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Strength and Compressibility Characteristics of Reconstituted Organic Soil at Khulna Region of Bangladesh

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ABSTRACT

This study depicts the experimental investigations into the effect of organic content on the shear strength and compressibility parameters of reconstituted soil. To these attempts, disturbed soil samples were collected from two selected locations of Khulna region. The reconstituted soil having organic content of 5-35 % were prepared in the laboratory to mix at various proportions of inorganic and organic soil at the water content equal to 1.25 times of liquid limits of collected samples .The usual procedure of preparation of soil slurry, deposition in a mold and application of surcharge were used to reconstitute sample. The mold diameter was 152 mm and height 222 mm and applied ultimate surcharge was about $60kN/m^2$. In the laboratory, ASTM (2004) methods were followed for the determination of strength properties and compressibility parameters of reconstituted soil at varying organic content. Here, it can be depicted that organic content significantly influence the shear strength and compressibility parameters of reconstituted soils. Moreover, some important correlations were developed based on strength and compressibility parameters and organic content which can be expressed by equations that may be proposed to estimate the various properties of soil of Khulna region using its organic content.

Keywords: *Organic content, Pre-consolidation Pressure, Strength and Compressibility Properties, Correlations, Comparison.*

1. INTRODUCTION

Khulna region is situated at the south-western part of Bangladesh near the world largest mangrove forest, Sundarbans. The sub-soil of this region consists of fine-grained soils with a considerable part of decomposed and semi-decomposed organic matter (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 (Rafizul et al. 2010). Due to presence of thick organic soil layers, the civil engineering constructions in such sites need special attention to against possible shear failure as well as total and differential settlement. To quantify the effects of such organic deposits on the adopted foundation systems, it is required to establish the behaviour of organic contents with the soil parameters. In Khulna region, the 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 of organic contents and geotechnical properties of this soil are found to vary from place to place. The soil is also erratic in nature both in the vertical and horizontal directions. 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 (Rafizul et al. 2006). To acquire appropriate understanding, it is necessary to analyse 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 (Fauzial 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 and to establish empirical correlations among the engineering parameters in relation to the variation of organic content. In this study, disturbed soil from two selected locations of Khulna region was collected to prepare reconstituted soils at varying organic content. One sample has 38% and another one contains 6% of organic content. Moreover, six different samples of reconstituted soil for the organic content of about 5, 12, 17, 21, 28, and 35% and were prepared in the laboratory by adjusting the different proportions of low and high content organic samples to obtain the wide range of organic content. The reconstituted soils were prepared in the laboratory based on the procedure followed by Burland (1990) to obtain the wide range of organic content under a pre-consolidation pressure. Moreover, develop some correlations among the strength and compressibility properties in relation to the variation of organic content of reconstituted soil. However, to depict the validity of the developed model then compared with the results available in the literature.

2. LABORATORY INVESTIGATION

In this study, disturbed soil samples were collected from two selected locations of Khulna region, one from Beel Dakatia, 2 Km away from KUET campus, Khulna at a depth of about 10 feet and another from KUET campus at a depth of about 5 feet from the existing ground surface. The detailed methodology followed for this laboratory investigation presented in Figure 1. In the laboratory through ASTM (2004) methods the physical properties of soil samples were determined provided in Table 1.

Table 1 Physical properties of soil used to prepare reconstituted soils

Location	OC (%)	w (%)	w_L (%)	w_P (%)	G_s	Percentages of constituted soil particles in samples			USCS Symbol
						4.75-0.076mm	0.076-0.002mm	<0.002 mm	
KUET campus	6	21	27	18	2.75	6.0	53.8	40.2	ML
Beel Dakatia	38	192	86	76	2.0	38.0	49.5	15.5	OH

Note: OC=organic content, w=moisture content, w_L=liquid limit, w_P=plastic limit, G_s=specific gravity and USCS=Unified Soil Classification System.

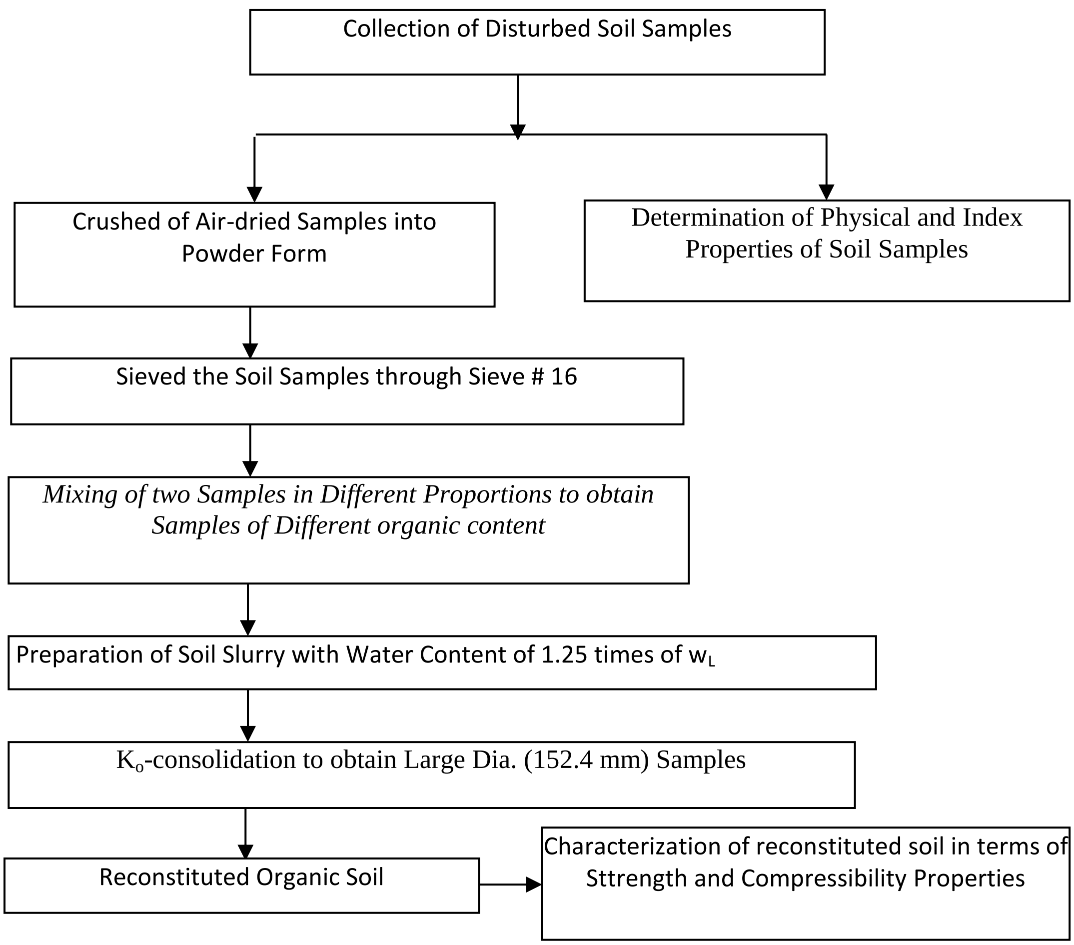

Figure 1: Flow chart of laboratory investigation

2.1 Preparation of Soil Slurry

In this study, the samples were first air-dried and then powdered. The powered samples were then sieved through No 16 sieve and the samples were then mixed with a water content equal to 1.25 times of liquid limits which was found as sufficient to yield uniform and homogeneous slurry. 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 sieve was used to obtain a better representative reconstituted organic soils. Details of soil slurry and test specimen preparation can be obtained in Rafizul (2010) and also in Alamgir et al. (2006).

2.2 Consolidation of Slurry

The slurry was consolidated to form a uniform reconstituted soil cake in a cylindrical consolidation mold of 152mm diameter and 222mm height as shown in the Figure 3. The required axial load of 60kN/m^2 was gradually applied to the sample using a loading frame 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 3kN/m^2 was applied to the sample for the next 24 hours. Similarly, the pressure was increased gradually by about 3, 5, 8, 12, 15, 20, 25, 30, 40, 50 and ultimately to the final value of 60kN/m^2. This pressure of 60kN/m^2 was maintained until the end of primary consolidation. After the completion of consolidation, a soil cake of about 114 to 127mm length and 152mm diameter was obtained from the reconstitute soils.

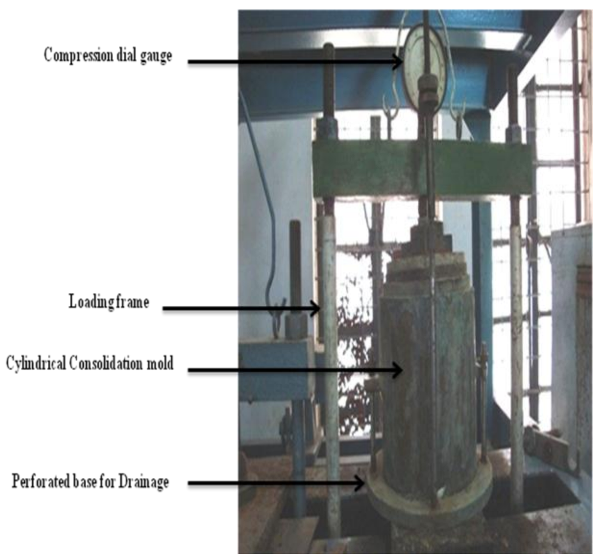

Figure 2 Arrangement for preparation of reconstituted soil samples

2.3 Selection of Overburden Pressure

Earlier, the minimum pre-consolidation pressure of 276kN/m^2 that make the clay soil just stiff enough and latter as the skill in testing it was found of 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, the reconstituted organic soil is fully decomposed with normally loaded state and shows highly compressible phenomena. The reconstituted soils were prepared in K_o-consolidation cell by a consolidation pressure of 60kN/m^2.

3. RESULTS AND DISCUSSIONS

This article deals with the presentation and discussions on the observed shear strength and compressibility properties at varying organic content (OC) through a series of laboratory tests. Based on the changing pattern of developed equations, the effect of OC on the engineering properties of reconstituted soil are highlighted and discussed in followings.

3.1 Strength Properties of Reconstituted Soil

The strength behaviour in terms of stress-strain behaviour and undrained shear strength at varying organic content of 5 to 35% has been established by conducting the unconfined compression test. The findings were presented and hence discussed in followings.

3.1.1 Stress-Strain Behaviour

The evaluated stress-strain behaviour at varying organic content is presented in Figure 3. The figure reveals that the stress was increased with the increase of axial strain and showing almost similar behaviour for the reconstituted soils at any organic contents. The figure also depicts that the strength decreases with the increase of organic contents.

3.1.2 Analysis of Undrained Shear Strength

The undrained shear strength (s_u) varies with the increase of organic contents as shown in Figure 4. Results showed that s_u has decreased significantly from 41.0 to 18.34kPa for the increase of organic content from 5 to 35%. Moreover, the s_u is a function of organic content 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 organic content.

s_u = -0.819*OC+36.35   for OC = 5 to 35%   (1)

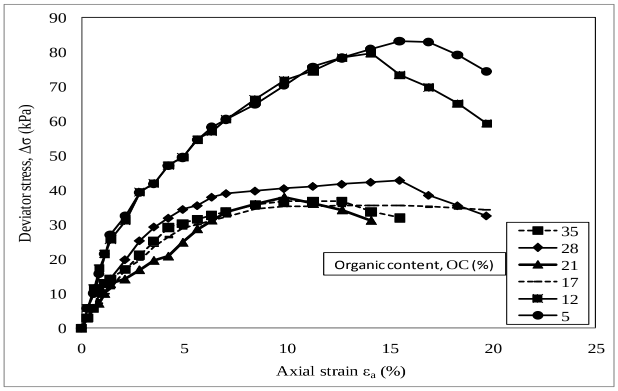

Figure 3 Deviator stress and axial strain of reconstituted soils at varying organic content

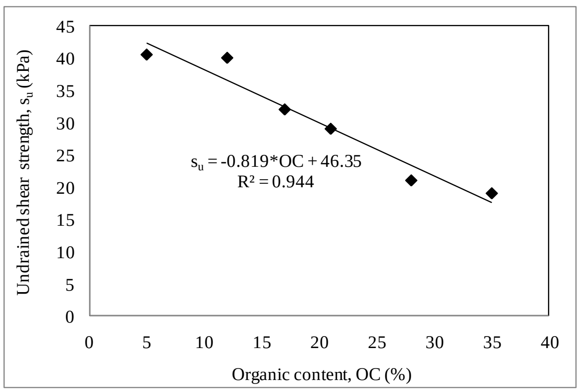

Figure 4 Variation of undrained shear strength with organic content of reconstituted soils

3.2 Compressibility Properties of Reconstituted Soil

The main purpose of consolidation tests 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 were obtained at varying organic contents of 5 to 35% in the reconstituted soils and hence discussed in followings.

3.2.1 Variation of Initial Void Ratio

The variation of initial void ratio (e_o) with the increase of organic content is shown in Figure 5. The figure shows that there is a definite increasing trend of e_o as a linear variation with the increase of organic contents. Here, e_o has increased significantly from 1.26 to 1.47 and 1.47 to 1.94 with the increase of organic contents from 5 to 17% and 17 to 35%, respectively. The finding is in good agreement with the general behavior of e_o versus organic contents. In organic soil the void space is more and filled up by air or/and water. Oades (1989) described that physical properties are changed significantly with organic contents. Moreover, the correlation between e_0 and OC can be expressed by the Equations 2(a) and 2(b).

e_o = 0.017*OC+ 1.165   for 5%≤ OC≤17%   (2 a)

e_o = 0.025*OC+ 1.054   for 17%≤ OC≤ 35%   (2 b)

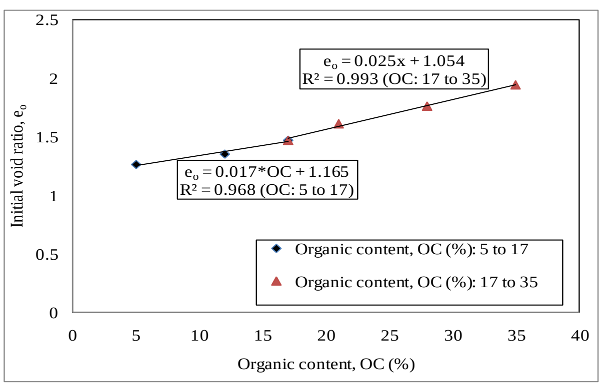

Figure 5 Variation of initial void ratio with organic content of reconstituted soil.

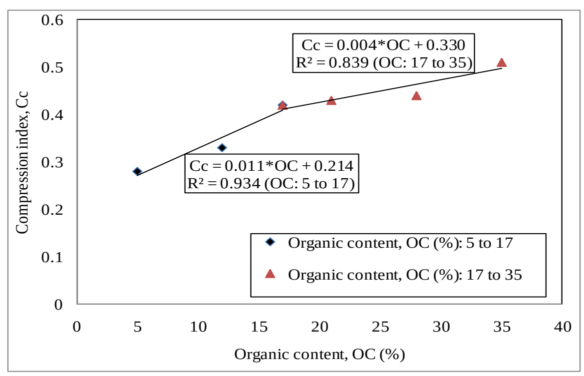

Figure 6 Variation of compression index with organic content of reconstituted soil

3.2.2 Analysis of Compression Index

The variation of compression index (C_c) with organic contents is evident in Figure 6. From the figure, it can be perceived that the values of C_c has increased significantly from 0.28 to 0.42 with the increase of organic content from 5 to 17% and the rate of increase was flatter. In addition, the figure also revealed that the C_c has increased significantly from 0.42 to 0.51 with the increase of organic content from 17 to 35% and the rate of increase was found as higher than the trend for the organic content of 5 to 17%. Here, it can be noted that the regression coefficient R^2=0.934 and 0.839 was found, for the organic content of 5 to 17% and 17 to 35%, respectively. Edil (1997) suggested that if the value of organic content lies in between 6 to 20%, it behaves of organic silts and clays. In addition, he also postulated that if the organic content lies in the rage of 21 to 74%, it behaves of clayey organic soil. The findings of the present study agree well with the postulation 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 of a soil mass depends on its composition and its pore spaces. It can be seen from here that, a correlation between c_c and OC is expressed by the Equations 3(a) and 3(b).

$$Cc = 0.011*OC + 0.214 \quad \text{for } 5\% \leq OC \leq 17\% \quad (3\text{ a})$$

$$Cc = 0.004*OC + 0.330 \quad \text{for } 17\% \leq OC \leq 35\% \quad (3\text{ b})$$

3.2.3 Analysis of Coefficient of Consolidation With Organic Content

The variation of coefficient of consolidation (C_v) with the increase of organic content as presented in Table 2 and also in Figure 7. The figure illustrates that there was an increasing trend of C_v with the increase of organic contents. The figure depicts that at a particular applied pressure, say 100kPa, the value of C_v has changed from 0.0037 to 0.0308 cm^2/sec for the increase of organic content from 5 to 35%. Similar increasing trend of C_v was also observed for other applied pressure ranging from 25 to 800kPa. Here, it can be concluded that the values of C_v was found as insignificant for low organic content and then significant for high organic content. 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.

Table 2 Coefficient of consolidation with organic content under applied pressure

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	0.0024	0.0028	0.0037	0.0070	0.0106	0.0117
12	0.0040	0.0047	0.0063	0.0109	0.0123	0.0188
17	0.0107	0.0117	0.0153	0.0217	0.0237	0.0248
21	0.0119	0.0132	0.0164	0.0226	0.0253	0.0300
28	0.0109	0.0123	0.0159	0.0221	0.0245	0.0281
35	0.0135	0.0169	0.0308	0.0465	0.0600	0.1200

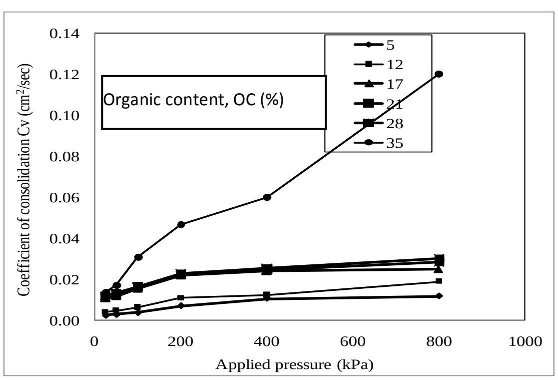

Figure 7 Variation of C_v with applied pressure at varying organic content

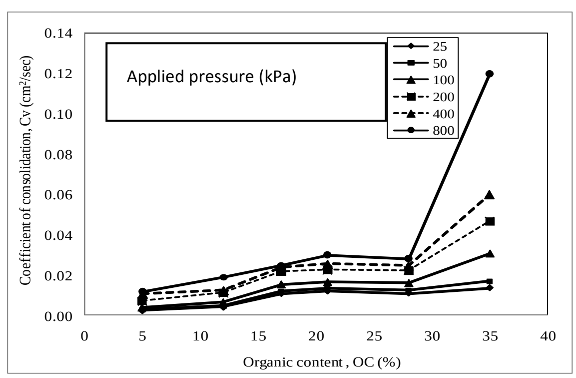

Figure 8 Variation of C_v with OC at varying applied pressure

3.2.4 Analysis of Coefficient of Consolidation With Applied Pressure

The variation of coefficient of consolidation (C_v) with the increase of applied pressure for different organic contents as depicted in Figure 8. The figure reveals that there was an increasing trend of C_v with the increase of applied pressure at varying organic content. For the organic content of 35%, the value of C_v increases from 0.0135 to 0.120cm^2/sec for the increase of applied pressure from 25 to 800kPa. Similar degree of increment was also observed for the other organic content.

Table 3 Primary consolidation period with the increase of organic content in reconstituted soil

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	9.67	8.23	6.2	3.25	2.16	1.95
12	5.68	4.89	3.62	2.09	1.86	1.21
17	2.13	1.95	1.49	1.05	0.96	0.92
21	1.92	1.73	1.39	1.01	0.9	0.76
28	2.09	1.85	1.43	1.03	0.93	0.81
35	1.69	1.35	0.74	0.49	0.38	0.19

3.2.5 Analysis of Primary Consolidation Period With Organic Content

The variation of primary consolidation period (t) with the variation of organic content at varying applied pressure is presented in Table 3 and also in Figure 9. The figure shows that there was a decreasing trend of t, for the increase of organic content at varying organic content. For the applied pressure 100kPa, the value of t, decreases from 6.20 to 0.74mins for the increase of organic contents of 5 to 35%. 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 organic content (Rafizul et al. 2010).

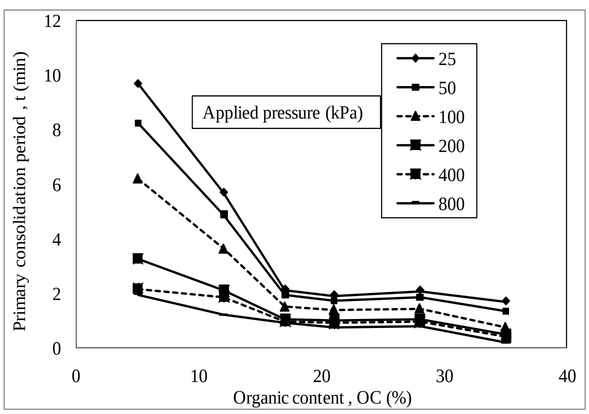

Figure 9 Variation of primary consolidation period with the increase of OC

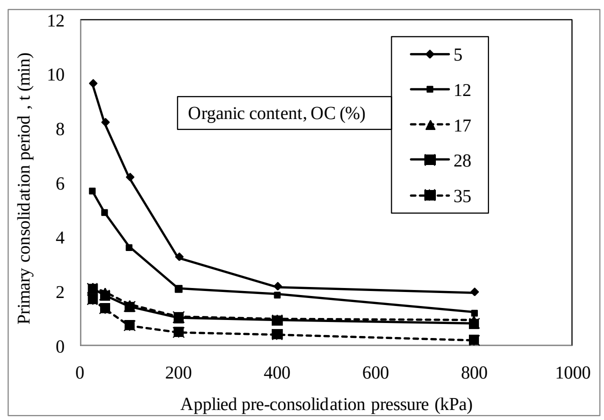

Figure 10 Variation of primary consolidation period at varying applied pressure

3.2.6 Analysis of Primary Consolidation Period With Applied Pressure

The values of t, of reconstituted soil with the increase of applied pressure as presented in Figure 10. 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 organic contents. For the organic contents of 35%, the value of t, decreases from 1.69 to 0.19 mins. for the increase of applied pressure from 25 to 800kPa. Similar degree of decrement is also observed for the other organic contents. From the figure it can be concluded that the values of t, was found significant at low organic content and then insignificant for the high organic content.

4. VERIFICATION AND COMPARISON

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 hence discussed in the following sections.

4.1 Undrained Shear Strength

The verification of undrained shear strength (s_u) at varying percentages of organic content of reconstituted soils as expressed in Equation 1 and also shown in Figure 11. The Figure 11 reveals that the proposed empirical equation (1), s_u decreases with the increase of organic content of the reconstituted soils. The results reported by Franklin et al. (1973) in case of reconstituted organic soil, was compared with the evaluated results in the present study and it was revealed that the s_u also decreases with the increase of organic content. The factors on which the magnitude of s_u depend 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 su for the reconstituted soils, undisturbed soil samples and publish results in case of organic clays decreases significantly from 41.0 to 35.5, 158.5 to 132.50 and 41.5 to 31.5kPa, respectively, with the increase of organic contents from 5 to 15%.

4.2 Initial Void Ratio

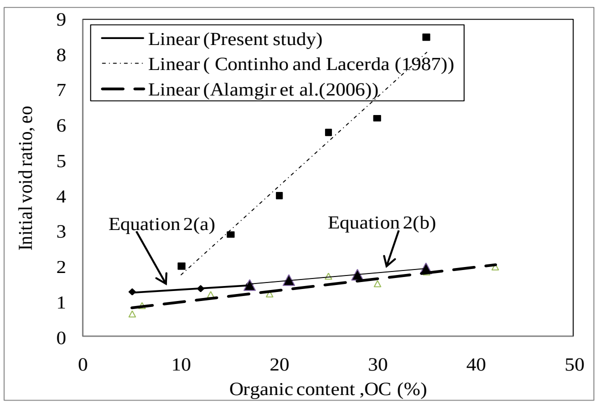

Figure 12 Comparison of e_0 obtained from the present study with other sources

4.3 Initial Void Ratio

Figure 12 represents the comparison of predicted results of initial void ratio (e_o) obtained from the proposed empirical equations (2a) and (2b) with the increase of organic contents was compared with those reported by Coutinho and Lacerda (1987). The values of e_o as reported by Coutinho and Lacerda (1987) increases with the increase of organic contents, 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 Coutinho and Lacerda (1987) 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 reconstituted organic soils, Coutinho and Lacerda (1987) and published results by Alamgir et al. (2006) increases significantly from 1.26 to 1.41, 1.0 to 2.90 and 0.646 to 1.195, respectively, with the increase of organic contents from 5 to 15%.

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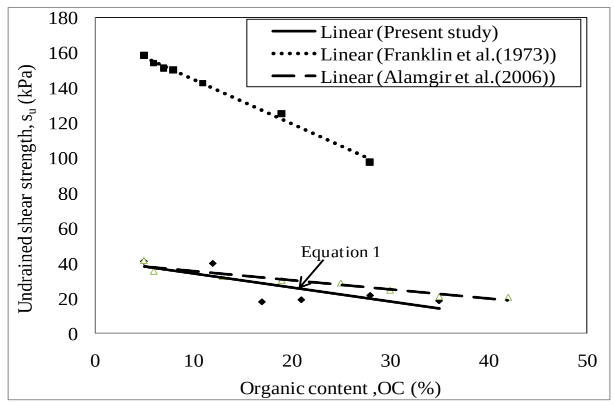

Figure 11 Comparison of s_u obtained from the present study with other sources

4.4 Compression Index

The compressibility properties, expressed by the parameter-compression index (C_c) was expressed an empirical equation of (3a) and (3b) and those of reported by Coutinho and Lacerda (1987) and the laboratory test results of reconstituted soil by Alamgir at al. (2006). Figure 13 illustrate the results for comparison of compression index versus organic contents relationship as proposed in the present study and the results reported by Coutinho and Lacerda (1987) and Alamgir et al. (2006). In the present study, the C_c increases with the increase of organic content of reconstituted soils and the rate of increase was found as flatter up to the organic content 17% and then the rate of increase was also higher in between the organic content of 17 to 35% and the finding revealed in good agreement with the general performance of compression index versus organic contents. In all cases, the C_c increases with the increase of organic content and the results were found in good agreement.

The results reported by Coutinho and Lacerda (1987) were found as higher than that of predicted by the present study and Alamgir et al. (2006). The increasing trend of C_c for the increase of organic contents was similar for both the cases and the prediction was very close to each other. From the figure, it can be seen that the value of C_c for the reconstituted organic soils, Coutinho and Lacerda (1987) and Alamgir et al. (2006) increases significantly from 0.19 to 0.40, 0.615 to 1.10 and 0.35 to 0.41, respectively, with the increase of organic contents from 5 to 15%. From the figure it was also observed that the increasing rate of C_c is 0.143 for the present study with the increase of organic contents from 5 to 15%, while the increasing rate of C_c was found 0.357 and 0.485, respectively, for the published results by Coutinho and Lacerda (1987) and Alamgir et al. (2006) with the same increase of organic contents. The increasing rate of C_c with organic content 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 reconstituted soil increases with the increase of organic content (Rafizul et al. 2009).

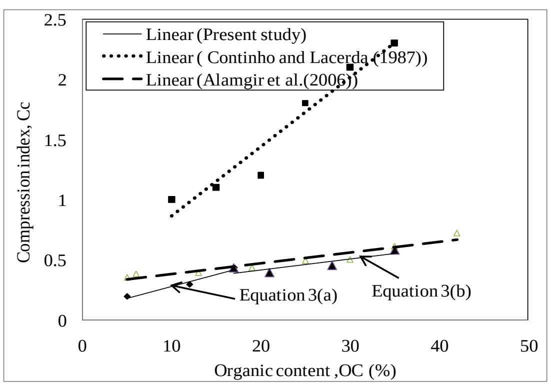

Figure 13 Comparison of C_c obtained from the present study with other sources

5. CONCLUSION

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

(i) The shear strength has decreased with the increase of organic content and the stress-strain diagram showing the almost similar behaviour for all the reconstituted soils.

(ii) Compression index has increased with the increase of organic content in reconstituted soils. Moreover, the coefficient of consolidation has increased for all applied loading conditions and increase of organic content of reconstituted soil. From consolidation test, it was concluded that the primary consolidation period has decreased for all applied loading conditions and with the increase of organic content.

(iii) Here, it can be concluded that the strength and compressibility properties of reconstituted soil at varying organic content 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.

(iv) Finally, based on observed results, it can be depicted that the findings in case of present study was well agreed with the results populated by the other researchers.

$$s_u = -0.819*OC+36.35 \quad \text{for } OC = 5 \text{ to } 35\% \quad (1)$$

$$e_o = 0.017*OC+1.165 \quad \text{for } 5\% \leq OC \leq 17\% \quad (2\text{ a})$$

$$e_o = 0.025*OC+1.054 \quad \text{for } 17\% \leq OC \leq 35\% \quad (2\text{ b})$$

$$Cc = 0.011*OC+0.214 \quad \text{for } 5\% \leq OC \leq 17\% \quad (3\text{ a})$$

$$Cc = 0.004*OC+0.330 \quad \text{for } 17\% \leq OC \leq 35\% \quad (3\text{ b})$$

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