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ABSTRACT

The conventional foundation systems are not suitable for the massive structures in Khulna region i.e. South-west part of Bangladesh because an organic soil layer exists at a depth 10ft to 25ft from the existing ground surface. The existence of organic soil layer in the deposits results excessive settlement due to its high compressibility and low shear strength. To overcome the problem, soil improvement techniques are usually adopted depending upon the type of constructions. It is necessary to know the degree of improvement for the different improved grounds prior to the selection of ground improvement techniques. So a laboratory investigation was conducted to find out the effect of improvement techniques on reconstituted organic soil to obtain a guideline for selection, design and construction of suitable soil improvement method for this region. The laboratory investigation reveals that the compacted sand bed improves bearing capacity of organic ground significantly.

INTRODUCTION

The valuable structures are sometimes collapsed due to excessive total and differential settlement of the foundations while constructed on the soft ground without adopting proper foundation system. Due to the presence of organic soil layer, the Civil Engineering constructions in such sites require special attention to overcome the possible adverse consequences. It is a big challenge to the Geotechnical Engineers in designing economic foundations to construct the necessary infrastructures (Alamgir et al., 2001).

To find out a reliable and cost effective solution, many research works have been conducted for the construction of massive structures in this region. Considering the inherent limitation of conventional foundation systems and benefit of ground improvement techniques, sand column has been practiced for long time. Common materials are usually used for stone columns/ granular piles are well graded clean sands, gravels or stones (Aboshi, Ichimoto, Enoki & Harada, 1979 and Soyez, 1985). However, the reduction of settlements rather than the increase of bearing capacity of stone column reinforced foundations is generally be the primary consideration of designing such ground improvement technique (Balaam & Booker, 1985; Schweiger & Pande, 1986). While adopting sand compaction pile in improving soft ground, the overall bearing capacity increase in the composite ground is interpreted as due to the increase of strength of the sand piles (Ogawa and Ichimoto, 1963; Baumann and Bauer, 1974; Hughes et al., 1975 and Takemura et al., 1991). The sand compaction pile method has actually reported the degree of vertical stress concentration on sand piles either observed or predicted (Aboshi et al., 1979; Ichimoto and Suematu, 1981; Enoki et al., 1991). Many successful uses proved that the granular column is a valuable addition to the special foundation system. The use of stone columns/ granular piles/ sand compaction piles as a technique of soil reinforcement is frequently implemented for improving soft clay and silt and also for loose granular deposit. Granular column offers a valuable technique for (i) increasing bearing capacity and slope stability; (ii) reducing total and differential settlements; (iii) increasing the time rate of consolidation and (iv) reducing liquefaction potential (Barksdale & Bachus, 1983). Meanwhile the geosynthetic reinforcement, first proposed by Casagrande who idealized the problem in the form of a weak soil reinforced with high-strength membranes laid horizontally in layers (westgaard, 1938), were used successfully in several forms to improve soft soil conditions.

The geosynthetic reinforced granular fill improve bearing capacity of soft soil systems and reduce settlement by distributing the imposed loads over a wider area of weak subsoil. For such benefit these are being extensively used for the foundation of shallow footing, unpaved roads, heavy industrial equipments and low embankments etc. In conventional construction technique without the use of any reinforcement, a thick granular layer is needed which may be expensive or may not be possible, especially in the sites of limited availability of granular materials of good-quality.

In this study, the improved grounds for four different conditions were investigated through the loading on an individual circular footing resting on the ground and compared with that of untreated ground as well as among themselves. The effectiveness of compacted sand bed with and without geotextile and granular column with and without geotextile sandwiched compacted sand bed in improving the bearing capacity of soft organic ground were investigated by a series of laboratory experiments. The result shows that the inclusion of geotextile in sand bed improves the capacity of the ground significantly. The outcome of the study can act as an useful guideline for the selection of appropriate soil improvement method for the construction of safe and economical foundation system for massive infrastructures in Khulna region. This illustration is a part of an original thesis as a requirement of M. Sc. Engg. Degree (Mahamud, 2007); however some aspects have already submitted in a companion paper (Mahamud and Alamgir, 2007).

BACKGROUND OF THE RESEARCH

Soft soil deposits exist up to the greater depth in the Khulna region, the southwest part of Bangladesh. In this region, a thick organic soil layer generally exists at 10 to 25ft depth measured from the existing ground surface (Islam 2006). Due to the expensive and time consuming nature of the conventional foundation system, the practicing engineers have been proposed granular columns for the improvement of soft ground. Some research works have already been conducted in the field level to examine the effectiveness of such ground improvement techniques in Khulna region (Zaher, 2000; Sobhan, 2001; and Hossain, 2007). However, experimental study in the laboratory has not yet been conducted to investigate the effect of load-settlement response of the improved grounds for different ground improvement conditions. As a follow-up of ongoing research on soft ground improvement technology in the Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, this research works have been conducted. Hence, reconstituted organic soil grounds have been prepared to represent the field condition of this region. Then the soft grounds have been treated with compacted sand bed with and without Geotextile and by the installation of sand column with and without geotextile sandwiched compacted sand bed. The results are compared with each other and also with untreated ground to find out effective ground improvement method for this region.

EXPERIMENTAL INVESTIGATIONS

In this study, load tests were performed on five experimental grounds. The first one is untreated ground and other four are the treated grounds of different improvement conditions. The detail experimental investigations are described in the following sections.

Methodology of Investigation

The 'Unit Cell' Concept (Barksdale and Bachus, 1983) is used here for the preparation of experimental ground representing different ground improvement conditions. Here the laboratory experiments were performed in a circular steel tank of about 1m diameter and 1m height to prepare convenient sized soft ground following the method of Leung and Tan (1993). The tank was filled with soils consisting of three layers: the bottom layer as compacted sand acted as a drainage media, the middle layer as reconstituted clay (having organic content more than 40% and water content equivalent to liquid limit which represents typical organic soil of Khulna region) and the top most layer as typical soft clay. Firstly, a bottom sand layer of about 150mm thickness was provided into a tank to obtain soil layer having negligible compressibility and also performed as a good drainage media. At the middle position, a reconstituted organic soil layer was provided which represents the problematic ground of Khulna region. The slurry was also kept under predetermined degree of surcharge and elapsed period before improvement to obtain grounds of same pre-consolidation pressure. Then the reconstituted soft grounds were improved by placing a compacted sand bed with and without geotextile and also with the inclusion of sand column with and without geotextile sandwiched compacted sand bed. The schematic diagram of the typical test grounds both the natural and improved are shown in Figure 1(a) and (b). Finally load-settlement behaviour of the untreated and treateded reconstituted organic grounds was determined by full-size footing load test.

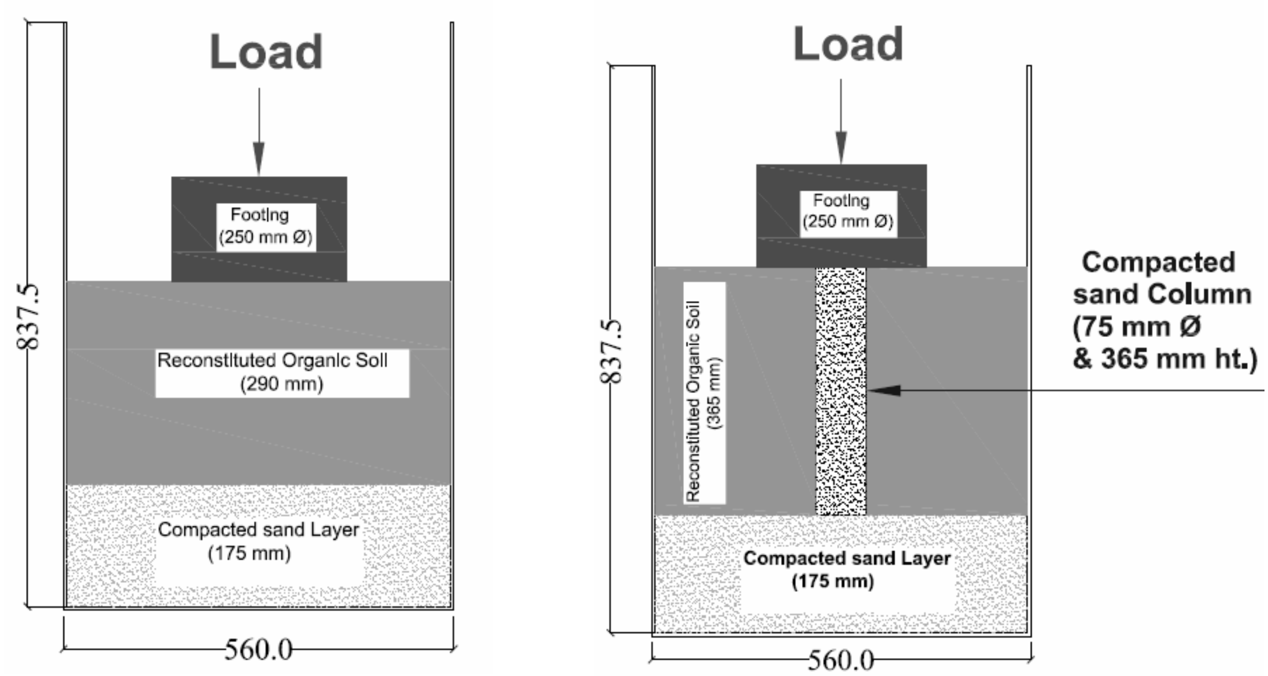
Preparation of Soft Organic Ground

The soft reconstituted organic soil layer was built on the compacted sand of bottom layer by following the method as described in Mahamud (2007). To prepare the soft organic grounds, the organic soil was collected from Mohersharpasa, Khan Jahan Ali thana, Khulna**.** The Depth of the collected soil is about 10ft from the existing ground surface. After collection of organic soil, the properties of the organic soil were determined in the laboratory as shown in Table 1.

Table 1 Properties of the Collected Organic Khulna Soil

Parameters	Values
Water Content (%)	281
Bulk Unit Weight (kN/m^3)	10.89
Dry Unit Weight (kN/m^3)	2.16
Specific Gravity	2.02
Liquid Limit (%)	350
Plastic Limit (%)	208
Plasticity Index (%)	142
Unconfined Compressive Strength (kPa)	54.5
Compression index C_c	2.43
Initial void ratio, e_o	5.77

shown in Figures 1(a) to (b). The sand was not only soil layer of negligible compressibility but also performed as a good drainage media. This sand bed was a normally compacted soil layer.



(a) Untreated ground (G-1)

(b) Treated ground with sand column (G-2)

Figure 1 Schematic diagram of two test grounds

Reconstituted soil was prepared by breaking down natural organic soil, mixing them thoroughly with water (1.25 times of liquid limit) to form slurry and reconsolidating at the pressure of pre-consolidation as followed by Islam (2006). The soil slurry was so weak to carry the predetermined pre-consolidation pressure fully from the very beginning. For this reason, the pressure was applied from low value and the dissipation of water was allowed through the bottom sand layer. When the ground would be able to carry the pre consolidation pressure continuously 12 hours without reducing, then the ground would be considered as a prepared ground for the pre-determined pre-consolidation pressure. The grounds were also kept under predetermined degree of surcharge and period before improvement to obtain desired grounds of same pre-consolidation pressure that would help to compare the degree of improvement among the soil improvement techniques. Then soil samples were collected from the prepared ground to determine its strength and compressibility properties as shown in Tables 3 and 4.

Placement of Bottom Sand Layer

A bottom sand layer of 175mm thickness was provided at the bottom of every ground in this laboratory investigation as

Preparation of Compacted Sand Bed over the Reconstituted Organic Ground

A compacted sand bed with and without geotextile and also sand column was provided on the reconstituted organic soil ground as a part of implementation soil improvement technique which was adopted by Mahamud (2007). Before using sand in compacted sand bed, the properties of sand were determined in the laboratory. The Finess Modulus of the sand was found as 1.52. The coefficient of uniformity and coefficient of gradation were found as 2.3 and 0.89 respectively. The Optimum Moisture Content and Maximum Dry Density of the sand were found as 14.42% and 16.23kN/m^3, respectively, by Standard Proctor Test. Then again bulk density of sand, wet density, dry density and moisture content were determined to find out the degree of compaction provided in sand compacted bed as presented in Table 4. The compacted sand bed was sandwiched with and without geotextile.

Installation of Sand Column in the Reconstituted Organic Ground

The sand column using local sand was installed in the reconstituted organic ground at the centre of the test mold by replacement method as shown in Figure 1(b). The sand column was installed in the prepared ground by saturated sand layers of height 150mm and the each layer was compacted by using the hammer of 50mm diameter and 5.5 lb weight. The number of blow per layer was 25 and height of free drop of hammer was 300 mm, which produced the compactive energy as 12,400ft-lb/ft^3. It was observed that such compaction energy and the method of construction leads to have a reasonably compacted sand column.

Placement of Geotextile

Geotextile was provided to impart stiffness and to increase bearing capacity of the soft organic grounds (Mahamud and Alamgir, 2007). To serve the purposes, geotextile should place on the soft ground in such a way that it must remain in tension after buried by sand bed. So during the placement of geotextile, extra care should be taken.

Table 2 Properties of used Geotextile (From Fleming 1999)

Manufacturer Product	: Polyfelt TS 650
Type of Geotextile	: Lightweight nonwoven geotextile
Composition	: Needle-punched nonwoven polypropylene
Mass (g/m^2)	: 235
Thickness (@ 2 kPa), mm	: 2.3
Filtration Opening Size (µm)	: 110
Grab Tensile Strength (N)	: 755
Mullen Burst Strength (kPa)	: 1795
Permittivity (s^{-1})	: 1.6

In this study, the geotextile has been used to improve soft organic soil whose properties are given in Table 2. Prior to the placement of geotextile, trench of about 30mm deep and 25mm wide was cut at the periphery of the ground/tank as shown in Figure 2. Moreover, geotextile would place on the soft ground in such way that it remain in tension. After placement, geotextile was buried by designated sand. The surrounding trench was acted as an anchor and would help the geotextile remaining in tension after construction.

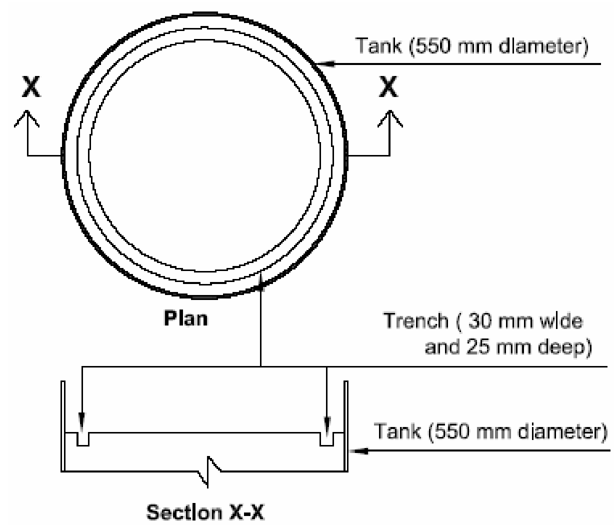


Figure 2 Placement of Geotextile on Ground

Load Test

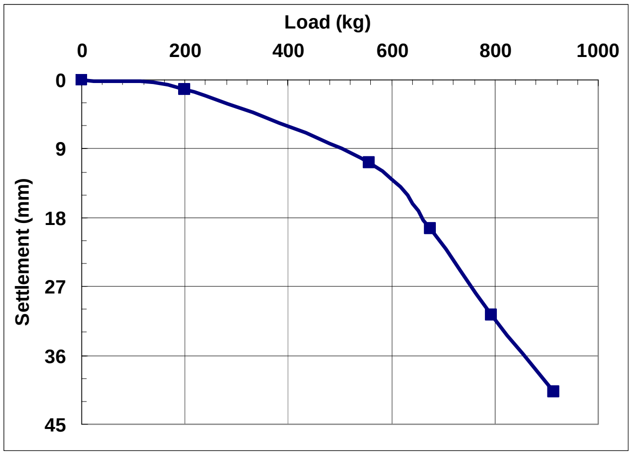
The load-settlement behaviour of the improved ground was measured by applying vertical reaction through a typical circular footing of 250mm diameter. The circular footing was placed at the centre of the improved ground and a hydraulic jack was placed on it to apply load to the improved ground. To measure settlement of the improved ground, two dial gages were set at positions having an included angle 180°. The load was applied by hydraulic jack and the settlement was measured by the dial gages. For an applied load, reading for settlement was taken at the elapsed time of 0, 1, 2, 4, 8, 16, 30, 60 minutes measured from the starting of loading. If the settlement was more than 0.25mm per hour, then settlement was taken at the time of 120minute. Then loading was increased and readings were taken at aforementioned durations and the readings were taken for more than 25mm settlement of footing. With the help of the load and settlement data, load-settlement curve for the grounds were drawn as shown in Figures 3(a) and (b).

Table 3 Properties of Untreated Reconstituted Organic Ground (G-1)

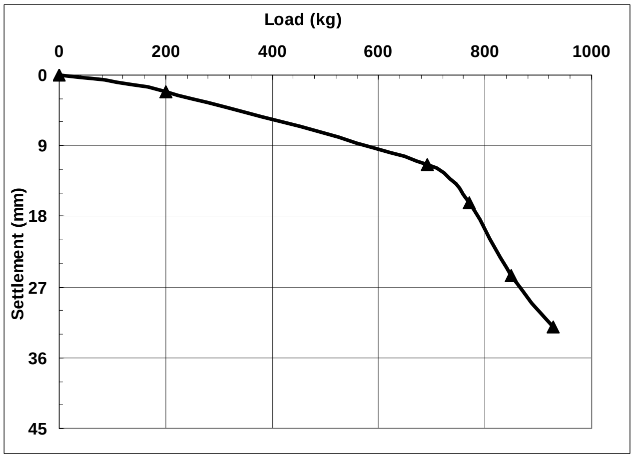
Parameters	Values
Organic content (%)	51
Water content (%)	162
Unconfined compressive strength (kPa)	51.7
Compression index C_c	0.56
Initial void ratio, e_o	3.85
Reconstituted organic ground thickness (mm)	290

Table 4 Properties of Treated Test Grounds

Parameters	Values			
	G-2	G-3	G-4	G-5
Organic content (%)	67	46	69	66
Unconfined Compressive Strength (kPa)	45 (w= 149%)	39 (w = 136%)	47 (w= 153%)	43 (w= 159%)
Compression index C_c	1.30	1.70	1.13	1.24
Initial void ratio, e_o	3.56	3.78	3.78	3.00
Finess Modulus	1.52	1.52	1.52	1.52
Optimum Moisture Content (%)	14.42	14.42	14.42	14.42
Maximum Dry Density (kN/m^3)	18.33	18.33	18.33	18.33
Bulk Density of Sand Bed (kN/m^3)	-	14.72	14.72	14.72
Wet Density of Sand Bed (kN/m^3)	-	19.33	19.33	19.33
Dry Density of Sand Bed (kN/m^3)	-	17.45	17.45	17.45
Moisture Content (%)	7.8	10.5	10.7	10.7
Degree of Compaction (%)	-	95	95	95
Reconstituted Organic Ground Thickness (mm)	290	345	480	520



(a) Untreated ground (G-1)



(b) Treated ground with compacted sand column (G-2)

Figure 3 Load-settlement responses of untreated and treated ground

RESULTS AND DISCUSSIONS

Load-settlement Response

The load test through individual circular footing was performed on prepared grounds to find out load-settlement response and hence compared it to that of the natural ground and as well as other improved grounds as stated in Mahamud and Alamgir (2007). The load-settlement curve for untreated ground and improved ground by sand column are shown in Figures 3(a) and (b). From these figures, it can be found out that the load-settlement response of untreated ground is critical. After the settlement of 10 mm, the rate of settlement due to loading has increased sharply. The point of failure can be identified easily by the settlement rate method. The load-settlement behaviour of untreated ground indicates that the construction of massive structures on the organic ground is very risky and structures may be affected by excessive total or differential settlement.

To find out the suitable soil improvement technique, sand column was used as an application of one of the four soil improvement conditions. In this case single sand column was used for improvement. The load- settlement curve of the soft ground improved by single sand column did not show significant improvement. The settlement rate increases sharply after the settlement reach to 15 mm. The bearing capacity of soft organic clay ground improved by sand column was not significant.

But it was found in the experiments that improvement by compacted sand bed without and with geotextile and also enhancing sand column have played a vital role in improving load-settlement behaviour of soft organic ground. The soft grounds are not only improved in context of settlement but also the settlement rate become uniform. These improved behaviours of soft ground can reduce the risk of sudden failure of foundation of structure due to excessive total and differential settlement.

Comparison of Improvement

In the study, to find out effective soil improvement method for this region, a comparison has made among the load-settlement behaviour of four improved grounds as shown in Figure 4 and also with the behaviour of untreated ground by finding out degree of improvement. For appropriate comparison, the reconstituted grounds for all conditions were constructed by common ground preparation technique, loading condition, loading duration and environment. Although some variations were found in the strength and compressibility parameters in the prepared grounds as shown in Table 4 but in geotechnical point of view these variations were negligible. The net bearing capacity of the improved grounds is shown in Table 6 for four different ground improvement conditions as investigated in the research work.

due to the use of geotextile, however, it is observed that further increase is insignificant while geotextile compacted sand bed is used in association with sand column.

Table 6 Net Bearing Capacity of Improved Grounds

Types of Ground	Net Ultimate Bearing Capacity (kN/m^2)	
	According to Settlement Rate Method	Considering 25 mm Settlement
G-1	111.74	145.6
G-2	135.18	163.60
G-3	193.05	183.64
G-4	199.83	238.20
G-5	184.04	246.43

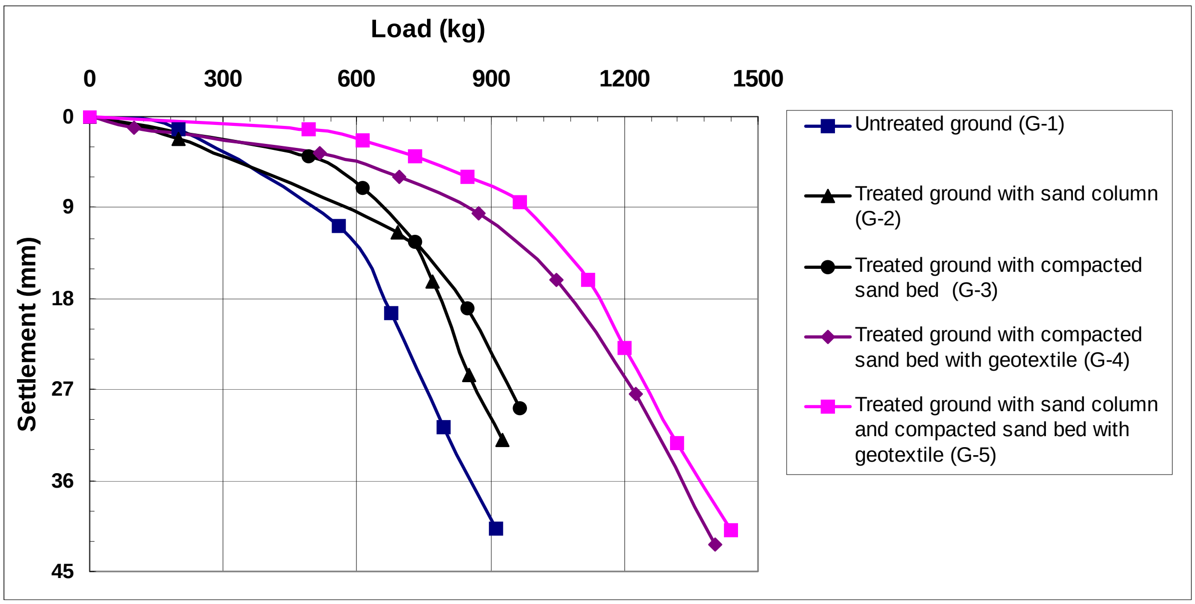


Figure 4 Comparison of load-settlement response of untreated and treated grounds

The net ultimate bearing capacity of the untreated ground was found as 145.6 kN/m^2 for 25 mm settlement. The degree of improvement for sand column was found as 1.12. Improving the untreated ground with compacted sand bed, the net ultimate bearing capacity is improved by 1.26 times of the untreated ground. Then the net ultimate bearing capacities of treated grounds with geotextile sandwiched sand compacted bed was obtained as 1.64 times than that of untreated ground. This improved value was increased to 1.69 times while the improvement associated with geotextile-sand bed and sand column. It was revealed from the comparison that the use of single sand column to improve soft organic soil is not significant. Besides this, it was also observed in the experiment that single sand column may not be able to balance the isolated footing horizontally i.e. there may have possibility of tilting. From Figure 4 and Table 6, it is found that the bearing capacity of the treated ground improved significantly

CONCLUSION

The laboratory investigation has revealed that the compacted sand bed with or without geotextile is effective to improve bearing capacity of organic soil of Khulna region and it is better to avoid the use of single column to improve organic soft ground. The soft ground treated by compacted sand bed shows slowly declined load-settlement curve which represents lower settlement rate and also results in reducing possibility of excessive settlement. This new developed properties increase factor of safety for massive structures and can avoid the risk of sudden failure of the foundation of structures.

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