Civil Engineering Beyond Limits 4 (2022) 1731
Civil Engineering Beyond Limits
journal home: www.acapublishing.com/journals/1/cebel

Research Article

Compressibility Characteristics of Southwest Bangladesh Organic Soil Stabilized with Sand Column

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Keywords

Compressibility,
Organic soil,
Sand column, Stabilization,
Consolidation test.

Abstract

This research investigates the characteristics of organic soil from southwest Bangladesh and the influence of sand columns on the void ratio (V_0), consolidation coefficient (C_C), and volume compressibility (C_V) of stabilized soil. On the laboratory scale, cylindrical columns of varying diameters were extruded through organic soil samples and stabilized with 3%, 5%, 8%, 10%, and 23% sand in various geometries. After evaluating the engineering parameters, a series of 1-D consolidation experiments were performed to assess the effect of the sand column on stabilized soil samples. According to the Unified Soil Classification System (USCS), the organic soil used in this research is defined as organic silt (OH). According to the findings, the organic soil has a liquid limit of 118% and its particles pass through a 0.075 mm sieve. By incorporating sand columns, rapid consolidation was obtained, and the sample containing 77% organic soil and 23% sand exhibited the best consistent compressibility features. The effects of column number and geometry on the compressibility behavior of organic soil samples were also examined. The results for the 77% organic soil and 23% sand in a single column and the 82% organic soil and 8% sand in a double column are nearly identical. This study reveals that stabilization with sand columns may significantly enhance the physical and consolidation behavior of organic soil in southwest Bangladesh.

1. Introduction

Every geographical location on the planet has peatland, which covers around 2.83% of the planet's geographical area. According to Xu et al., a significant portion of the earth's natural peat land is located in Asia (38.1%) and North America (31.6%), mainly in Canada and Alaska. Regarding percentages, Europe accounts for 12.5%, South America for 11.5%, Africa for 4.4%, and Australasia and Oceania for 1.6% [1]. Bangladesh is a South Asian country with a high population density, low-lying, and primarily riverine terrain with a coastline that extends 580 km along the island's northern part in the Bay of Bengal. One of the most significant and troublesome soils in Bangladesh is a peatland. In Bangladesh, approximately 0.70 million hectares, or 4.8% of the country's land area, are covered with peat soil [2]. Peat soils were present in the low-lying sections of the Gopalganj-Khulna region, as well as more locally in certain areas of the eastern Surma-Kushiyara floodplain, the adjacent northern and eastern Piedmont plains, the Ganges Rivers, and tidal floodplains, and intermittently in a few locations in Bangladesh [3]. The Hakaluki series, Harta series, Tarala series, Mohangonj series, Rajoir series, Sarail series, Satgaon series, Satla series, and Juri series are nine different types of soil series that belong to the peat soils of Bangladesh, according to the USDA's categorization of soils. These soil series have a variety of horizon-related distinguishing features [4]. However, the Khulna Beel's organic layers range from fibrous material to sapric material from location to location, making it difficult to categorize. In Bangladesh, little effort has been made to determine the kind and stage of decomposition of organic matter [5]. The Bengal Basin's peat is found at relatively modest depths and reaches the surface of the ground. In terms of geologic background, the deposits' highest depth is just around 15 m below the surface, which is fairly shallow and suggests that they were deposited relatively recently. The center portions of the basin, seen in Figure 1 and, where extensive marshes known as haors are present, are where the peat deposits are concentrated [6]. The peat-dominated area of Bangladesh is also mentioned in Table 1.

Table 1. Peat-dominated region of Bangladesh in the Bengal Basin [2]

No	Area	District
1)	Hakaluki Haor	Moulvibazar and Sylhet
2)	Baggia Chanda	Gopalganj
3)	4000 Hectre,Bijoynagar	Brahmanbaria
4)	Kola Mouza	Khulna
5)	Ajmirigonj	Habigonj

The aforementioned table also demonstrated that peat-dominated regions, which still consist of depressions or basins under the current conditions, have been mostly located in Bangladesh's middle Bengal Basin.

Peat deposits are produced by the deposition and fossilization of fragmented, partially degraded plant remnants [7]. Peat is often defined as a geo-technically difficult soil and described as a woody organic soft soil. Several interest groups commonly use their definitions because there is no singular definite definition of peat. As an illustration, Burton and Hodgson described peat as soil having at least 50% organic content, which is assessed by measuring the ash left after burning [8]. Joosten and Clarke defined peat as a sedentarily accumulated substance with a minimum of 30% (dry mass) of dead organic matter [9]. According to Andriesse, Islam and Hashim, peat has a very poor bearing capacity that is impacted by incompletely decomposed woody components and excessive in-situ water depth. Organic soils are often weak in their natural forms due to their ability to hold significant water levels [10-11]. However, consolidation can result in considerable strength gains [12]. In comparison to peat removal, peat stabilization is a quick and affordable solution to peat soil geotechnical difficulties. Stabilizers are used to enhance the engineering qualities of soil properties and make them suitable for use as building materials for foundations [13-14].

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Received 09 Oct 2022; Revised 07 Dec 2022; Accepted 07 Dec 2022
https://doi.org/10.36937/cebel.2022.1731

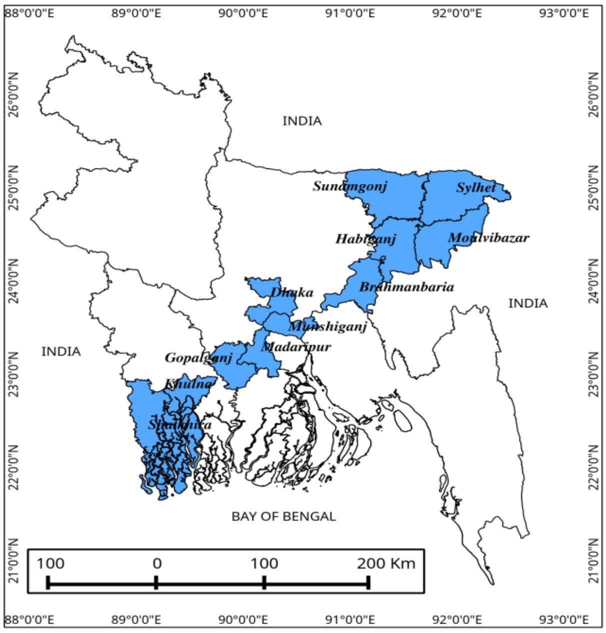


Figure 1. Map of Bangladesh's peat land distribution [6]

In comparison to peat removal, peat stabilization is a quick and affordable solution to peat soil geotechnical difficulties. Stabilizers are used to enhance the engineering qualities of soil properties and make them suitable for use as building materials for foundations. Numerous studies were conducted on enhancing the geotechnical qualities of peat due to its high compressibility and poor shear strength (Cheng et al. [15], Celik & Canakci [16], Erdem & Edil [17], Kazemian et al. [18] and Kalantari et al. [19]. Following experience with laying fills on peat, MacFarlane [20] observed that considerable changes in the strength properties of peat occur when the pressures of pore water are fully subsided. In comparison to lime, which was employed as the conventional stabilizer, Ahnberg et al. noted cement as the best option for stabilizing peat soils [21]. In their 2008 study, Wong et al. examined the initial permeability and unconfined compressive strength of peat soils stabilized by combinations of siliceous sand, Portland cement, and powdered granulated blast furnace slag [22]. They reported considerable improvement in stabilized peat's unconfined compressive strength as compared to undisturbed peat. They found an interesting phenomenon: if black humic acid within peat is not sufficiently neutralized by a binding material, the acid tends to interact with calcium hydroxide released during cement hydrolysis, delaying the growth of stabilized peat's undrained shear strength. The peat was stabilized by Kalantari et al. utilizing steel and polypropylene fibers as chemically inert additives and ordinary Portland cement (OPC) as a cementing material [23]. Using 5% OPC, 0.15% polypropylene fibers, and 2% steel fibers raised the unconfined compressive strength of peat by 748.8\%. Erdem and Edil also investigated the chemically stabilized peat soils by incorporating self-cementing fly ash into them [17]. The latest study on peat stabilization using columns made by a deep mixing approach by Huat et al. investigates the effects of cement, a conventional binder, combined with a chemical binder and kaolinite on the undrained shear strength of peat [24]. They observed that compressibility declined as cement concentration increased and discussed the impact of the area ratio of the column on compressibility behavior.

To increase strength and improve the consolidation properties of soft soils, it is common practice to incorporate a column of compacted sand or stone (Vesic [25], Hughes & Withers [26], Priebe [27], Malarvizhi & Ilamparuthi [28], Guetif et al. [29] and Deb et al. [30]. Sivakumar et al. [31] investigated the load-deformation behavior of clay reinforcement specimens with individual sand columns of varying lengths. They noticed that the granular columns significantly increased the soft clay's ability to transport loads. It was observed that load-carrying capacity did not grow further for columns that were longer than roughly five times their diameter. The influence of sand columns on the engineering properties of undisturbed organic soil was studied by Jorat et al. in 2013. Shear and consolidation tests were run on the stabilized and undisturbed soil after adding 20, 30, and 40% of sand to the soil to stabilize it. For stability, sand columns with various diameters and geometries were employed. According to test results, adding a sand column to peat increased its permeability, shear strength, and consolidation rate [32].

In conclusion, stabilization is one of the best solutions to the peat-related problems since peat soils have poor geotechnical qualities. Sand column improvement techniques have been used effectively to enhance the geotechnical characteristics of inorganic soil. Sand is an eco-friendly substance that may be used to improve peat soils. For foundation construction in peat soil, peat has two critical weaknesses: high compressibility and poor shear strength. Therefore, the main objective of this study is to examine the properties of natural organic soil and evaluate the compressibility behavior of peat (organic soil) stabilized by sand columns. A series of 1-D consolidation tests were performed on the sand column-reinforced samples to determine the proper solution. On the laboratory scale, sand columns with varying percentages of sample volume and geometries are added. The parts that follow will go into further detail.

2. Materials and Methods

2.1. Materials

Samples of organic soil collected from the Khulna-Mongla Railway boring site at village: Arongghata, Khulna (Figure 1). Samples were collected at a depth of 10ft to 15ft below the ground surface and sufficient soil samples were taken for laboratory tests. Figure 2 shows the collection of soil samples. The peat soil collected from this region consists of partially decomposed in nature. There are various climatic factors like temperature variation, rainfall characteristics and humidity influence on the characteristics of organic soil. To determine the physical properties of soil sample there are various laboratory tests like soil classification, organic content, compaction, particle size distribution, consolidation, specific gravity and Atterberg limits need to be performed.

Figure 2. Collection of soil samples

The Sylhet sand used in this study was supplied by KUET Civil Engineering Laboratory. Sylhet Sands are industrially available in large quantities from the origin sand pits. The variation of percent finer (%) to the particle size of Sylhet sand is indicated in Figure 3. The particle size distribution curve illustrated that the particle size was remained between 5mm to 0.09mm and sand particles are well graded. The density of sand used as sand column was in between 1.746 gm/cc to 1.755 gm/cc.

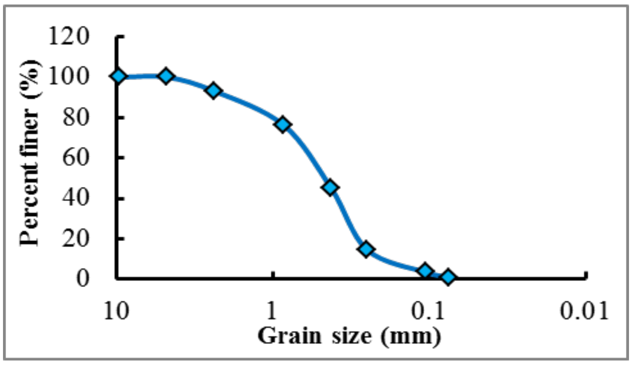


Figure 3. Particle size distribution of sylhet sand

2.2. Research Methodology

In general, the research was conducted in five stages, as described flow chart Figure 4.

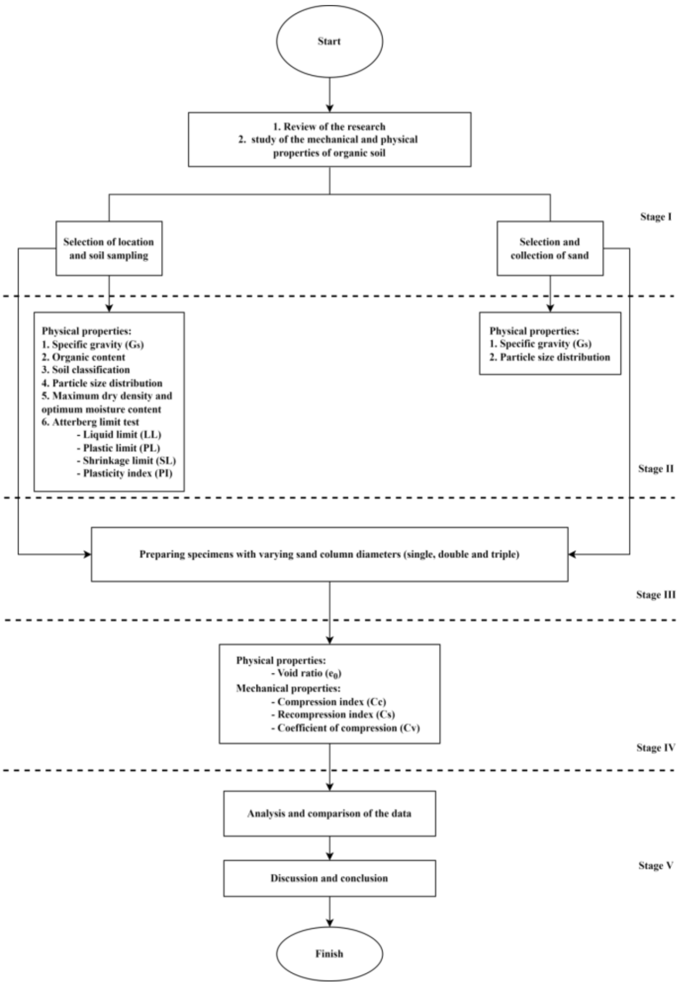


Figure 4. Research methodology

The explanation of flowchart in Figure 4:

✓ Stage I

The first step is the selection of the location and soil sampling. Along with the selection and collection of sand required to prepare sand column.

✓ Stage II

The second phase of this experiment was conducted to determining physical properties of virgin organic soil (without sand column) and to determining the physical properties of the collected sylhet sand. Physical properties test consist of soil classification (ASTM D2487-17), specific gravity test (ASTM D854-00), organic content (ASTM D2974-00), Atterberg limits test (ASTM D4318-00), particle size distribution (ASTM D422-63), compaction (ASTM D698) [33-38].

✓ Stage III

On this stage single, double and triple vertical holes were created through organic soil sample by using steel cylindrical extruder to insert sand column (Table 2). The cylindrical holes were filled with sylhet sand to determining physical (void ratio, e0) and mechanical properties like compression index (Cc), coefficient of compression (Cv), and the coefficent of volume compressibility (mv). Sylhet sand was used to fill the cylindrical holes in three equal phases, each taking up one-third of the total capacity. Following each addition, the sand was compacted by periodic taps on the consolidation or direct shear ring's outer perimeter until no additional change in the volume of the sand columns could be seen visually. The quantities of sand in columns were altered by altering the diameter of the holes since the height of samples within consolidation rings is constant, allowing for the creation of test samples with various ratios of sand to organic soil. Then, precisely placed samples were added to the consolidation test device.

✓ Stage IV

The fourth phase was conducted to determining physical and mechanical properties of organic soil stabilized with various diameter of sand column. Physical property test consist of void ratio (e0) and mechanical properties test consist of compression index (Cc), coefficient of compression (Cv) and the coefficient of volume compressibility (mv). This test was accomplished according to the ASTM D 2435-90.

✓ Stage V

At this stage, data analysis was conducted to obtain the conclusion of the research. The physical and mechanical properties of stabilized organic soil using various diameter sand columns are compared with untreated organic soil and discussed in the paper.

2.3. Laboratory Program

Different volume ratios of sand to organic soil were achieved by using different diameters of sand columns. The sample combinations and detail descriptions are shown in Table 2 below.

Table 2. Descriptions of specimen

Specimen Type	Consolidation Test			
	Ring		Sand Columns	
	Diameter (cm)	Height (cm)	Diameter (cm)	Height (cm)
Natural Organic Soil (NOS)	6.35	2.54	-	-
Organic Soil (97%) + sand (03%) (97OS03Sc) - 1 columns	6.35	2.54	1	2.54
Organic Soil (90%) + sand (10%) (90OS10Sc) - 1 columns	6.35	2.54	2	2.54
Organic Soil (77%) + sand (23%) (77OS23Sc) - 1 columns	6.35	2.54	3	2.54
Organic Soil (95%) + sand (5%)(95OS05Sc) - 2 columns	6.35	2.54	2x1	2.54
Organic Soil (92%) + sand (08%) (92OS08Sc) - 3 columns	6.35	2.54	3x1	2.54

After preparing specimen, tests were performed on undisturbed organic soil samples and five different volume properties of sand and organic soil:

- Natural Organic Soil (denoted by NOS)
- 97% of Organic Soil (OS) with 03% of Sand column (Sc) (denoted by 97OS03Sc)
- 90% of Organic Soil (OS) with 10% of Sand column (Sc) (denoted by 90OS10Sc)
- 77% of Organic Soil (OS) with 23% of Sand column (Sc) (denoted by 77OS23Sc)
- 95% of Organic Soil (OS) with 05% of Sand column (Sc) (denoted by 95OS05Sc)
- 92% of Organic Soil (OS) with 08% of Sand column (Sc) (denoted by 92OS08Sc)

3. Result and Discussion

3.1. Classification and Physical Properties of Organic Soil

Table 3 below shows the basic properties of organic soil sample. Soil classification based on Unified Soil Classification System (USCS). Visual inspection reveals some moderately degraded plants in the organic soil sample with dark brown color. The soil is categorized as highly compressible organic soil (OH) because the liquid limit is more than 80% and the organic content is more than 35%.

Table 3. Properties of southwest Bangladesh organic soil

Basic properties of Organic Soil sample	Value
Color	Dark brown
Specific Gravity	1.90
Liquid Limit (%) of air dry	118
Liquid Limit (%) of oven dry	82
Ratio of oven dry and air dry liquid limit	0.69
Plastic Limit (%)	71
Shrinkage Limit (%)	41
Plasticity Index (PI)	47
Organic content (%)	38.63
Optimum moisture content (%)	33
Maximum dry density (KN/m^3)	11.25
Soil Classification (USCS)	OH (Organic Silt)

There are no gravel or sand particles, according to the grain size distribution of the organic soil sample. All particles with sizes ranging from 0.06 mm to 0.001 mm pass through sieve #200. A graph of the organic soil's grain size distribution is shown in Figure 5. The organic silt and organic clay in the soil sample had well-graded particle sizes.

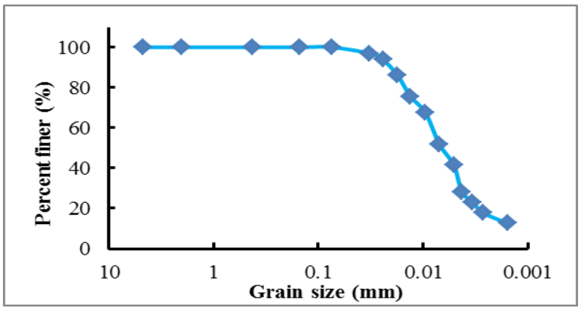


Figure 5. Grain size distribution curve of organic soil sample

Based on the standard Proctor test results, compaction curves were drawn for untreated organic soil sample as shown in Figure 6. It is seen that maximum dry density of untreated organic soil is 11.25 KN/m3 with 33% optimum moisture content.

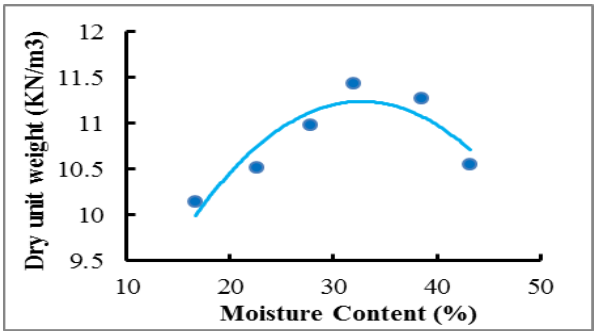
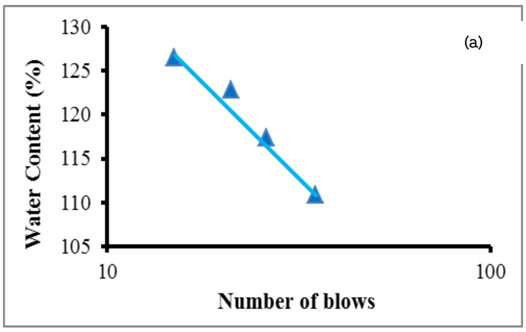


Figure 6. Compaction curve of organic soil sample

The specific gravity, plasticity index and shrinkage limit are 1.90, 47 and 41, respectively, for the organic soil samples. The air dry liquid limit and the oven dry liquid limit of the organic soil samples is 118 and 82, respectively. Figure 7a-b shows the relationship between water content (%) VS number of blows of air dried soil sample and oven dry soil sample respectively. The ratio of oven dry and air dry liquid limit is 0.69.



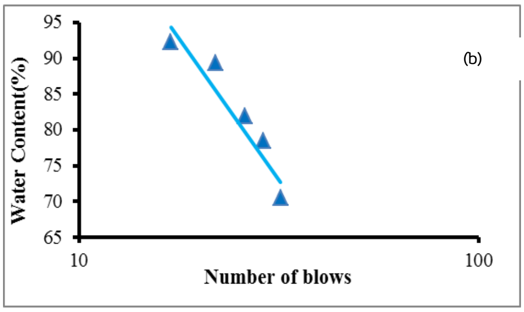


Figure 7. Relationship between water content (%) Vs number of blows (log scale) of a) air dried soil sample, b) oven dried soil sample

3.2. Compressibility Behavior

The compression of every soil sample was compared using the void ratio (e0)-log p curves, which are depicted in Figure 8, and were used to assess the soil's long-term compression characteristics. The untreated organic soil sample has the maximum initial void ratio (0.86), which drops under loading pressures before somewhat increasing under unloading pressure. All of the organic soil samples showed the same pattern. When the sample is loaded, air is forced out of the sample, which lowers the void ratio. The void ratio marginally rises when the organic soil sample absorbs air during unloading.

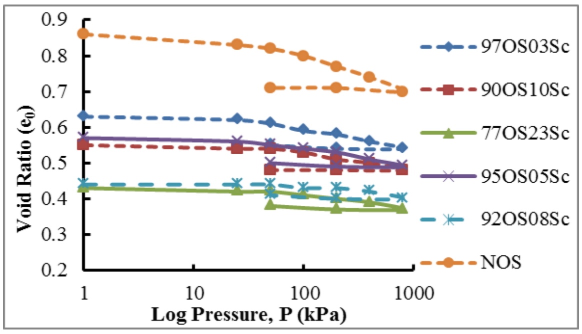


Figure 8. e0-log P graph for organic soil sample

The void ratio was observed to be affected by the different sand column diameters. In comparison to other samples with lesser percentages of sand columns, organic soil treated with 23 percent (in volume) of sand column had a lower void ratio. Organic soil treated with a 23 percent sand column, a 10% sand column, a 3% sand column, and a 0% sand column has an initial void ratio of 0.43, 0.55, 0.63, and 0.86, respectively. It is notable that even though soil sample 92OS08Sc included 8% of a sand column, the initial void ratio results were almost identical to those of 77OS23Sc, which contained 23% of a sand column. The consolidation behavior of 97OS03Sc was intermediate between 77OS23Sc and NOS.

The coefficient of consolidation is the most useful parameter derived from the consolidation test, which is particularly significant when using the preloading method for ground stabilization [39]. If the sample is loaded incrementally while recording how the sample's height changes over time, the coefficient of consolidation (Cv) may be calculated using the data from the laboratory consolidation test. There are several approaches to determining Cv using laboratory test results. Each technique is intended to avoid the ambiguity associated with detecting where consolidation settle begins and finishes during the experiment. The coefficient of consolidation (Cv) is evaluated in this study using the Time Fitting Approach, which is the most commonly used method for determining Cv from laboratory test data. In this approach, a curve is obtained by plotting the dial gauge reading on the Y axis and the square root of the elapsed time (t) on the x-axis. Then, a common technique is used to link two characteristics—the time factor for consolidation and the length of the drainage path—in order to determine Cv. The determined Cv variation with consolidation pressure is shown in Figure 9. Increased sand content in samples reduces the drainage path to sand columns and results in higher Cv values.

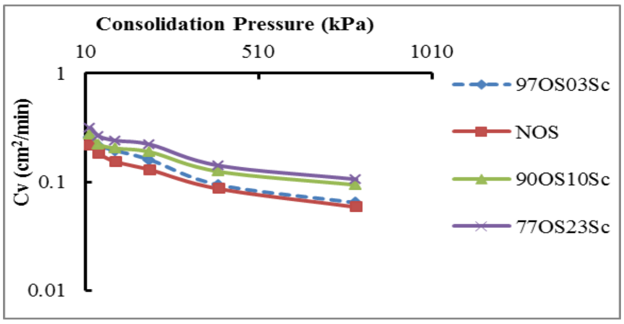


Figure 9. Variation of coefficient of consolidation with consolidation pressure

At the initial stage of consolidation, the peak and least values of Cv were 0.315 cm2/min for 77OS23Sc and 0.214 cm2/min for NOS, respectively. All samples showed a decrease in Cv values as consolidation pressure started rising. For all load limits, NOS displayed the lowest values of the coefficient of consolidation, whereas 77OS23Sc had the highest values. We attribute this to the slightly thicker sand column inside this 77OS23Sc specimen, from which we deduce that it significantly enhanced permeability and elastic modulus and, thus, accelerated consolidation.

In the investigation performed by Jorat et al. [32], the values of the coefficient of consolidation for samples stabilized by sand columns declined fast as the consolidation force approached, reaching a low at the maximum loading value. The larger volume of sand column samples had the highest Cv for all load ranges across the different sand column samples. According to Figure 10, the value of the compression index reduced as the volume of the sand column in the organic soil increased.

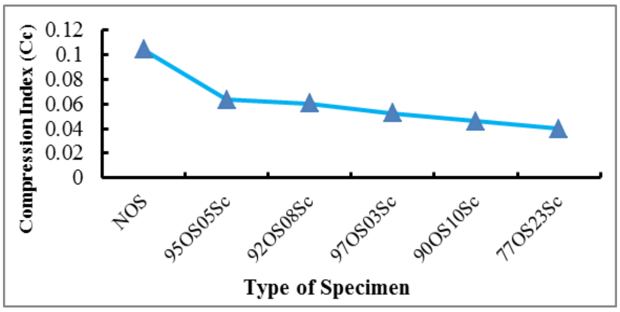


Figure 10. Variation of compression index with specimen type

The effect of the number and shape of the additional sand columns also shows that the Cc achieved with sand placed in two and three columns is 0.06335 and 0.06065, respectively.

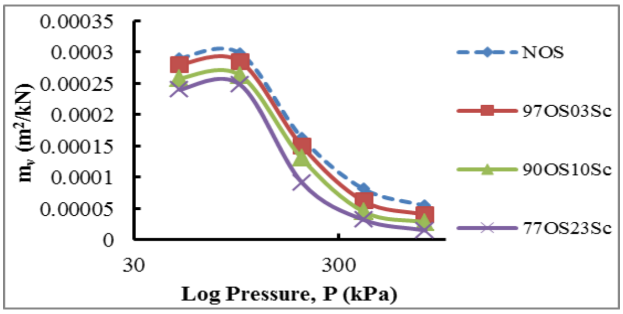


Figure 11. mv - log P curve of organic soil

According to Figure 11, the coefficient of volume compressibility (mv) of all organic soil samples is generally rising at 99 kPa and starting to fall when more pressure is added. The mv of the untreated organic soil exhibits the greatest value, which is 5.42 x 10-5 m2/kN, when using the endpoint of mv, which is at 792 kPa, as a reference point for comparison. Organic soil treated with sand in a column results in a decrease in mv; samples treated with 10% and 23% sand in volume, respectively, reveal mv values of 2.8 x 10-5 and 1.5 x 10-5 m2/kN. As a result, the soil's compressibility is decreased by the addition of a greater sand column.

4. Conclusion

The outcomes of a physical and mechanical engineering characteristics investigation into sand column stabilized organic soils from the Bangladeshi city of Khulna were examined and discussed. Many lab tests were conducted to investigate the compressibility behavior of treated organic soil. The volume of the sand column was increased by 3, 5, 8, 10, and 23%. The geotechnical characteristics of organic soils that sand columns have stabilized are correlated in several ways. The investigation produced the following findings on sand column stabilized organic soil:

- ✓ Generally, incorporation of the sand column reduces the compressibility of organic soil as observed from the void ratio, compression index and the coefficient of volume compressibility. The reduction in e_0, C_c and m_v is caused by the increasing density of the soil and decreasing water content as the soil undergoes the process of consolidation and stabilization.

- ✓ The compressibility of 3% in volume sand column treated organic soil does not show a significant improvement in soil compressibility, however, it is expected that soil compressibility can be gradually improved with the increase of sand percent.

- ✓ In consolidation tests, the sample with 23% sand showed greater compressibility than all other samples. Vertical drainage provided by sand columns leads to faster consolidation of the peat layer.

- ✓ The influence of sand column number and geometry on compressibility was examined in samples containing 5% and 8% sands in volume. Specimens with three sand columns showed greater compressibility. The consolidation of the 5% and 8% sand experiments with two and three sand columns respectively demonstrated the fact that geometry and spacing factors influence compressibility of stabilized organic soil.

Overall, the research reported in this study proves that the organic soil can be stabilized satisfactorily with the addition of about 23% sand in single column and 8% sand in two columns.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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How to Cite This Article

Rashid, M.H.A., Kabir, M.H., Rahman, M.M., and Ahmed, R., Compressibility Characteristics of Southwest Bangladesh Organic Soil Stabilized with Sand Columns, Civil Engineering Beyond Limits, 4(2022),1731.
https://doi.org/10.36937/cebel.2022.1731.