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RESEARCH ARTICLE

Geotechnical Engineering

The microstructure and the behaviour of low organic clayey soils in Sri Lanka

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Abstract: Numerous studies focus on investigating organic soils with high organic content. However, only a limited amount of literature discusses the properties and behaviour of low organic content soils. Sri Lankan organic soil is an excellent example of a low organic content soil, demonstrating different behaviour from highly organic fibrous soil. Scanning electron microscope (SEM) images of Sri Lankan organic soil were studied to determine the reasons for these observed variations. Sri Lankan organic soils were observed to consist of highly decomposed organic matter in an amorphous state with higher proportions of mineral matter. The microstructure characteristics observed through SEM images mostly explained the variation of properties and behaviour of the Sri Lankan organic soil in contrast to highly organic fibrous soil. Correlations were also derived between properties of Sri Lankan organic soil and compared with similar relationships derived from other geological conditions. While some correlations derived in this study closely follow the relationships for other organic soils with similar microstructure characteristics, the acidity of the deposit resulted in different behaviour of a few correlations. This study improves the current knowledge of the effect of microstructure characteristics on the properties and behaviour of Sri Lankan low-organic clayey soils, which otherwise primarily depend on theories for highly organic peaty soils. Furthermore, the correlations derived and validated for low organic soils can be utilized in any organic clay deposit with similar microstructure characteristics.

Keywords: Correlations, engineering properties, low organic content, microstructure characteristics, peat, organic soils.

INTRODUCTION

Organic soil is formed by the accumulation of fully or partially decomposed organic matter under wet and anaerobic conditions. In engineering practice, these soils are often considered problematic soils due to high compressibility, low shear strength, localised sinking, slip failure, variability in material properties, difficulty in sampling, shrinkage, and change in material (chemical and biological) (Edil & Den Haan, 1994; Den Haan & Kruse, 2006; Haut, 2006). The physical and mechanical properties of organic soils are governed mainly by their microstructure (O'Kelly & Pichan, 2013). The degree of decomposition and the nature and type of plant components affect the microstructure of the organic soils. Because these factors vary greatly from one geological condition to another, the properties and behaviour of organic soil show significant variations across different deposits (Hobbs, 1986). According to Vasander (2014), there is a considerable variation between organic soil/peat deposits in temperate regions and tropical regions. Vasander (2014) further mentioned that differences

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could be noted in high-altitude deposits and low-altitude deposits, even within tropical regions. Therefore, the study of the geotechnical behaviour of Sri Lankan organic soils formed under tropical climatic conditions is very important.

Sri Lankan organic soil

Sri Lankan organic soil deposits can mainly be found in the Western and Southern coastal regions, where low-lying grounds with poor water drainage are a common topographical feature (Karunawardene, 2007; Ariyarathna *et al*., 2010). As shown in Figure 1, major rivers supply these low-lying grounds with flood water intermittently throughout the year, and these conditions provide an ideal environment for the accumulation and formation of organic deposits. In the analysis of organic soils in Sri Lanka, it was found that these deposits are mainly characterised by low organic content (less than 75%). In most classification systems including the ASTM system, organic soils with more than 75% organic content are referred to as peat and the soils with organic content of less than 75% are just called organic soils (Leong & Chin, 2000). Since the ASTM classification system is followed in the current study, the term organic soil will be used for Sri Lankan deposits in the text instead of peat. However, many studies do not discuss the organic content limit for defining inorganic soil. In the present study, soils with an organic content of less than 10% will be considered inorganic soils following the classification system defined by Kearns & Davidson (1983).

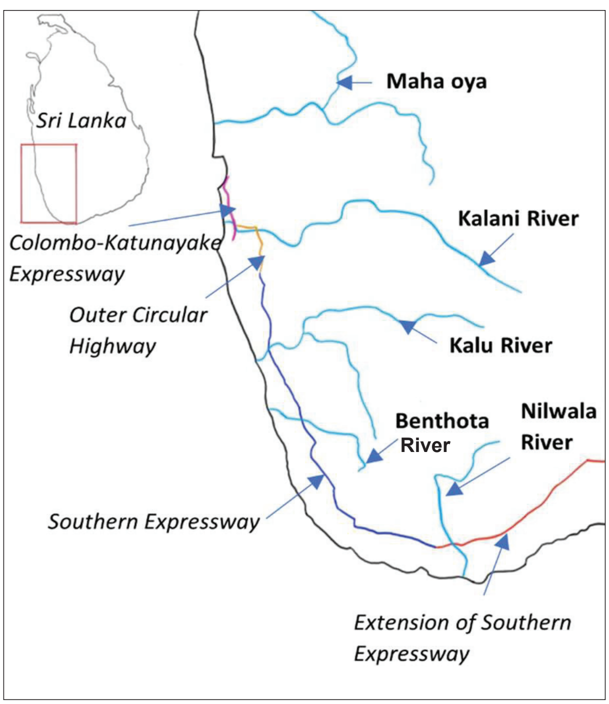

Figure 1: Rivers and expressway network in the Western and Southern coastal areas of Sri Lanka.

As mentioned above, the microstructure of organic soil mainly affects its physical and mechanical properties. There are only a limited number of studies conducted on the microstructure of Sri Lankan organic soil. Zimar *et al.* (2020) recently studied the microstructure of the organic soil samples recovered from the surface of the deposits. These surficial deposits consist of partially decomposed fibrous material and are mostly classified as Fibric to Hemic and contain a higher percentage of macropores (Zimar *et al.*, 2020). However, these organic soil deposits are about 15 m deep. To properly understand the behaviour of the entire organic soil deposit, the properties and behaviour of these deep layers should be studied. Therefore, in this research, the microstructure of the Sri Lankan organic soil recovered from more than 5 m below the surface was studied using Scanning Electron Microscope (SEM) images. These microstructure characteristics were then used to explain the variations observed in Sri Lankan organic soil in comparison to organic soils formed under different geological conditions.

MATERIALS AND METHODS

Data description

For the present research, three primary data sources were utilised. An extensive data set was obtained from the pre-construction and post-construction ground investigation data of the Colombo-Katunayake Expressway (CKE) project (obtained from the Road Development Authority of Sri Lanka). The other two sources were data from the literature and the results of laboratory tests conducted on undisturbed soil samples extracted in the present study. Data from the above sources were combined to create a database for the present study, including properties such as natural water content, initial void ratio, consistency limits, specific gravity, soil densities, compression indices, and settlement monitoring data.

Laboratory testing program

Several sections of the expressway network that connects the Western, Southern and Central provinces of Sri Lanka were built over the previously discussed organic soil deposits (Figure 1). For the present investigation, undisturbed organic soil samples from various depths up to 12 m were recovered in 8 locations along this expressway network. According to relevant ASTM standards, one-dimensional consolidation tests, moisture content tests, organic content tests, liquid limit tests, and specific gravity tests were conducted on these undisturbed soil samples.

Organic soil specimens with different organic contents obtained from the undisturbed soil samples were then used to determine the microstructure characteristics. SEM images of 1,000x, 2,000x, 5,000x and 10,000x magnifications and Energy-dispersive X-ray spectroscopy (EDAX) data were obtained for the samples mentioned above.

Comparison of Sri Lankan organic soil with other soil types

The index soil parameters of Sri Lankan organic soil obtained from the above data set were compared with similar properties of highly organic peaty and inorganic soils. The field settlement monitoring data of the CKE embankment was then used to determine the actual consolidation behaviour of Sri Lankan organic soil deposits. Finally, the compressibility properties obtained from the laboratory results were compared to highly organic peaty and inorganic soils. Numerous variations observed in the comparison of properties and behaviour of Sri Lankan organic soils were then explained using the microstructure characteristics determined by the SEM images.

As mentioned above, the laboratory test results obtained from this study were combined with similar properties available from the literature to form a wider database than previously existed. Empirical correlations between different properties in this database were derived, and a cross-validation analysis was carried out using Python programming language to validate these relationships statistically. These correlations were then compared with similar correlations from other geological conditions.

RESULTS AND DISCUSSION

Table 1 contains the properties of Sri Lankan organic soil compared with the properties of peat from the USA, Canada, and Malaysia (Adams, 1965; Mesri *et al*., 1997; Mesri & Ajlouni, 2007; Adnan & Wijeyesekara, 2008; Kazemian *et al*., 2011; Lee *et al*., 2015; Raghunandan & Anirudh, 2017), and mineral soil from the USA, Bangladesh, and India (Force, 1998; Santagata, 1999; Sridharan & Nagaraj, 2004; Vikas *et al*., 2015; Wasif *et al*., 2016). Soil properties given in Karunawardena (2007) are combined with the current data set to represent the properties of Sri Lankan organic soil. Here, the variations observed in the index soil parameters of Sri Lankan organic soil are noticeable.

Apart from the index soil parameters, noticeable variations in the consolidation behaviour of Sri Lankan organic soil were also observed. According to the literature, the primary consolidation of highly organic soils is completed almost immediately after loading (Mesri & Ajlouni, 2007). Hence, in peaty soils, the time taken for primary consolidation settlement to occur is considered insignificant. Figure 2 shows a typical embankment height *vs* settlement graph for an embankment on a Sri Lankan organic soil deposit, and upon the analysis of similar field settlement monitoring data of several embankments on Sri Lankan organic soil

Table 1: Comparison of index soil properties of Sri Lankan organic soils with similar properties of peat and inorganic soils from other locations

Property	Peat	Sri Lankan Organic Soil	Inorganic Clay
Natural water content (%)	623–1,340	200–800	25.2–43.4
Initial void ratio	10.1–23.5	2.0–8.0	0.64–1.24
Organic content (%)	90–96	20–50	4.4
Specific gravity	1.53–1.65	1.5–2.2	2.77–2.81
Liquid limit		100–400 (Present study)	30–47
Plastic limit		50–250 (Present study)	11.7–25.0

deposits, it was discovered that completion of primary consolidation takes about 6 to 8 months on average. This implies that the time taken for the completion of primary consolidation is also important in these deposits, unlike other highly organic soils. Additionally, a considerable amount of secondary consolidation settlement seems to continue after the primary consolidation settlement is over.

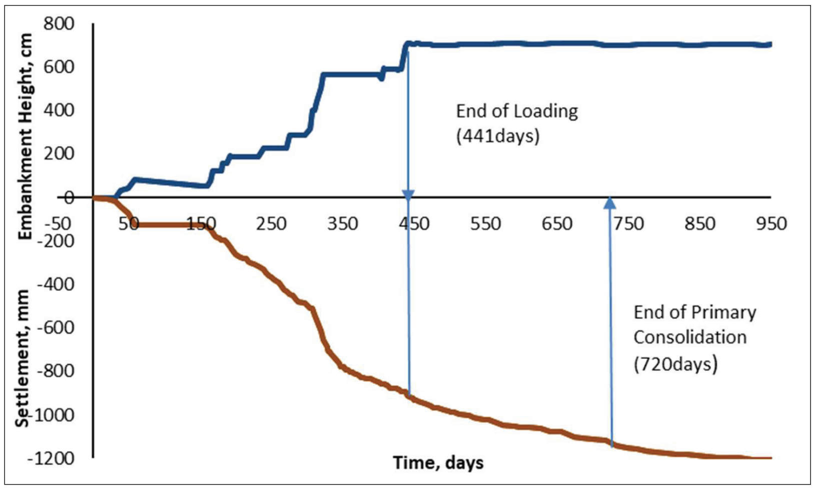

Figure 2: End of loading vs end of primary consolidation of Sri Lankan organic soil deposits

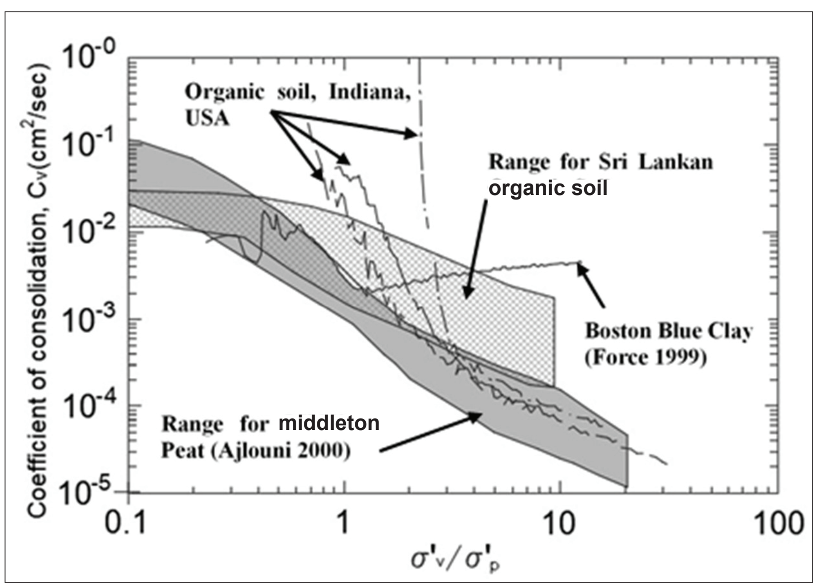

Figure 3: Variation of C_v with normalized effective vertical stress [Source: Santagata *et al*. (2008)]

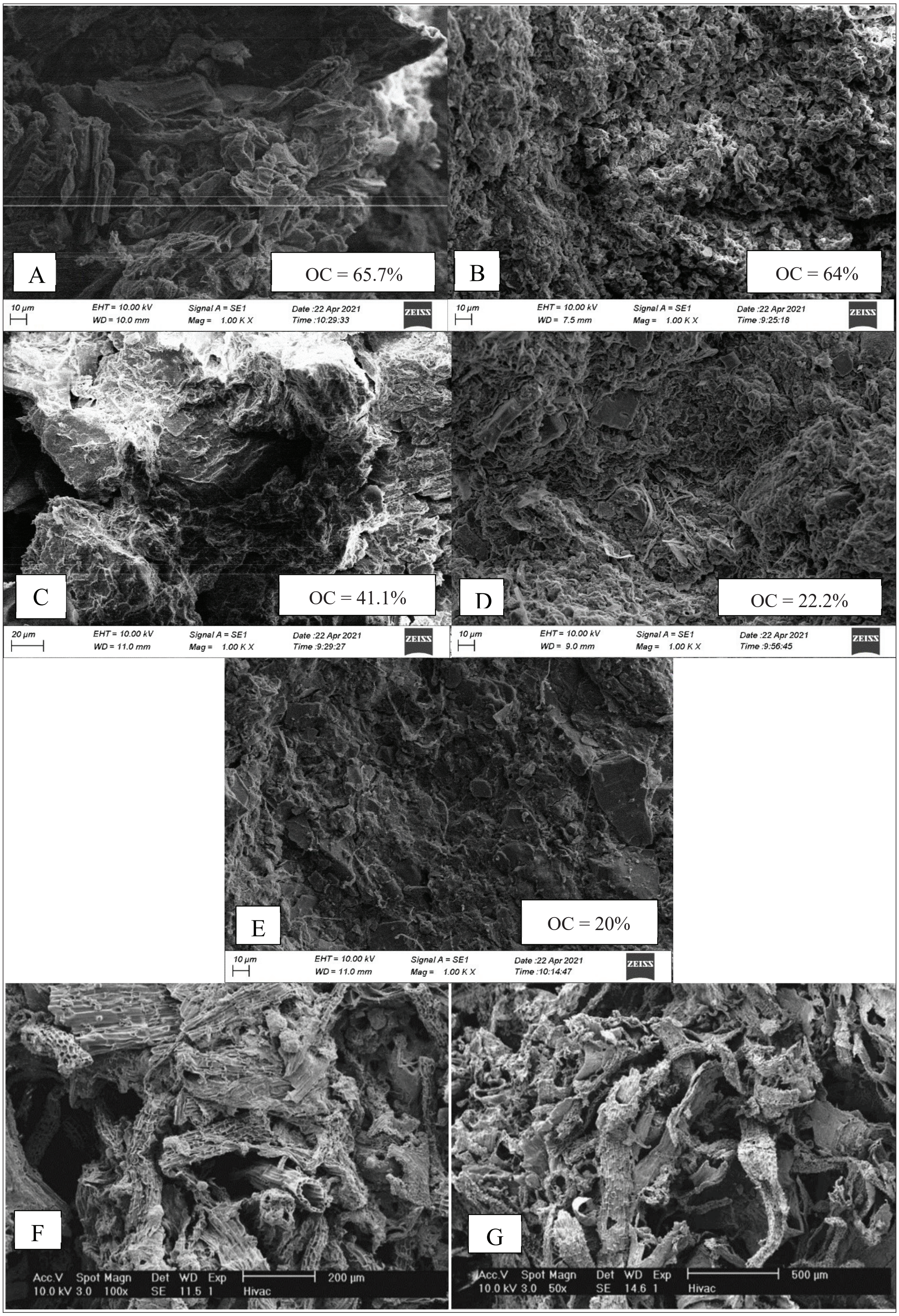

Figure 4: A to E: SEM images of Sri Lankan organic soil specimens; F and G: SEM images of James Bay Peat (Mesri & Ajlouni, 2007)

The variation of coefficient of consolidation (C_v) with normalised effective overburden pressure (σ'_v/σ'_p) for highly organic Middleton peat and inorganic Boston Blue clay in Figure 3 was developed by Santagata *et al*. (2008). A similar variation between C_v vs σ'_v/σ'_p for Sri Lankan organic soil obtained in the present study is also included in Figure 3 for comparison. The effective overburden pressure (σ'_v) was normalised with respect to the preconsolidation pressure (σ'_p) for reasonable comparison among different soil types and samples. It was observed that the C_v of Sri Lankan organic soil remains unchanged in the overconsolidated region ($\sigma'_v/\sigma'_p < 1$) and starts to slowly decrease around $\sigma'_v/\sigma'_p = 1$. In comparison, the C_v of Middleton peat decreases considerably in all aforementioned ranges of σ'_v/σ'_p.

To clarify the above-observed variations in the properties and behaviour of Sri Lankan organic soil, its microstructure characteristics were studied using SEM images.

Microstructure characteristics of Sri Lankan organic soil

Figures 4A to 4E carry SEM images of organic soil samples of Sri Lankan deposits extracted in the present study. When compared to the microstructure of uncompressed surficial soil, the compressed soil from deep layers of the deposit contains a lesser amount of macropores. Figures 4A and 4B illustrate microstructures of non-surficial specimens with comparatively high organic contents. Though some partially decomposed fibrous material can be observed in these two specimens, the structure is mainly comprised of highly decomposed amorphous materials, and a visible cellular structure of organic matter is absent. Despite the lack of macropores, a higher number of micropores can be identified. However, this observed amount of macro and micropores is remarkably low when compared with the microstructure of highly organic fibrous peat such as James Bay peat (Mesri & Ajlouni, 2007) with highly perforated hollow fibrous material (Figures 4F and 4G). In the medium to low organic content specimens of Sri Lankan organic soil (Figures 4C to 4E), the microstructure comprises a small proportion of highly decomposed organic material and mineral soil grains, as clearly visible in the SEM images. These specimens include only a limited number of micropores except in Figures 4C, where voids are observed between the large mineral grains. The following sections discuss the effect of these microstructure characteristics on the index soil parameters, consolidation properties and behaviour.

Effect of microstructure characteristics on index soil parameters

The SEM images demonstrate that most Sri Lankan organic soil has a lesser amount of both macro and micropores when compared to James Bay peat (Figures 4F and 4G) (Mesri & Ajlouni, 2007). It is also noted that, unlike the James Bay peat, no proper cellular structure can be identified in the microstructure of Sri Lankan organic soil. This lack of pore spaces and cellular structure explains the lower levels of natural water content (w_0) and initial void ratio (e_0) of Sri Lankan organic soil when compared to highly organic fibrous peat (Table 1). The specimens with lower organic contents (OC) (Figures 4 C-F) have visible mineral particles and a faint amount of decomposed organic matter. Such specimens are associated with the high specific gravity (G_s) values recorded in Table 1. In contrast, occasional specimens with high organic content and partially decomposed organic matter contribute to the lower specific gravity values in the Sri Lankan organic soil. On the other hand, the microstructure of highly organic peat (Figures 4F and 4G) consists of slightly decomposed organic matter. The specific gravity of this organic matter is usually in the range of 1.4 to 1.5 (O'Kelly & Pichan, 2013). With the lack of mineral particles in their microstructure (Mesri & Ajlouni, 2007), these highly organic peats usually have very low specific gravity values, as mentioned in Table 1.

Generally, the liquid limit (LL) and plastic limit (PL) values are not considered important in highly organic fibrous peat above H_3 in the von Post humification scale, as they cannot be accurately determined due to the lack of required minimum mineral soil proportion and difficulty of testing (Hobbs, 1986). However, when comparing the Sri Lankan organic soils with such fibrous soils, the mineral portion is significantly high. The EDAX analysis showed that the Sri Lankan organic clayey samples contained Aluminium (12% - 18% by weight), Silicon (16% - 22% by weight), and Iron (5% - 7% by weight), among other elements such as magnesium and potassium in lower percentages. These elements account for more than 50% of the samples by weight. Hence, when discussing the index soil properties of Sri Lankan organic soil, consistency limits cannot be disregarded.

Effect of microstructure characteristics on compressibility properties and behaviour of Sri Lankan organic soil

In the previous section, the effect of microstructure characteristics on the index soil properties was discussed.

It is also important to understand the effect of these microstructure characteristics on the compressibility properties and behaviour of the organic soil. Figure 3 contains the variation of the coefficient of consolidation (C_v) with the normalised effective vertical stress for different soil types. Santagata *et al.* (2008) explained the significant decrease observed in C_v for peat and organic soils in the normally consolidated (NC) region as a result of the subsequent reduction in hydraulic conductivity (k_v) with the increasing stress level offsetting the increase in constrained modulus ($D = 1/m_v$) and vice versa for Boston Blue Clay in which the C_v gradually increases in the NC region. The C_v variation of the Sri Lankan organic soil falls in between the above-mentioned highly organic soil and inorganic clay. This demonstrates that, compared to the highly organic soils, the reduction in k_v does not significantly offset the increase in constrained modules in Sri Lankan organic soil. The presence of high mineral content can be identified as the main reason for the above observations. Furthermore, in the overconsolidated region, the proportion of macropores in fibrous peat is greater than in amorphous organic soil, as illustrated in the above SEM images (Figure 4). In this region, the higher proportion of macropores in fibrous peat facilitates faster water drainage and hence, higher C_v, whereas in amorphous Sri Lankan organic soil, the limited number of macropores blocks easy dissipation of excess pore water, resulting in lower C_v values than for fibrous peat. Hence, constant C_v values for Sri Lankan organic soil can be expected up to $\sigma'_v/\sigma'_p = 1$. In the normally consolidated region, the reduction of C_v for Sri Lankan organic soil is less than that for fibrous peat. The inability of Sri Lankan amorphous peat towards further compression due to a lack of macropores and fibrous organic matter has resulted in the C_v variation observed in Figure 3.

According to Mesri and Ajlouni (2007), the secondary compression component of fibrous peat is more significant than the primary consolidation as it completes almost immediately after loading. As evident from Figures 4F and 4G, the highly organic fibrous peat, has a larger proportion of macropores in its microstructure. These macropores, combined with the undecomposed porous fibrous organic material, facilitate easy and rapid dissipation of pore water upon loading. Hence, the primary consolidation of these soils happens almost immediately after loading. In contrast, upon analysis of settlement monitoring data in the Colombo-Katunayake Expressway project to determine the end of primary consolidation using the Asaoka method (Asaoka, 1978), it was found that it takes about 6 to 8 months for completion of primary consolidation (Figure 2) in Sri Lankan organic soil deposits. Zimar *et al*. (2020) claimed that the surficial deposits of the Sri Lankan organic soil have a considerable amount of macropores and micropores, and the oedometer tests reported achieving the end of primary consolidation in a short period. However, even these proportions of pores are considerably lower than that reported for highly organic fibrous peat. Furthermore, when the deep layers of organic soils are considered, the proportion of both macropores and micropores is reduced (Figure 4). This absence of enough macropores reduces the rate of dissipation of pore water and consequently increases the time taken to achieve the end of primary consolidation. Therefore, unlike highly organic fibrous deposits, Sri Lankan organic deposits take a considerably longer time to achieve primary consolidation under an embankment load.

Validity of commonly used empirical correlations for organic soils with low organic content.

Empirical correlations can be used to determine the engineering parameters of organic soils with considerable accuracy without the need to conduct expensive ground investigations. Numerous such correlations reported in the literature have been derived for different geological conditions across the world. It was observed in the previous sections that the Sri Lankan organic soils are significantly different from the highly organic soil deposits. Thus, it is required to compare the already existing correlations for organic soils to check whether they are valid for low organic soil deposits in Sri Lanka and whether it is required to have a separate set of correlations derived for such soils. The present study used data from the literature, data from pre-construction and post-construction ground investigation reports of the CKE project (obtained from RDA), and data from laboratory tests conducted on undisturbed soil samples (present study).

Rather than using simple curve fitting, the cross-validation analysis technique was applied using the Python programming language to check the most suitable degree of the polynomial of the correlations. Each correlation was then compared with similar correlations reported in the literature to validate the derived correlations and to check the effects of microstructure characteristics on the correlations. Figures 5 -12 contain the comparison of correlations derived in the present study with similar correlations available in the literature. Figures 5, 6, 8, 9, 10, 11, and 12 were reproduced from Hobbs (1986), whereas Figure 7 was replicated from Huat *et al*. (2007). The correlations obtained in the current study were then plotted on these reproduced graphs for comparison.

Correlations that depend on the microstructure characteristics and type of deposit

The microstructure of the Sri Lankan organic soil is mostly amorphous with no traces of a proper cellular structure and most voids are filled with mineral particles. Therefore, the w_0, e_0, LL, and C_C values were low compared to highly organic soils. This is reflected in Figures 5 -12 as most of the data points representing Sri Lankan organic soils fall in lower w_0, e_0, LL, and C_C ranges. Figures 5 and 6 represent the comparison of the correlation between w_0 vs e_0 and C_C vs w_0, respectively. The correlations derived in the present study between the above parameters are given in equations 1 and 2.

$$e_0 = 0.0156\, w_0 + 0.942 \quad ...(1)$$

$$c_c = 0.0078\, w_0 \quad ...(2)$$

It can be observed in Figures 5 and 6 that the correlation derived in the present study falls among the correlations for organic soils with similar conditions, such as amorphous microstructure and high mineral content. Hobbs (1986) stated that the UK Fen peat has an amorphous microstructure, and Cook (1956) mentioned that most of the peat samples used in his study were naturally mixed with contaminants (mineral soil). Lea & Brawner (1963), Miyakawa (1960), and Mickleborough (1961) did not specify the type of peat that mostly contributed to the derivation of the correlation. Furthermore, in the above two comparisons, the correlation derived for the present study shows clear variation from the correlation for highly organic fibrous soils such as Quebec peat (Brochu & Pare, 1964) and Welsh bog peat (Hobbs, 1986).

There is an excess scatter between the correlations for different organic soil deposits in Figure 6. This is mainly due to the differences in the amounts of water retained (water-holding ability) in the following states: (i) intracellular water, (ii) interparticle water held by capillary force, and (iii) adsorbed water (Ramanov, 1968; Hayward & Clymo, 1982; Hobbs, 1986; Farrell, 2012; O'Kelly, 2014). Only the water in states (i) and (ii) will be dissipated during consolidation. Therefore, the consolidation of soil by expelling water does not entirely depend on the total amount of moisture but depends mostly on the amount of water held in each state (Hobbs, 1986). When oven drying at 60 °C to determine w_0, a small quantity of water in conditions (i) and (ii) above will not be entirely removed (O'Kelly, 2004). On the other hand, oven drying at 105 °C to determine w_0 will cause the fibrous material to char, eventually overpredicting the w_0 (O'Kelly, 2004). Therefore, the w_0 determined at 60 °C and 105 °C can have different values and slightly misinterpret the definite amount of water held in each state. This can be considered a major contributor to the excess data scatter and significant variation between correlations observed in Figure 6.

As evident by the above observations, the correlations derived in the present study (equations 1 and 2) may be successfully used in a low organic content soil with amorphous microstructure and high mineral content.

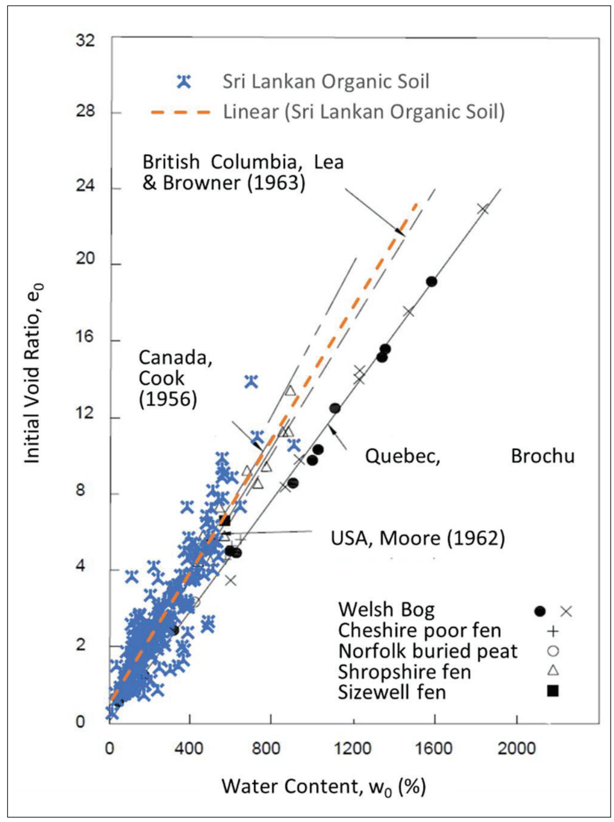

Figure 5: Comparison of correlation between w_0 and e_0

The correlation between ρ_d and w_0 for Sri Lankan organic soil is given in equation (3) and illustrated in Figure 7, along with some correlations from different geological conditions. The relationships obtained by Den Haan (1997) and Huat *et al*. (2007) are given in equations (4) and (5) respectively for comparison.

$$\rho_d = 33.462\, w_0^{-0.842} \quad ...(3)$$

$$\rho_d = 35.075\, w_0^{-0.856} \quad ...(4)$$

$$\rho_d = 24.422\, w_0^{-0.804} \quad ...(5)$$

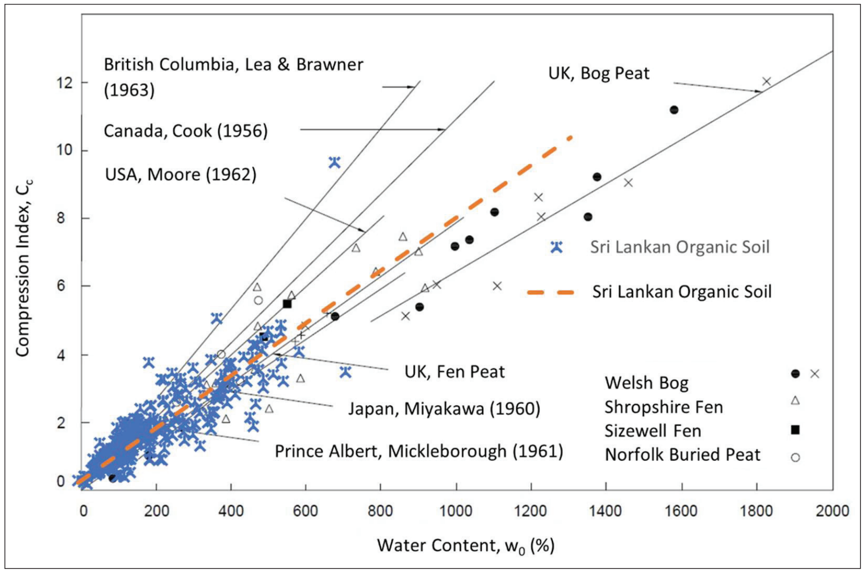

Figure 6: Comparison of the correlation between C_c and w_0

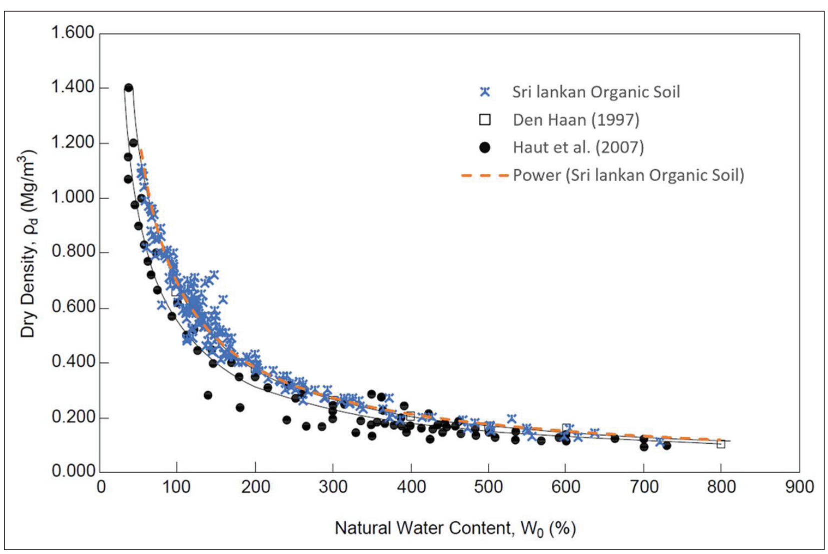

Figure 7: Comparison of correlation between ρ_d and w_0

Den Haan (1997) observed that the ρ_d *vs* w_0 correlation does not vary much for different organic contents and specific gravity values. According to Figure 7, data from the present study follow a trend similar to the relationship proposed by Den Haan (1997) which was derived based on organic soil with low organic content mixed with impurities. The relationship given by Huat *et al*. (2007) falls below the regression for Den Haan (1997) and the present study, which depicts that the dry densities of the local soil deposits are slightly high. The organic content of the samples that were considered by Huat *et al*. (2007) is in the range of 70% - 88%, with an average specific gravity of 1.5. As evident by the SEM images in Figure 2, Sri Lankan organic soil has decomposed organic matter with fewer macro and micropores. This lack of pores, combined with the presence of a higher percentage of mineral particles has resulted in higher dry density values when compared to soils with high organic content. The correlation derived in this study (equation 3) might be used for organic soils with low organic content and similar microstructure characteristics.

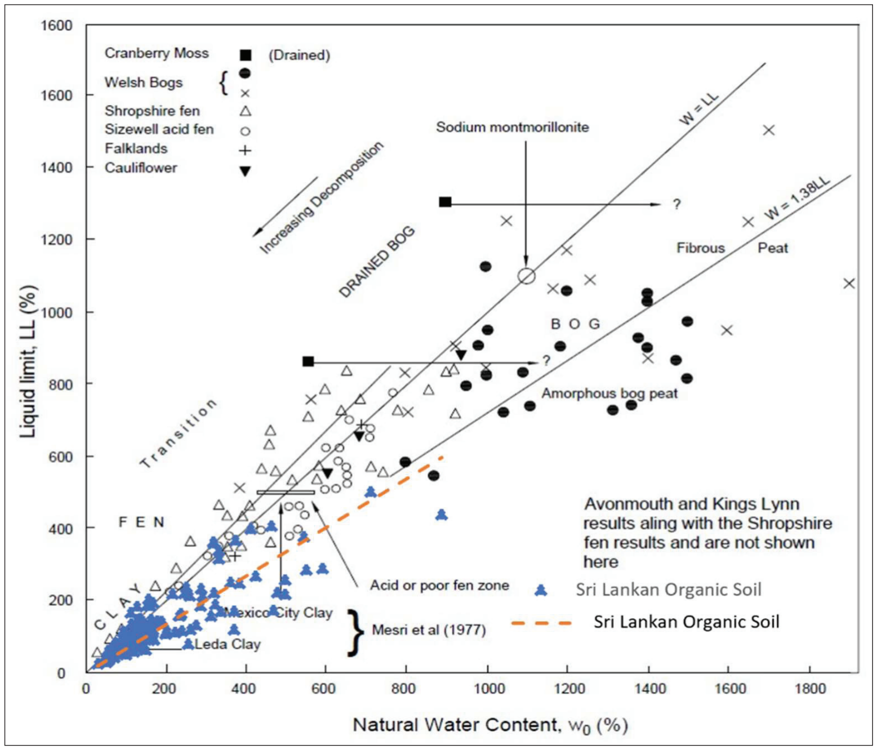

Figure 8: Comparison of correlation between w_0 and L_L

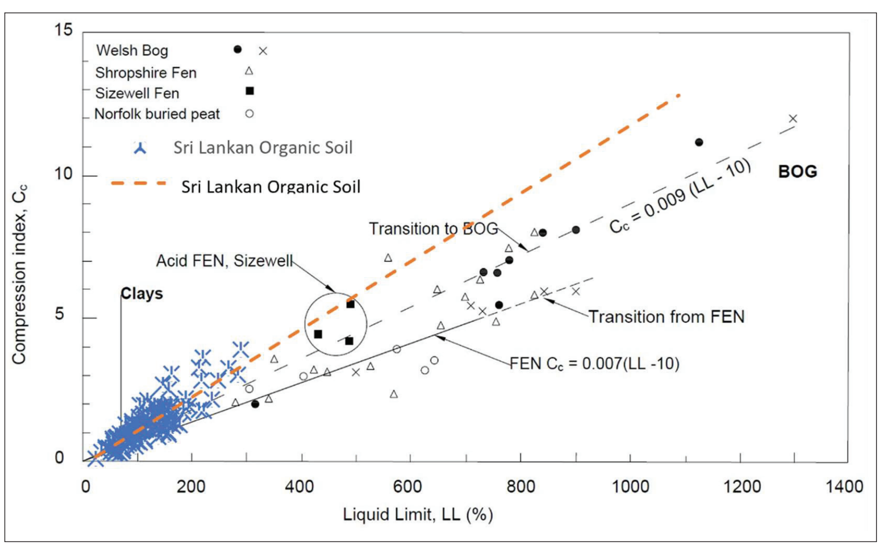

Figure 9: Comparison of correlation between C_c and L_L

Special observations

In the above section, it was observed that the correlations for Sri Lankan organic soils follow trends similar to other amorphous organic soils. However, in Figures 8 and 9, Sri Lankan organic soil follows different trends.

Organic soils with high mineral content and amorphous structure have LL closer to their w_0 as the interparticle voids are filled with liquid clay (Hobbs, 1986). This is shown by the correlation of w_0 = LL obtained for amorphous UK Fen peat and NC clay in Figure 8. In highly organic soils such as UK Bog peat, the interparticle voids are filled with water. Therefore, their LL is less than the w_0. Even though having an amorphous structure, organic soil deposits such as acidic amorphous peat in Sizewell, acidic amorphous UK bog peat, and acidic organic soil deposits in Sri Lanka (pH = 5.0) (Dissanayake *et al*., 1982; Dissanayake, 1987; Karunawardena, 2007)) has LL lower than its w_0 (Figure 8). Hobbs (1986) proposed that the acidity in organic soil reduces its cation exchangeability. According to Yilmaz (2004), cation exchangeability is directly proportional to LL. Thus, these acidic amorphous organic soils have lower LL values for a given w_0 than their non-acidic counterparts. This behaviour is further observed in Figure 9, where local organic soil and Sizewell peat have a lower LL value than the other amorphous organic soils for a given C_C value. Therefore, the correlations derived in the present study between w_0 vs LL and C_C vs LL, given in equations 6 and 7, respectively, may be used for acidic organic soils with similar microstructure characteristics.

$$w_0 = 1.5124\,LL \quad ...(6)$$

$$C_c = 0.0118\,(LL - 7.31) \quad ...(7)$$

Correlations that are independent of the microstructure characteristics and type of deposit

Correlations discussed in the previous sections showed behavioural differences depending on their microstructure characteristics. However, when comparing correlations given in Figures 10, 11, and 12, such variations were not observed.

Generally, the recompression index of an organic soil sample is 10% of its compression index value, which may vary within a range of 5% to 20%. The correlation developed for Sri Lankan organic soil given in equation 8 was compared with the relationship in Hobbs (1986), as shown in Figure 10. It was observed that the data points relevant to different types of organic soils strictly satisfy one relationship. Hobbs (1986) then concluded that the correlation between C_c and C_r is not affected by morphological differences between the two deposits. However, the type of testing may affect the relationship. The variation between the local correlation and the relationship suggested by Hobbs (1986) may be due to differences in the methods of testing.

$$C_r = 0.0987\,C_c \quad ...(8)$$

Generally, organic soil is undersaturated due to the presence of gas emitted from humification. Its bulk density (ρ) is less than mineral soils and is related to its organic content (which influences the specific gravity (G_S)), natural water content (w_0) and degree of saturation (S_r) as evidenced by equation (9) (Hobbs, 1986).

$$\rho = \left(\frac{1+w_0}{S_r + G_S\,w_0}\right) G_s S_r \gamma_w \quad ...(9)$$

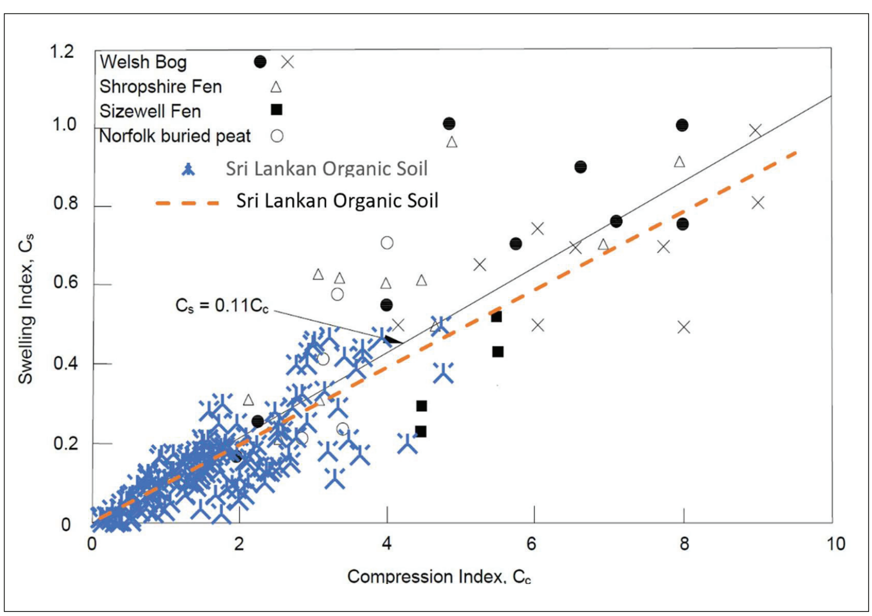

Figure 10: Comparison of the correlation between C_c and C_r

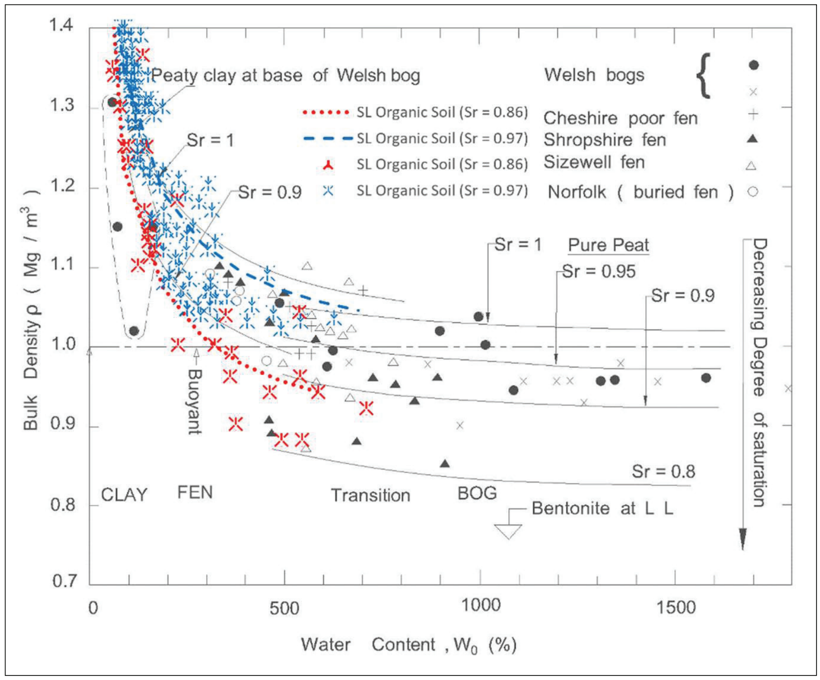

Figure 11: Comparison of correlation between ρ and w_0

The data available for Sri Lankan organic soil was divided into two ranges depending on the S_r values. These two sets of data were then used to graphically represent equation 9 in Figure 11. It is observed that the curves representing the Sri Lankan organic soil deposits follow the curves for other organic soils drawn using equation 9 but with different G_s and S_r values. Such evidence suggests that equation 9 can be used regardless of the difference in the microstructure characteristics. The inconsistency in degree saturations of different samples at higher water contents causes the excessive scatter of data points observed in Figugre 11.

The correlation between e_0 and C_c for Sri Lankan organic soil is given in equation 10 and represented in Figure 12. Here, Hobbs (1986) only defines one correlation for both amorphous and fibrous organic soil, indicating that the correlation is valid for deposits with different microstructure characteristics. The correlation derived in the present study follows a similar trend as the correlation proposed by Hobbs (1986). Therefore, the correlation proposed in the present study may be used for a deposit with similar microstructure characteristics.

$$C_c = 0.4272\, e_0 - 0.0536 \qquad \text{...(10)}$$

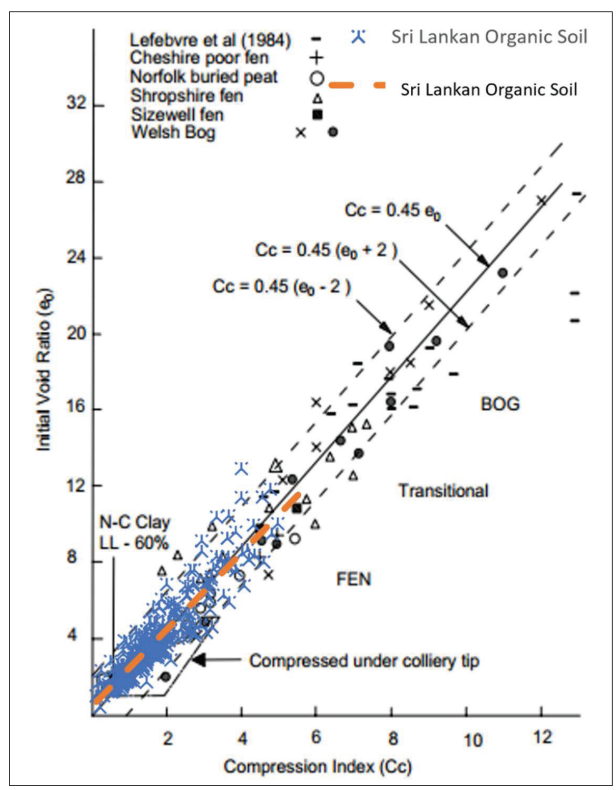

Figure 12: Comparison of correlation between e_0 and C_c

CONCLUSIONS

It was observed that the soil properties and compressibility behaviour of Sri Lankan low-organic clayey soils differ from the highly organic soils in other parts of the world. Thus, in this study, the microstructure of Sri Lankan organic soil was evaluated to understand the observed variations. The microstructure analysis through SEM images showed that the Sri Lankan organic soil has an amorphous microstructure that contains slightly to highly decomposed organic matter and a considerable proportion of mineral particles. As a result, the w_0, e_0, LL, C_c, and G_s values considerably vary from those reported for highly organic soils. Due to the considerable amounts of mineral matter in the Sri Lankan organic soil, consistency limits can be considered a critical soil parameter, contrary to the highly organic peaty soils, where consistency limits are often disregarded. The lack of macropores observed in the microstructure combined with low amounts of highly compressible organic matter resulted in reduced rates of pore water dissipation and, hence, slow rates of primary consolidation. Due to these observed differences in properties and behaviour of Sri Lankan organic soil deposits, it was required to derive and update correlations between its properties. It was observed that the e_0 vs w_0, w_0 vs C_c, and ρ_d vs w_0 correlations for Sri Lankan organic soil agree well with the relationships for other amorphous organic soil types worldwide. In contrast, correlations such as C_c vs C_r, ρ vs w_0 and e_0 vs C_c do not vary depending on the type of deposit or microstructure. Due to the acidity of the Sri Lankan organic soil, the correlations related to liquid limits demonstrated slightly different behaviour from the non-acidic amorphous soils. The correlations suggested in this study can be used to predict soil properties in any low organic clayey deposits with similar microstructures. In conclusion, this study highlights the importance of understanding the effect of microstructure characteristics on the engineering behaviour of low organic clayey soil.

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