid limit (w_L) (Burland, 1990). Soil slurry with initial water content well beyond the w_L has been commonly used as an initial state for sample preparation. The termed "intrinsic" has been used to describe the properties of clays which has been reconstituted at a water content of between w_L and 1.5 w_L (preferably 1.25 w_L) and then consolidated (Hopper, 1992; Siddique, 2000). However, higher initial water contents provide higher degree of saturation and higher freedom of particle orientation but require larger initial volumes and longer consolidation periods. Since large volume of soil was required for preparing enough samples and also in order to reduce the consolidation time, it is essential to use initial water content which is sufficient to yield uniform and homogeneous slurry. In this study, the samples were first air-dried and then powdered. The powered samples were then sieved through No 16 and the samples were then mixed with a water content equal to 1.25 times of w_L which was found as sufficient to yield uniform and homogeneous slurry. The soil and water were then thoroughly mixed by hand to form slurry to ensure full saturation. Generally No. 40 sieve is used for making reconstituted inorganic soils by various researchers, such as Bashar (2002), however, in this study a standard sieve of larger opening size i.e. No. 16 was used to obtain a better representative reconstituted organic soils.

2.2 Selection of Overburden Pressure

An external pressure is required to consolidate the slurry to obtain reconstituted soil samples. Earlier, it was considered that a pre-consolidation pressure of 276 kN/m^2 was about the minimum value which could make the clay soil just stiff enough to allow setting up specimens (Kirkpatrick and Khan, 1984). Latter as the skill in testing has improved and it is found that the sample is possible to remove at 150kN/m^2 (Kirkpatrick and Khan, 1984). Singh (1992) suggested that soil containing high organic matter shows large volume changes on loading and expulsion of water, low shear strength and low dry density. In addition, reconstituted organic soil is fully decomposed with normally loaded state shows highly compressible phenomena. So, in this study, RCS at the desired OC were prepared in K_o-consolidation cell by the ultimate applied consolidation pressure of 100kN/m^{2}untill the end of primary consolidation.

2.3 Consolidation of Soil Slurry

The slurry was consolidated to form a uniform RCS cake in a cylindrical consolidation mold of 152 mm (6 inch) diameter and 222 mm (8.75 inch) in height. A 3 mm thick perforated steel disc with filter paper to permit uniform drainage was placed at the bottom of the mold. The inner surface of cylindrical consolidation mold was coated with thin layer silicon grease to minimize side friction. The slurry was then poured into the mold and stirred with steel rod to remove the entrapped air. At the top of the slurry, a 3 mm thick perforated steel disc with a filter paper separation was placed and the required axial load of 100 kN/m^2 was gradually applied to the soil sample using a loading frame. An arrangement for the preparation of RCS samples is provided in Figure 4. Initially the slurry was allowed to consolidate by the self-weight and the weight of the porous metal discs for about 24 hours. Then a small pressure of 3 kN/m^2 was applied to the sample for next 24 hours. Similarly, the pressure was increased

gradually by about 5, 8, 10, 13, 18, 26, 34, 42, 50, 59, 67, 75, 87, 92 and ultimately of 100 kN/m^2. This pressure of 100 kN/m^2 was maintained until the end of primary consolidation, which was indicated by the constant reading of compression dial gauge. The consolidation process required about seven or eight days for the completion of primary consolidation. After the completion of consolidation, the top and bottom part of the mold was separated using a mechanical extruder to take out the soil cake. A soil cake of about 114 to 127 mm (4.5 to 5.00 inch) length and 152 mm (6 inch) diameter was obtained by this procedure. This procedure was repeated for each RCS sample containing 5 to 42 % of OC.

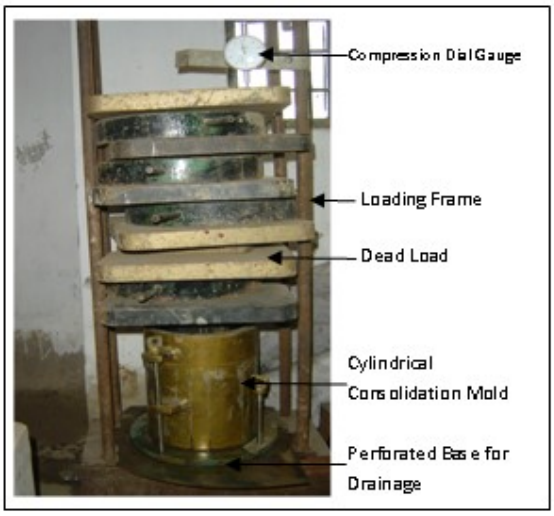

Figure 4: An arrangement for preparation of reconstitute soils at varying organic content.

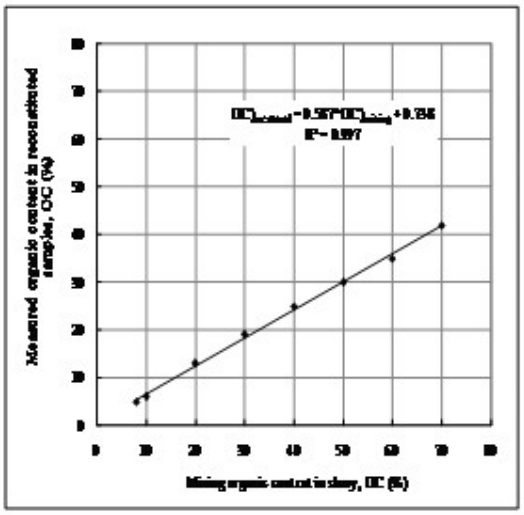

Figure 5: Organic content in reconstituted samples with mixing organic content in soil slurry.

2.4 Organic Content in the Reconstituted Soil

In the laboratory, it has been intended to prepare RCS at the OC of about 8, 10, 20, 30, 40, 50, 60 and 70 % by mixing of soil samples collected from KUET campus and Beel Dakatia. However, the soil samples of OC of 8 % and 70 % were obtained as the samples from KUET campus and Beel Dakatia, respectively, without any mixing. Although slurry was prepared to achieve such OC, but after prepared RCS samples in the laboratory, the measured OC was rounded as 5, 6, 13, 19, 25, 30, 35 and 42 %, respectively, against to that of predetermined OC as stated earlier. The RCS at each designed OC were prepared in the laboratory based on the procedure followed by Burland (1990). The Figure 5 represents the variation of measured OC in RCS samples with mixing OC in slurry and the Figure 5 reveals that the OC in all RCS samples were measured about 60 % to that of mixing during the preparation of slurry. As obtained from the experiences of various researchers, such as Burland (1990) as well as the present study, the factors can be identified which effect the percentages of mixing organic contents in the RCS samples as (i) initially determination of OC of soils at solid state condition; (ii) during preparation of soil slurry with water the lighter organic matter are floating on the top surface of slurry, but the measured OC obtained in inner portion of RCS; (iii) storage period of soil samples; (iv) the method that used to reduce the OC of the organic soils (replacement method); (v) amount of water, which was added to prepare of soil slurry; (vi) intensity of overburden/surcharge pressure used for pre-consolidation of soil slurry to have RCS samples and (vii) interval of time and the rate of applied overburden pressure on the soil specimen.

3. ASSESSMENT OF GEOTECHNICAL BEHAVIOUR OF RECONSTITIUTED SOILS

The RCS at varying OC as prepared in the laboratory were tested to investigate the geotechnical behavior in terms of phase relation, plasticity, hydraulic, compressibility, shear strength, compaction properties as well as constituents of soil particles. Moreover, the assessment of the effect of OC on the geotechnical parameters of RCS as stated earlier was analyzed and hence discussed in the following articles.

3.1 Index Properties

The RCS at varying OC of 5 to 42 % were tested in the laboratory to investigate the physical states in terms of saturated moisture contents (w_{sat} %), initial void ratio (e_o), specific gravity (G_s), degree of saturation (S_r %) and bulk unit weight (γ kN/m^3). However, the changes of physical state for the variation of OC from 5 to 42 % are presented in Table 3 and hence some parameters were discussed here. The variation of saturated moisture content

(w_{sat}) with the variation of OC depicts in Figure 6. From the figure, it can be signified that the values of w_{sat} increased significantly from 35 to 45 % with the increase of OC from 5 to 25 % and the rate of increase was moderate. In addition, the figure also reveals that the w_{sat} increased significantly from 35 to 82 % with the increase of OC from 25 to 42 % and the rate of increase was found higher than the trend for the OC from 5 to 25 %. A Researcher Edil (1997) suggested that if the value of OC of soils lies in between 6 to 20 %, it affects the properties of organic silts and clays. In addition, he also postulated that if the OC of soils lies in between 21 to 74 %, organic matter governs properties as the clayey organic soil. The finding in case of present study agreed well with the postulation given by Edil (1997). Natural moisture content of a soil depends on its water holding capacity. A fine- grained soil can exist in several states in which the state depends on the amount of water in soil (Lambe, 1969). So, it increases in RCS with increasing of OC.

Table 3: Physical properties at varying organic content of RCS

Organic content, OC (%)	Saturated moisture content, w_{sat} (%)	Initial void ratio, e_0	Specific gravity, G_s	Degree of saturation, S_r (%)	Bulk unit weight, γ (kN/m^3)
5	35	0.646	2.78	150	16.8
6	35	0.883	2.65	105	16.4
13	34	1.195	2.50	71	16.1
19	42	1.214	2.35	81	15.2
25	45	1.717	2.29	60	14.3
30	58	1.503	2.24	86	13.2
35	70	1.839	2.10	80	13.1
42	82	1.980	2.01	83	11.3

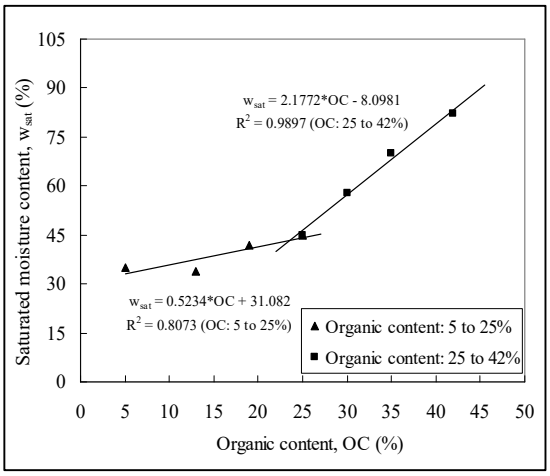

Figure 6: Variation of saturated moisture content with organic content in the reconstituted soils.

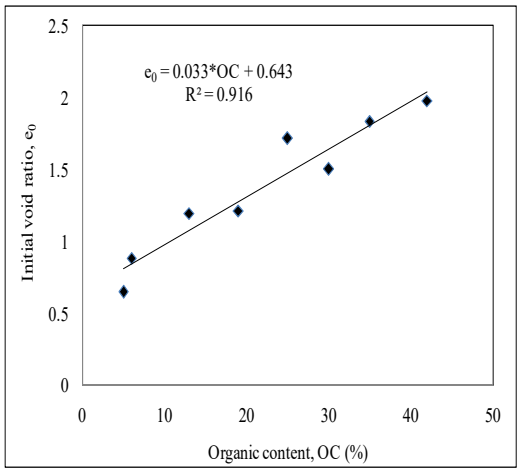

Figure 7: Variation of initial void ratio with organic content in the reconstituted soils.

In contrary, the variation of initial void ratio (e_o) with the increase of OC as shown in Figure 7. The figure reveals that there was a definite increasing trend of e_o as a linear variation with the increase of OC. Here, it is interesting to note that the values of e_o increased significantly from 0.646 to 1.98 with the increase of OC from 5 to 42 %. Based on Figure 7, it can also be concluded that the finding revealed in good agreement with the general behavior of e_o versus OC. Moreover, Oades (1989) stated that in organic soil the void space is more and filled up by air or/and water and the physical properties are changed significantly.

3.2 Soil Composition

The particle size distribution of RCS has been established by conducting the combined method of sieve and hydrometer analysis for the OC of about 5 to 42 %. The particle size distribution for the OC of about 5 to 42 % is provided in Figure 8. The Figure 8 reveals that the relationship of percent finer and particle diameter showing almost similar pattern for all RCS. However, as the OC increase, the diameter of the particle size increases for the same percentage of finer. From Figure 8, it can be revealed that for the percent of finer of 70 %, the diameter of

particle size increase from 0.007 to 0.034 mm, at varying OC of 5 to 42 %. From this figure it can also be seen a well graded shaped curve was obtained for each OC in the RCS.

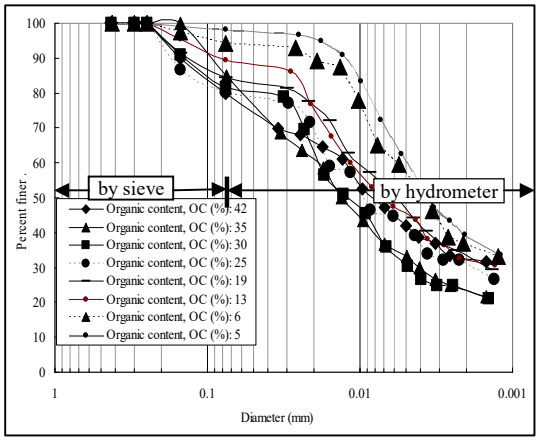

Figure 8: Grain size distributions of reconstituted organic soils.

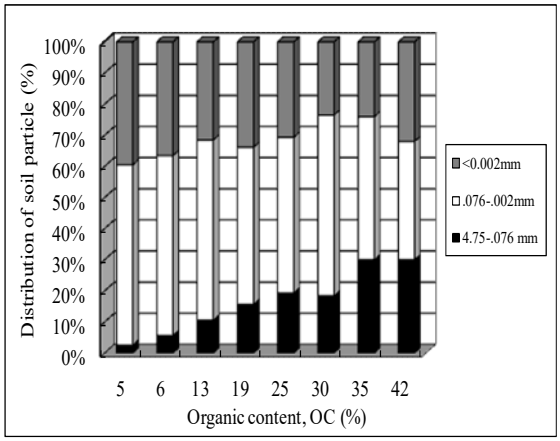

Figure 9: Distribution of soil constituents at varying organic content in the reconstituted soils.

Moreover, the constituted soil particles were categorized into three groups as 4.75 to 0.076 mm., 0.076 to 0.002 mm and <0.002 mm shown in Figure 9. The figure reveals that the particle sized of 4.75 to 0.076 mm increases significantly from 2.60 to 30.00 % with the increase of OC of 5 to 42 %. The Figure 9 also reveals that the particle sized of 0.076 to 0.002 mm decreases significantly from 57.9 to 50 % with the increase of OC from 5 to 19 % after that it increases from 50 to 58.10 % with the increase of OC from 19 to 30 % as well as it also decreases from 58.10 to 38 % with the increase of OC from 30 to 42 %. Moreover, the particle sized of less than 0.002 mm decreases significantly from 39.50 to 31.50 % with the increase of OC of 5 to 13 % after that it increases from 31.50 to 33.50 % with the increase of OC of 13 % to 19 %. Here, it can be noted that the amount of coarser particle increases with the increase of OC in the RCS.

Table 4: Plasticity properties at varying OC in the RCS

Organic content, OC (%)	Liquid limit, w_L (%)	Plastic limit, w_p (%)	Plasticity index, I_p
5	40	30	10
6	50	35	15
13	53	41	12
19	55	41	14
25	58	42	16
30	62	45	17
35	70	50	20
42	78	57	21

3.3 Plasticity Properties

The water contents corresponding to the transition from one state to another usually differ for clays having different physical properties in the remolded state. Moreover, the Atterberg limits vary with the amount of clay present in a soil, OC on the type of clay mineral and on the nature of the ions absorbed on the clay surface. In this study, only the influence of OC on Atterberg limits for a particular RCS was considered and depicted in Table 4. Figure 10 illustrates the variation of liquid limit (w_L) with the increase of OC of the RCS. The Figure 10 depicts that the values of w_L increased significantly from 50 to 58 % with the increase of OC from 6 to 25 % and the rate of increase was moderate. In addition, the figure also reveals that the w_L increased significantly from 58 to 78 % with the increase of OC from 25 to 42 % and the rate of increase was found higher than the trend for the OC of 6 to 25 %. Edil (1997) suggested that if the value of OC of soils lies in between 6 to 20 %, it behaves as like as organic silts and clays. In addition, he also postulated that if the OC of soils lies in between 21 to 74 %, organic matter governs properties as the clayey organic soil. Here, it can be concluded that the finding in case of present study agreed well with the postulation given by Edil (1997). Moreover, Casagrande (1932) deduced that the $w_L$changes depend on the aggregates or the clusters of the basic units that interact to develop the strength in the

soils, the average adsorbed water layer thickness and the average size of intermolecular pores in the soils. As a result, the values of w_L changes with the variation of OC.

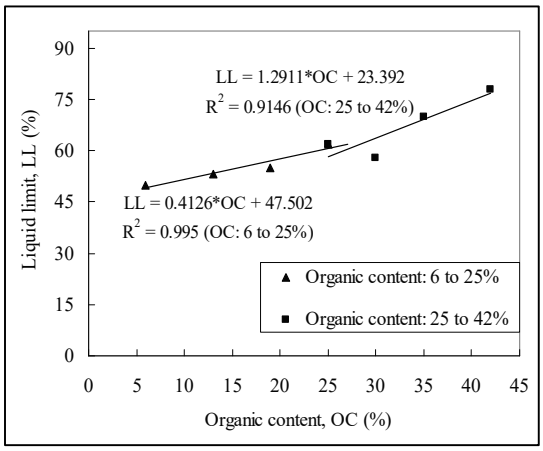

Figure 10: Variation of liquid limit with organic content in the reconstituted soils.

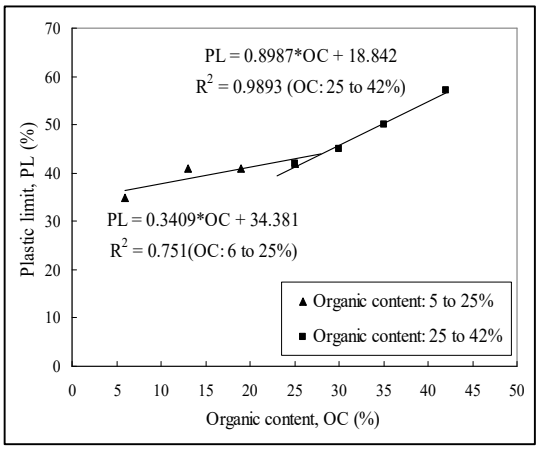

Figure 11: Variation of plastic limit with organic content in the reconstituted soils.

In addition, Figure 11 shows the variation of plastic limit (w_p) at varying OC of RCS and it can be signified that w_p increased from 35 to 42% with the increase of OC from 6 to 25 %. In addition, the figure also reveals that the values of w_p increased significantly from 42 to 57% with the increase of OC from 25 to 42% and the rate of increase was found as higher than the trend for the OC from 6 to 25 % in the RCS. .

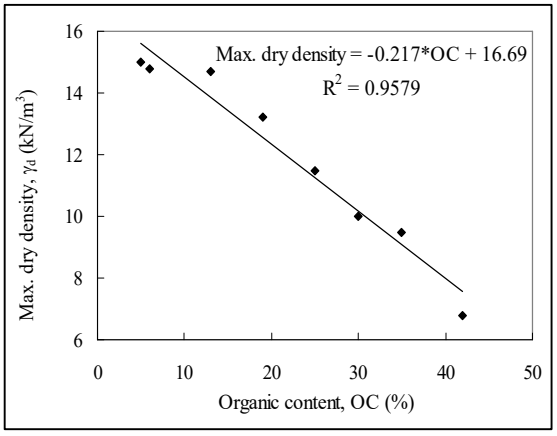

Figure 12: Variation of maximum dry density with organic contents in the reconstituted soils.

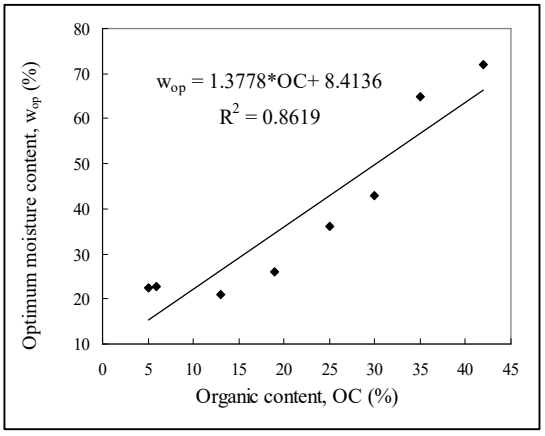

Figure 13: Variation of optimum moisture content at varying organic content of reconstituted soil.

The compaction properties in terms of maximum dry density and optimum moisture content has been established by conducting the Standard Proctor test on RCS of OC ranging from 5-42%. The reduction pattern of maximum dry density (γ_d^{max}) with the increase of OC as presented in Figure 12. The figure reveals that a linear variation of decrease of γ_d^{max}, with increasing of OC. From the figure, it can be seen that γ_d^{max} changed significantly from 15 to 6.80 kN/m^3 with the increase of OC of 5 to 42 %. The degree of compaction of a soil is measured in terms of dry density (Alamgir et al., 2006). The density and water content value obtained from a compaction test are affected by the composition of soils, presence of organic matter and the compaction test procedures. The increase of OC in a soil tends to decrease the maximum dry density and increase the compressibility (Franklin et al., 1973). This remark agreed reasonably well with the findings of the present study.

On the other hand, the optimum moisture content (w_{op}) of RCS varies due to the variation of OC shown in Figure 13. The figure reveals that there is a linear increase of w_{op}, with the increase of OC. From the figure, it can be implied that the w_{op} increased significantly from 23 to 84 % with the increase of OC of 5 to 42 %. The purpose of laboratory compaction test is to determine the proper amount of mixing water when compacting the soil in the field and the resulting degree of denseness which can be expected from compaction at this w_{op} (Rafizul et al., 2009). Moreover, due to induced OC in the soil mass, the value of w_{op} has changed significantly. Here it can be noted that the results of this study have shown a good agreement with the findings of other researchers.

3.5 Compressibility Properties

The main purpose of consolidation test is to obtain the data that may be used in predicting the rate and the amount of settlement of structures. Conducting a series of K_o-consolidation tests in the laboratory, the compressibility parameters in terms of compression index (C_c) and coefficient of consolidation (C_v), as well as primary consolidation period (t) were obtained for RCS and at varying OC of 5-42%. The variation of compression index (C_c) with varying OC of RCS is shown in Figure 14. From the figure, it can be perceived that the values of C_c increased significantly from 0.3226 to 0.4815 cm^2/sec with the increase of OC from 5 to 25 % and the rate of increase was flatter. In addition, the figure also revealed that the C_c increased significantly from 0.4815 to 0.720 cm^2/sec with the increase of OC from 25 to 42 % and the rate of increase was found as higher than the trend for the OC of 5 to 25 %. Edil (1997) suggested that if the value of OC lies in between 6 to 20 %, it behaves of organic silts and clays. In addition, he also postulated that if the OC lies in the rage of 21 to 74 %, it behaves of clayey organic soil. The finding of the present study agreed well with the statement given by Edil (1997). To predict the amount of settlement, knowledge on C_c of soil must be understood to solve the soil engineering problems (Lambe, 1969). However, the amount of settlement depends on its composition and its pore spaces.

Table 5 Coefficient of consolidation with organic content under different applied pressure on RCS

OC (%)	Coefficient of Consolidation, C_v (cm^2/sec) for Different Applied Pressure, σ (kPa)					
	25.00	50.00	100.00	200.00	400.00	800.00
5	0.0015	0.0023	0.0025	0.0065	0.0252	0.0359
6	0.0024	0.0027	0.0028	0.0067	0.0288	0.0370
13	0.0040	0.0045	0.0059	0.0131	0.0297	0.0397
19	0.0043	0.0048	0.0062	0.0165	0.0312	0.0437
25	0.0079	0.0091	0.0131	0.0168	0.0478	0.0501
30	0.0099	0.0103	0.0141	0.0188	0.0542	0.0556
35	0.0115	0.0148	0.0158	0.0280	0.0594	0.0605
42	0.0135	0.0188	0.0330	0.0439	0.0639	0.0690

The variation of coefficient of consolidation (C_v) with the increase of OC of RCS as presented in Table 5 and also in Figure 15. The figure illustrates that there was an increasing trend of C_v with the increase of OC. The figure depicts that at a particular applied pressure, say 100 kPa, the value of C_v has changed from $2.52x10^{-3}$ to $3.3x10^{-2}$ cm^2/sec for the increase of OC from 5 to 42 %. Similar increasing trend of C_v was also observed for other applied pressure ranging from 25 to 800 kPa. Here, it can be concluded that the values of C_v was found as insignificant for low OC and then significant for high OC. The value of C_v depends on organic matter, permeability, void ratio, C_c and applied pressure (Lambe, 1969). Moreover, due to induced organic matter in the soil mass, the C_v has changed significantly, with respect to the applied pressure.

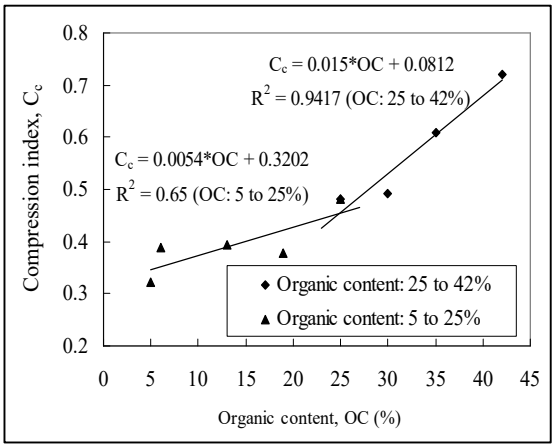

Figure 14: Variation of compression index with organic content in the reconstituted soils.

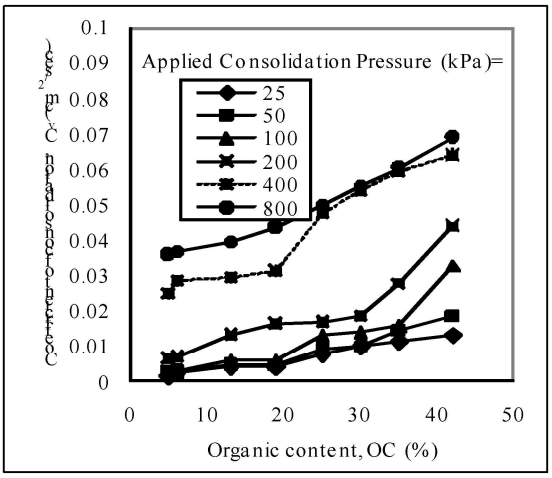

Figure 15: Variation of coefficient of consolidation with organic content in the reconstituted soils.

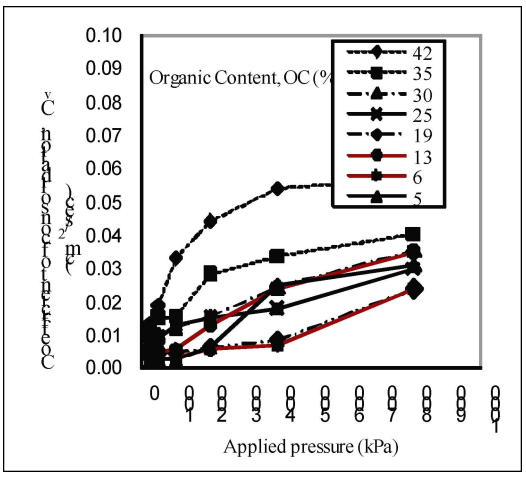

Figure 16: Variation of coefficient of consolidation with applied pressure in the reconstituted soils.

In contrary, the variation of coefficient of consolidation (C_v) with the increase of applied pressure for different OC of RCS as depicted in Figure 16. The figure reveals that there is an increasing trend of C_v with the increase of applied pressure at varying OC. For the OC of 25 %, the value of C_v increases from $8.0x10^{-3}$ to $1.3x10^{-2}$ cm^2/sec for the increase of applied pressure from 25 to 100 kPa. Similar degree of increment was also observed for the other OC.

Table 6: Primary consolidation period with the increase of organic content in the RCS

OC (%)	Primary Consolidation Period, t (mins.) for Different Applied Pressure, σ (kPa)					
	25.00	50.00	100.00	200.00	400.00	800.00
5	11.85	9.86	9.06	5.497	4.903	1.384
6	9.61	8.352	8.01	4.92	4.312	0.96
13	6.66	5.663	6.88	3.742	2.961	0.656
19	5.29	5.063	4.884	2.497	2.624	0.561
25	2.89	2.528	2.742	1.513	1.281	0.457
30	2.31	2.22	1.877	1.44	0.941	0.34
35	1.99	1.54	1.44	0.81	0.673	0.263
42	1.6900	1.21	0.6889	0.518	0.4225	0.176

The variation of primary consolidation period (t) with the variation of OC at varying applied pressure presented in Table 6 and also in Figure 17. The figure shows that there is a decreasing trend of t, for the increase of OC in the RCS. Here it is interesting to note that for the applied pressure 100 kPa, the value of t decreases from 9.06 to 6.88 mins. for the increase of OC of 5 to 13 %. Similar degree of decrement was also observed for the other applied pressure. The figure also depicts that the values of t, was found insignificant at high pressure and then it was significant for low pressure. The organic soils generally posses low shear strength and high compressibility and the time required for primary consolidation has varied significantly with the change of applied pressure and OC (Franklin *et al.,* 1973).

On the other hand, the primary consolidation period (t) of RCS at varying OC with the increase of applied pressure as presented in Figure 18. The figure depicts that there was a trend of non-linear variation of the decrease of t, with the increase of applied pressure in all percentages of OC. For the OC of 25 %, the value of t, decreases from 2.89 to 2.52 mins. for the increase of applied pressure from 25 to 50 kPa. Similar degree of decrement is also observed for the other OC. From the figure it can be concluded that the values of t, was found significant at low OC and then insignificant for the high OC in the RCS.

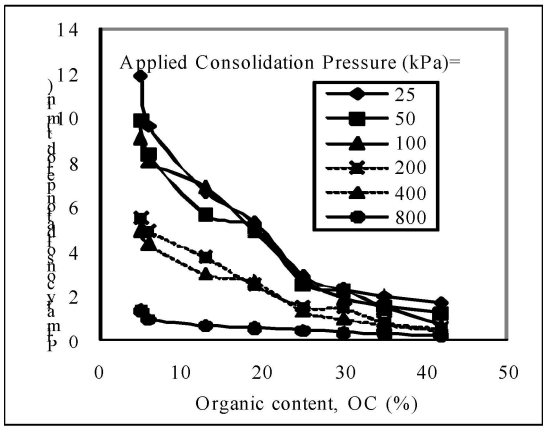

Figure 17: Variation of primary consolidation period with the increase of organic content.

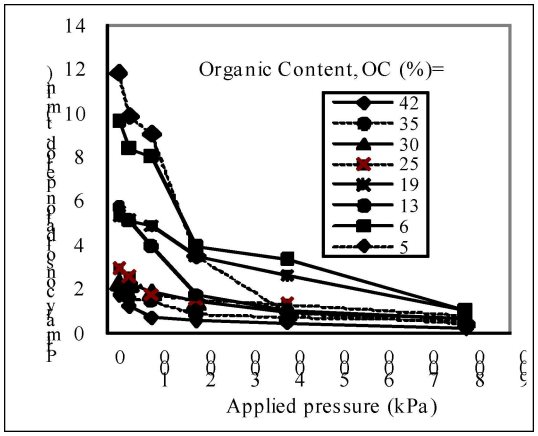

Figure 18: Variation of primary consolidation period with the increase of applied pressure.

3. 6 Strength Properties

The strength behaviors in terms of stress-strain behavior and undrained shear strength at varying OC of about 5 to 42% has been established by conducting the unconfined compression test on the RCS. The evaluated stress-strain behavior at varying OC is shown in Figure 19. The figure reveals that the stress increased with the increase of axial strain and showed almost similar behavior for the RCS at any OC. The figure also depicts that the strength decreases with the increase of OC in the RCS.

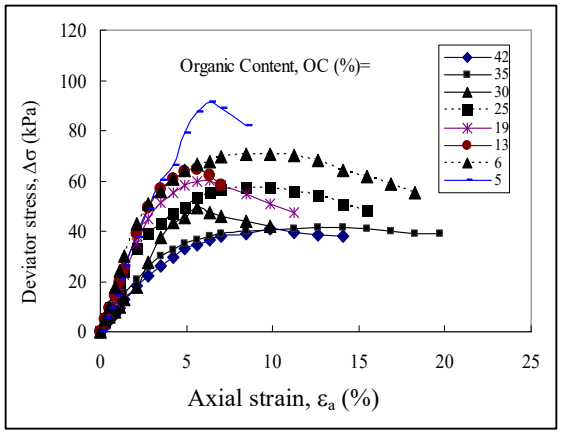

Figure 19: Deviator stress and axial strain of reconstituted soils at varying organic content.

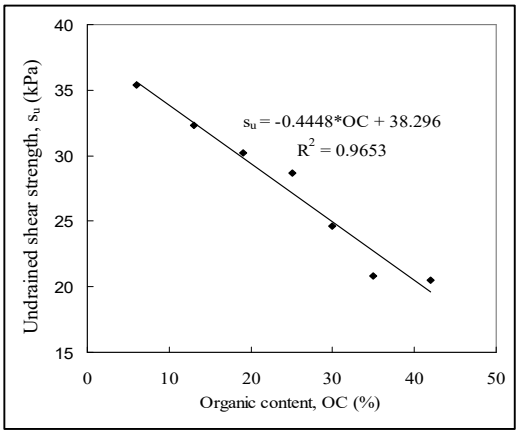

Figure 20: Undrained shear strength at varying organic content of reconstituted soils.

Moreover, the undrained shear strength (s_u) varies with the increase of OC of RCS as shown in Figure 20. From the figure it can be seen that the s_u decreased significantly from 35.36 to 20.50kPa for the increase of OC from 6 to 42%. Moreover, the s_u is a function of OC for a natural soil and soil peat mixtures and also the interconnected bonding of soil particles i.e. the cementing bonding (Franklin *et al.,* 1973). In organic soils, the particles interconnected contracts have established within organic matters. As the organic matter bears low strength and high compressibility, the strength properties of soil reduced with increase of OC (Bashar, 2002).

3.7 Hydraulic Properties

The variation of coefficient of permeability (k) of RCS with that of varying OC depicted in Figure 21. From the figure, it can be signified that the values of k, has increased significantly from 2.84×10^{-6} to 2.70×10^{-3} mm/sec with the increase of OC from 5 to 25 % and the rate of increase was flatter. In addition, the figure also reveals that the values of k has increased significantly from 2.70×10^{-3} to 4.65×10^{-3} mm/sec with the increase of OC from 25 to 42 % and the rate of increase was found as higher than the trend for the OC from 5 to 25 %. Edil (1997) suggested that if the value of OC of soils lies in between 6 to 20 %, it affects on properties but behavs like as organic silts and clays. In addition, he also postulated that if the OC of soils lies in between 21 to 74 % the behaviour is like silty or clayey organic soils. The finding in case of present study agreed well with the statement

given by Edil (1997). The value of k is a property of soil which indicates the flow of water through the interconnected void spaces. The rate, at which the volume changes during consolidation in a soil, is directly related to the permeability (Alamgir *et al.,* 2006).

The physical, plasticity, hydraulic, compressibility and strength properties of reconstituted soils at varying OC of RCS can be expressed by a series of empirical equations with reasonable degree of accuracy and judgment. Among the proposed empirical equations, the following equations (where the symbols bear their usual meanings) can be considered as very important, considering the evaluation of most important parameters of organic soils.

w_{sat}= 0.53*OC+31.1 (R^2=0.807) for 5%≤ OC≤ 25% ……..(1 a)
w_{sat}= 2.18*OC-8.10 (R^2=0.989) for 25%≤ OC≤ 42% …….(1 b)
w_L = 0.41*OC+ 47.5 (R^2=0.995) for 5%≤ OC≤ 25%.....(2 a)
w_L = 1.29*OC+ 23.4 (R^2=0.915) for 25%≤ OC≤ 42%.....(2 b)
e_o = 0.03*OC+0.64 (R^2=0.916) for OC= 5 to 42%.....(3)
G_s= –0.02*OC+2.77 (R^2=0.976) for OC= 5 to 42%.....(4)
s_u = -0.44*OC+38.3 (R^2=0.965) for OC = 6 to 42%.....(5)
C_c = 0.005*OC+0.32 (R^2=0.65) for 5%≤ OC≤ 25%.....(6 a)
C_c = 0.02*OC+0.08 (R^2=0.942) for 25%≤ OC≤ 42%.....(6 b)

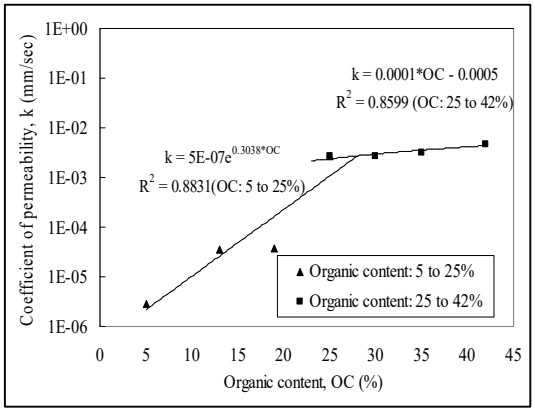

Figure 21: Variation of coefficient of permeability with organic content in the reconstituted soils.

4. VERIFICATION OF PROPOSED EQUATIONS

Any developed correlation is subjected to verification with the existing literature proposed by the other researchers. To these attempts, the relevant statistical model was considered, proposed by the other researchers and with those results of undisturbed soil samples collected from four locations of Khulna region, namely, KUET campus, Boyra, Fulbarigate and Circuit House and hence discussed in the following sections.

4.1 Saturated Moisture Content

The relationship of saturated moisture content (w_{sat}) with OC in RCS is provided in Figure 22 that expressed by the empirical equation of (1 a) and (b). In the present study, the values of w_{sat} increase with the increase of OC of RCS and the rate of increase was found flatter up to the OC of 25 % and then the rate of increase also found higher in between the OC of 25 to 42 % and the finding revealed in good conformity with the general performance of w_{sat} versus OC. The results from the approaches proposed by Coutinho and Lacerda (1987) in case of organic clay was compared with those of predicted results and the empirical equation was also compared with those results of undisturbed soil samples collected from four locations of Khulna region, namely, KUET campus, Boyra, Fulbarigate and Circuit House. The figure also depicts that the w_{sat} increases with the increase of OC in all the cases and the predicted results i.e w_{sat} corresponding to OC lies the other studies. The magnitudes of the measured value in case of undisturbed soils for organic soil was found very scatter to each other than the present study which was expected. The moisture content of a soil depends not only on OC but also on mineralogy, stress history, nature, location, depositional phenomena and the overburden pressure. In addition, the water holding capacity of natural organic soil is higher due to the presence of solid particles with void space than the reconstituted soils (Rafizul *et al*., 2006). Due to the influence of the above factors, the magnitude of w_{sat} for RCS was found as lower than the other cases although the trend was found as similar. For example, from the figure, it can also be depicted that the value of w_{sat} for RCS, undisturbed soils in case of organic soils, publish results in case of organic clays increases significantly from 34 to 40, 51 to 103 and 93 to 120 %, respectively, with the increase of OC of 5 to 15 %. From the figure it was also observed that the increasing rate of w_{sat} was found as 6 %

for the present study with the increase of OC of 5 to 15 %, while the increasing rate of w_{sat} of 52 and 27 %, respectively, for the undisturbed soil and publish results with the same increase of OC. So, the empirical equation was appreciable for the organic soils with respect to the region and having similar parameters.

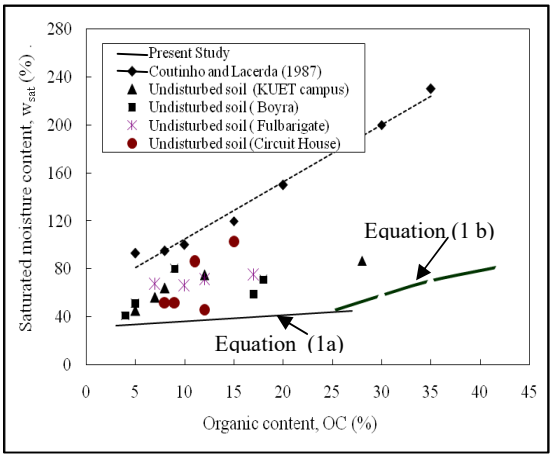

Figure 22: Comparison of saturated moisture content based on empirical equation with published results.

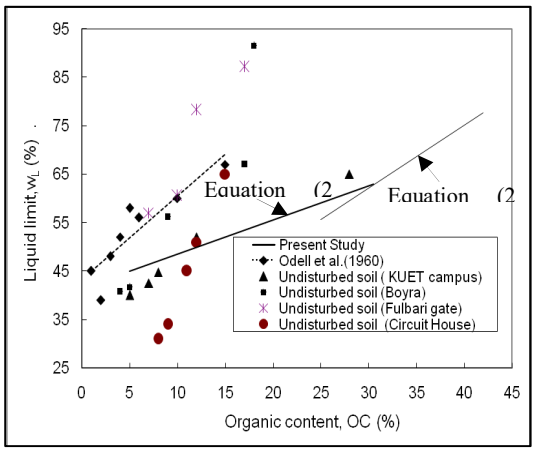

Figure 23: Comparison of lid limit based on the empirical equation with the other researchers.

4.2 Liquid Limit

The increase of liquid limit (w_L) with the increase of OC as obtained from the empirical equation of (2 a) and (b) proposed in the present study was compared with those of results for undisturbed soil and results reported by Odell et al., (1960) and hence presented in Figure 23. In the present study, the values of w_L increases with the increase of OC and the rate of increase was found as flatter up to the OC 25 % and then the rate of increase was also higher in between the OC of 25 to 42 % and the finding was found as in good conformity with the general performance of w_L versus OC. The increasing trend of w_L with the increase of OC was found as similar for both the cases, however the rate of increment was different. The magnitude of the evaluated results in case of present study was lower than that of reported by Odell *et al.* (1960). In addition, the magnitudes of the measured value for undisturbed soil were very scatter to each other than the present study which was expected. The figure depicted that the value of w_L for the RCS, results in case of undisturbed soil, publish results in case of organic clays increases significantly from 40 to 53.50, 41 to 85 and 58 to 67 %, respectively, with the increase of OC from 5 to 15 %. From the figure it was also observed that the increasing rate of w_L was found 13.50 % for the present study with the increase of OC from 5 to 15 %, while the increasing rate of w_L of 43.35 and 9 %, respectively, for undisturbed soil and publish results with the same increase of OC.

4.3 Initial Void Ratio

Figure 24 represents the comparison of predicted results of initial void ratio (e_o) obtained from the proposed empirical equation (3) with the increase of OC was compared with those reported by Coutinho and Lacerda (1987) and results of undisturbed soil samples. The values of e_o as reported by Coutinho and Lacerda (1987) increases with the increase of OC, and it was also observed for the proposed empirical equation, however the rate of increase was different. The magnitudes of the measured e_o in case of results for undisturbed soil was found very scatter to each other than the present study which was expected due to the inherent properties of in-situ soil. However, an increasing trend also exists. For example, from the figure, it can be seen that the value of e_o for the RCS, results in case of undisturbed soil, publish results in case of organic clays increases significantly from 0.646 to 1.198, 0.762 to 2.13 and 1.10 to 2.50, respectively, with the increase of OC from 5 to 15 %. From the figure it was also observed that the increasing rate of e_o of 0.552 for the present study with the increase of OC from 5 to 15 %, while the increasing rate of e_o is 1.368 and 1.40, respectively, for the undisturbed soil and publish results with the same increase of OC. The increasing rates of e_o with OC for the present study was found relatively lower than the undisturbed soil and publish results.

4.4 Specific Gravity

Figure 25 represents the comparison of proposed empirical equation (4) with those results available in the literature and also the results of undisturbed soil. The figure reveals that the value of G_s decreases with the increase of OC of soils of all the cases; the empirical relations, reported by Whitman (1969) and results of undisturbed soil samples. The predicted degree of accuracy was found as tolerable and the decreasing trend of G_s

for the increase of OC was comparable for all the soil samples except KUET campus, which shown lower values. The line of the predicted results from the empirical equation in case of RCS was found as parallel to those of the line proposed by Whitman (1969). In addition, the magnitudes of the measured value in case of results for undisturbed soil was found very scatter to each other than the present study which was expected as there are inherent differences of properties of natural soils and RCS. The G_s of a soil depend does not only on the OC but also on mineralogy, stress history, nature, location, depositional phenomena and the overburden pressure. Due to the influence of the above factors, the magnitude of G_s for the same OC was different although the trend was similar. For example, from the figure, it is interesting to note that the value of G_s for the RCS, results of undisturbed soil, publish results in case of organic clays decreases significantly from 2.71 to 2.45, 2.70 to 2.18 and 2.92 to 2.83, respectively, with the increase of OC from 5 to 15 %. From the figure it was also observed that the decreasing rate of G_s 0.26 for the present study with the increase of OC from 5 to 15 %, while the decreasing rate of G_s 0.52 and 0.09, respectively, for the undisturbed soil and publish results with the same increase of OC.

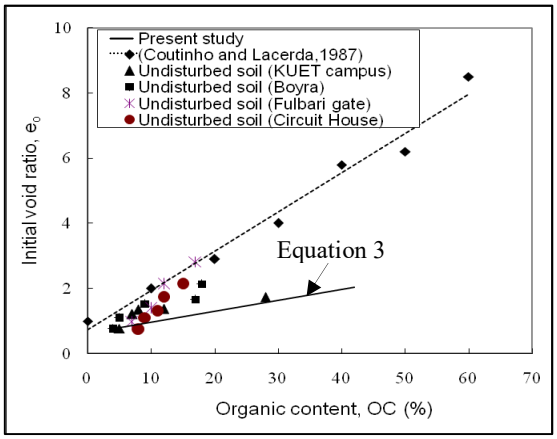

Figure 24: Comparison of initial void ratio based on the empirical equation with the literature.

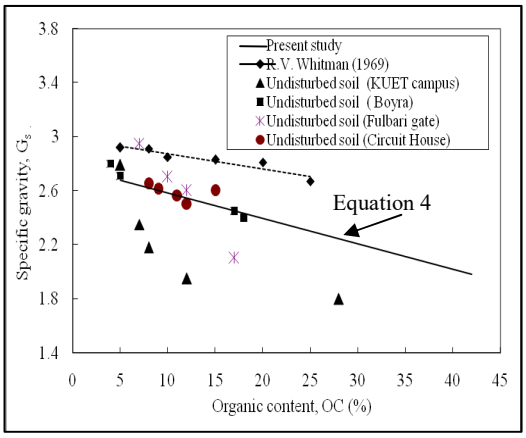

Figure 25: Comparison of the predicted empirical equation in the present study with other sources.

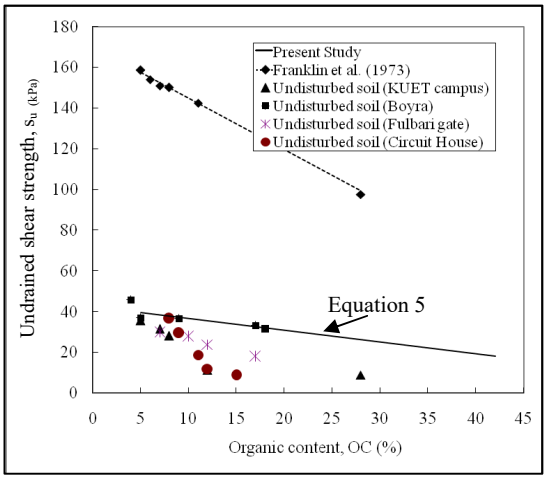

Figure 26: Comparison of predicted values of undrained shear strength with other sources.

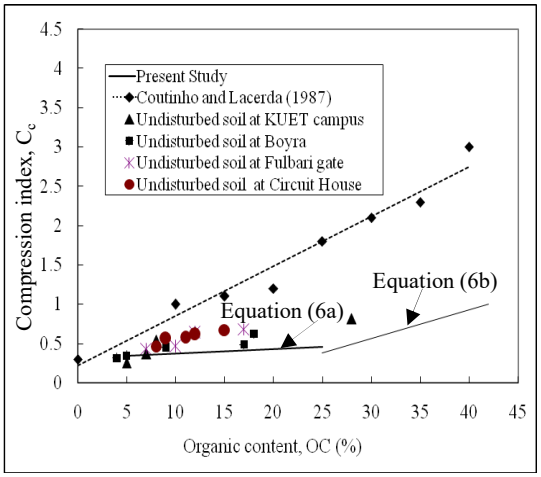

Figure 27: Comparison of the predicted values of compression index and the results from other sources.

4.5 Shear Strength

The verification of undrained shear strength (s_u) at varying percentages of OC in the RCS as depicted in Figure 26. The Figure 26 reveals that the proposed empirical equation (5), s_u decreases with the increase of OC in the RCS. The results reported by Franklin *et al.* (1973) in case of RCS, was compared with the evaluated results in the present study and it was revealed that s_u also decreases with the increase of OC. The magnitude of the measured value for undisturbed soil was found as very scatter to each other than the present study which was expected. The factors on which the magnitude of s_u depends on soil types, composition, fabrics and structures, depositional environment, stress history and physical and mechanical properties. Due to these important factors, the results obtained from present study and that of reported by Franklin *et al.* (1973) differs from each other significantly. The results obtained in the present study was found as greatly lower than that of the Franklin *et al.*

(1973), which may be due to loss of cementation bonding, which did not regain due to short thixotrophy period after remolding. From the figure, it can be seen that the value of s_u for the RCS, undisturbed soil and publish results in case of organic clays decreases significantly from 45.71 to 36.5, 36.9 to 8.7 and 158.5 to 132.50 kPa, respectively, with the increase of OC from 5 to 15 %. From the figure it also observed that the decreasing rate of s_u, was 9.20 kPa for the present study with the increase of OC of 5 to 15%, while the decreasing rate of s_u was 28.20 and 26.00 kPa, respectively, for the undisturbed soil and published results with the same increase of OC.

4.6 Compression index

The compressibility properties, expressed by the parameter-compression index (C_c) was expressed an empirical equation of (6 a) and (b). The verification of this proposed equation with those of reported by Coutinho and Lacerda (1987) and the laboratory test results of undisturbed soils. Figure 27 illustrates the results for comparison of C_c versus OC relationship as proposed in the present study and the results reported by Coutinho and Lacerda (1987) and results of undisturbed soil. In the present study, the C_c increases with the increase of OC of RCS and observed that the increasing rate of C_c was 0.153 for the present study with the increase of OC from 5 to 15 %, while the increasing rate of C_c was found 0.357 and 0.485, respectively, for the undisturbed soil and publishes results with the same increase of OC. The increasing rate of C_c with OC for present study was relatively lower than field and publish results. Due to changes of physical state and the relevant soil parameters, the compressibility of RCS increases with the increase of OC (Rafizul *et al.,* 2009).

5. CONCLUSIONS

Based on this study, the following conclusions can be revealed:

(i) The experimental results revealed that the OC in all RCS samples prepared in the laboratory were measured about 60% to that of mixing during the preparation of slurry.

(ii) Here, it is interesting to note that the physical properties such as saturated moisture contents, liquid limits, plastic limits, initial void ratio and coefficient of permeability were found to increase while, the specific gravity decreased with the increase of OC in the RCS.

(iii) Maximum laboratory dry density decreased, while the optimum moisture content increased for the increase of OC in the RCS.

(iv) The shear strength decreased with the increase of OC and the stress-strain diagram showed almost similar behavior in all the RCS.

(v) Compression index increased with the increase of OC of RCS. Moreover, the coefficient of consolidation increased for all applied loading conditions as well as with the increase of OC. From consolidation test, it was also concluded that the primary consolidation period has decreased for all applied loading conditions and with the increase of OC of RCS.

(vi) The physical, hydraulic, compressibility and strength properties of reconstituted soils at varying OC of RCS can be expressed by a series of empirical equations with reasonable degree of accuracy and judgment. (vii) The findings in case of present study agreed well with the results postulated by other researchers and the results of undisturbed soil.

REFERENCES

Alamgir, M. Rafizul, I. M. and Bashar, M. A.: Physical Properties of Reconstituted Organic Soils at Khulna Region of Bangladesh, 59th Canadian Geotechnical Conference,Vancouver,Canada, pp.1-6, 2006.

Alamgir, M., Zaher, S.M., Haque, M.A. and Kabir, M.H.: Performance of Some Ground Improvement Methods Recently Practiced in the Soft Ground of Bangladesh, Proc. of the Indian Geotechnical Conf. (IGC2001), Indore, India, 2001.

ASTM: Annual Book of ASTM Standard: Soil and Rock (1). D420- D4914. Vol.04.08 and 04.09, Section 4, 2004.

Babel, U.: Micromorphology of soil organic matter. In: Gieseking J.E., Editor, Organic Compounds, Soil Components, Springer Journals, Berlin (1975), Vol. 1, pp. 369–473, 1975.

Bashar, M. A.: Stress-deformation characteristics of selected coastal soils of Bangladesh and their sampling effects, Ph. D. Thesis. Dept. of Civil Engg., BUET, Bangladesh, pp. xxvii,6-8, 21, 2001.

Burland, J. B.: The Thirtieth Rankine Lecture: On the compressibility and shear strength of natural soils, Geotechnique 40, No.3, pp. 329-378, 1990.

Casagrande, A.: Research on Atterberg Limits of Soils, Public Roads, Vol. 13, pp. 121-130, 145, 1932.

Coutinho, L.K. and Lacerda, M.Y.: Compressibility Characteristics of Organic Peat Soil, Highway Research Board, Bulletin 311, 1987.

Edil, T. B.: Construction over Peat and Organic Soil, Proc. On Recent Advances in Soft Soil Engg, Kuc, 1997.

Edil, T. B.: Recent Advances in Geotechnical Characterization and Construction over Peats and Organic Soils." In 2nd International Conference on Advances in Soft Soil Engineering and Technology, Putrajaya, 2003.

Fauziah, A., Ahmad, S.Y. and Farooqi, M. A.: Characterization and Geotechnical Properties of Penang Residual Soils with Emphasis on Landslides. American J. of Env. Sciences 2 (4): 121-128, 2006, ISSN 1553-345X.

Franklin, A.F., Orozco, L.F, Semrau, R.: Compaction and Strength of Slightly Organic Soils, Journal of Soil Mecahnics Foundation Division, ASCE, V-99,No. SM 7. 1973.

Hernandez, M., F. G., and Al- Tabbaa, A.: Effectiveness of Different Binders in the Stabilisation of Organic Soils. In International Symposium on Deep Mixing and Admixture Stabilization, Okinawa, 2009.

Hopper, R. J.: The effects and implications of sampling clay soils, Ph. D Thesis, Univ. of Surrey, England, 1992.

Huat, B. B. K.: Organic and Peat Soils Engineering." 1st print, Universiti Putra, Malaysia Press. ISBN 983-2871-08-5, 2004.

Jarrett, P.M.: Geoguide 6: Site Investigatio for Organic Soils and Peat. JKR Document 20702-0341-95. Institut Kerja Raya Malaysia, 1995.

Kirkpatrick, W. M. and Khan, A. J.: The Reaction of Clay to Sampling Stress Relief, Geotech., V-34, No.1, 1984.

Lambe, T. W.: Soil testing for engineering, Wiley Eastern limited, New Delhi, India, pp. 74-75, 81, 83, 1969.

Magnan, J. P.: Construction on Peat. Proceeding of the International Workshop on Advances in Understanding and Modelling the Mechanical Behaviour of Peat, Revitalisation of Organic and Peat, Balkema, Rotterdam, pp. 369-380, 1993.

Mahamud, M.A., Alamgir, M., Rafizul, I. M and Gazi, M. A. H. 2007: Behaviour of Soft Ground Improved by Geotextile Reinforced Compacted Sand Bed, Proc. of the IS on Geotechnical Engg., Ground Improvement and Geosynthetics for Security and Environmental Preservation, Bangkok, Thailand, pp.457-467, 2007.

Moore, P. D.: The ecology of peat-forming processes. International Journal of Coal Geology, Vol. 12, No.1–4, pp. 89–103, 1989.

Oades, J. M.: An Introduction to Organic Matter in Mineral Soils, In: J. B. Dixon and S. B.. Weed (E_{DS}.), Minerals in Soil Environment, 2nd edition, Soil Science Society of America Book Series: 1, Madison, WI, 1989.

Odell, R.T., Thornburn, T. H. and Mckenzie, L.1.: Relationships of Atterberg Limits to some other Properties of Illinois Soils, Proc. Soil Sci. Soc. Am., 24 (5): pp. 297-300, 1960.

Radforth, N. W.: Muskeg as an Engineering Problem. Muskeg Engineering handbook, I. C. MacFarlane, ed., University. of Toronto Press, Toronto, pp. 3–30, 1969.

Rafizul, I. M., Alamgir M. and Bashar, M. A.: Compressibility Properties of Reconstituted Organic Soils at Khulna Region of Bangladesh, 4th International Conf. on Soft Soil Engg. (ICSSE), Vancouver, Balkema, Canada, pp.367-372, 2006.

Rafizul, I. M., Alamgir, M. and Bashar, M. A.: Strength and Compaction Properties of Reconstituted Organic Soils of a Selected Site in Khulna Region, Procs. of the Bangladesh Geotechnical Conference, BGS 2009, BGS-2009, BUET, Dhaka, Bangladesh, pp.109-115, 2009.

Rafizul, I. M., Alamgir, M. and Mahamud, M.A..: Effect of Pre-consolidation Pressure on the Geotechnical Properties of Reconstituted Organic Soils of Khulna Region, Proc. of the IS on Geotechnical Engg., Ground Improvement and Geosynthetics for Security and Environmental Preservation, Bangkok, Thailand, pp. 541-549, 2007.

Rafizul, I. M.: Geotechnical Properties of Reconstituted Organic Soils. M. Sc. Engineering Thesis, Department of Civil Engg., KUET, Khulna, pp1-5, 9-10,38-40, ,42-103, 105-112, 2006.

Rafizul, I.M. Assaduzzaman, M. and Alamgir, M.: The Effect of Chemical Admixtures on the Geotechnical Parameters of Organic Soil: A New Statistical Model, International Journal of Applied Science and Engineering Research (IJASER), doi:10.6088/ijaser.0020101064, Vol. 1, Issue 4, 2012, (ISSN 2277-9442), pp.623-634, 2012.

Rakmi, et al.: Effects of Organic Load on Basic Geotechnical Properties of Compacted Sand-kaolinite Mixture, Pertanika J. Sci. & Technol. 3(1):87-98(1995), ISSl: 0128-7680, © Universiti Pertanian Malaysia Pres, 1995.

Siddique, A.: An experimental study of sampling disturbance, Ph. D. Thesis, University of Surrey, England, 2000.

Singh, A.: The Determination of Swelling Pressure of Expansive Organic Clays. I.I.P. Board, New Delhi, 1992.

Soon, T.T. and K. K. Phoon: Characterization and Engineering Properties of Natural Soils, International Proc. of specialty workshop, pp: IX-X, National University of Singapore, Singapore, 2003.

Soper, E. K., and Osbon, C. C.: The Occurrence and Uses of Peat in the United States. U.S. Geological Survey 2010 bulletin, No. 728, pp. 1–207, 1922.

Stanek, W., and Worley, I. A.: A Terminology of Virgin Peat and Peatlands. In Proceeding of International Symposium on Peat Utilization, Bemidji State University, Bemidji, United States., pp. 75–104, 1983.

Tahia, R., Rafizul, I.M., Assaduzzaman, M. and Alamgir, M.: Strength and Compressibility Characteristics of Reconstituted Organic Soil at Khulna Region of Bangladesh, the International Journal of Engineering & Technology (IJET), Volume 2, Number 10, pp. 1672-1680 (ISSN: 2049-3444), 2012.

Van der Heijden, E., Bouman, F., and Boon, J. J.: Anatomy of Recent and Peat Field Calluna Vulgaris Stems: Implications for Coal Mineral Formation. In Proceeding of International Journal Coal Geology, Vol. 25, No. 1, pp. 1–25, 1994.

Whitman, R.V., D'Appolonia, D.J. and D'Appolonia, E.: Sand Compaction with Vibratory Rollers, Journal of Soil Mecahnics Foundation Division, ASCE, V-95, No. SM 6. 1963.

Wong, L. S., Hashim, R., and Ali, F. H.: Behaviour of Stabilized Peat Soil in Unconfined Compression Tests. American Journal of Engineering and Applied Sciences, Vol. 1, No. 4, pp. 274-279, 2008.