Assessment of Bearing Capacity and Settlement Characteristics of Organic Soil Reinforced by Crushed Concrete and Sodium Silicate Columns

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Abstract. Organic soil has a high content of water and compressibility. This paper sheds light on organic soil and improving its shear resistance through the use of stone columns to strengthen the shear resistance and reduce precipitation. Four columns of crushed concrete were used after mixing them with 9% sodium silicate, and this ratio was chosen after several laboratory tests to determine the ideal ratio. The ideal curing period gives the highest compressive strength for crushed concrete mixed with sodium silicate. The experiment was conducted several times with untreated soil, then the soil was treated with untreated loamy columns, and it showed an improvement rate of 423% compared to unimproved soil. Then, columns based on a base were used. The improvement rate has reached 700% of the unimproved soil, considering the use of the same test conditions and the same percentage of sodium silicate, in addition to using similar diameters and lengths of columns.

Keywords: Organic soil; crushed concrete; stone column; sodium silicate; shear strength.

1. INTRODUCTION

Shear strength is an important property required in the analysis of building work over organic and peat soils and generally has a limiting low rate for such soils. Shear strength was a concern during building for supporting construction equipment and at the end of building in supporting the structure. Peat, due to its fibrous organic content, presents a distinct behavior from inorganic soils. The presence of fibers modifies the ideas of strength behavior in numerous ways [1,2]. Organic soil was characterized by very low shear strength and high compressibility index. This soil causes serious foundation problems and constitutes one of the most difficult ground conditions for the construction of civil engineering structures. The high compressibility and mainly large secondary consolidation compression characteristic of the organic soil due to the settlement characteristic related to this soil is very complex [3].

The stone column soil improvement method is one of the oldest and most popular methods of improving soft soils. The bending moment, footing settlement, and vertical soil stresses can all be decreased using stone columns [4-6]. They create a model of a single stone column with stiff instrumented loading plates so that the total load applied to the footing of the model and the load applied to the stone column can be tracked independently, and an experimental foundation for the stress concentration ratio's value can be established. A single stone column and groupings of two, three, and four were used in the model trials to treat the soil. During model testing, 10% cement was added to the columns' backfill substance. Moreover, the backfill material was changed, containing 70% crushed stone and 30% sand by weight. When sand was added to crushed stone in treated soil with a shear strength of c_u = 12 kPa, it had a marginal effect on the stress concentration ratio, but there was no significant effect when sand was added to stone in treated soil with a shear strength of c_u = 6 kPa [7].

Al-Khalidi [8] studied the performance of reinforced compacted soil by sand columns stabilized with sodium silicate. The experimental work is divided into two stages. Study the effect of adding four percentages of liquid sodium silicate (4, 6, 8, and 10%) on the strength of dune sand. It has been treated for different curing times (3, 5, 7, and 14 days). The second stage was carried out by using a lab model to evaluate the performance of both the floating and end-bearing sand columns. The findings of this study demonstrated that a system of prefabricated vertical drains combined with the use of vacuum pressure is an efficient way to increase the rate of the consolidation of soft soils. When vacuum pressure is used, the porewater pressure is greatly reduced. When an unsaturated soil layer is present, soil settlement has been seen to diminish. It should be noted that the time settling of a half-depth of unsaturated soil is roughly 35% of a full-depth, fully saturated soil profile. In contrast to fully saturated soil, porewater pressure spreads more quickly in the unsaturated soil layer. The experimental findings and the conclusions of the numerical analysis were in good accord. The majority of C and D waste is produced during the demolition of old structures and infrastructure. This means the process of using and recycling damaged materials, and this method was not commonly used in the past, as many concrete structures were demolished and buried without being recycled. In this soil improvement process, these concrete blocks are used after being ground to improve some engineering properties of the soil. The amount of trash is increasing daily. Recycling and reusing C and D trash is a long-term solution for lowering landfill waste, and since it must be dumped in a landfill, the material is free. Recycling C and D waste will lessen the overproduction of harmful gases and CO2 emissions, directly affecting global warming. Also, it will reduce the need for continual raw material extraction and lengthy transportation. On the other side, it will lessen the demand for new landfills. A sustainable solution for decreasing C and D garbage in geotechnical applications is concrete demolishing waste (CDW). Nonetheless, it will enhance the geotechnical qualities of the soil [9].

Soft, weak soil properties can be improved by using chemicals added to the soil, and this improvement is at a high level and is also highly efficient. The measurements made before and after testing showed that the undrained shear strength in models of footing on soft clay soil improved by tire ash material. The undrained shear strength is increased by about (1.3–14) % due to the implementation of soil stabilization [10]. Recently, many chemical compounds have been used to improve the soil. One of these compounds is steel slag, where the results showed a significant improvement in the shear resistance of clay soil, which developed from 4.5 to 16%, with the addition of 0 to 20% of steel slag, where the examination was carried out in CBR [2].

Several techniques and materials can be used to improve the geotechnical properties of different types of soil, such as stone columns, lime, cement, concrete demolishing waste (CDW), and grouting gel. These techniques can be used for shallow and deep improvement of soil layers even when the weak soil extends to high depth [11-15]. In this study, the stone column technique was used to improve the shear strength of organic soil.

2. EXPERIMENTAL WORK

2.1 Materials

1) Soil: Natural clay soil collected from Baghdad, and the content of organic matter was) 5%. It was washed to clean it of organic matter and then mixed with organic matter from roots and plant residues.
2) Crushed concrete: Concrete cubes that were crushed and passed through sieve No. 4 for use as columns inside the soil.
3) Sodium silicate: The ability of sodium silicate to produce gels is used to aid with soil stability.

2.2 Sample Preparation

Soil samples were collected from the city of Baghdad, and after conducting a chemical analysis on them, it was found that the percentage of organic matter indicated by the combustion test was 5%. Organic matter on bearing capacity and settlement: The cleaned soil was mixed with plant roots and some plant fertilizers to reach a certain percentage in which the soil bearing capacity is weak and the settlement rate is very high, where the improvement is clear in the weak soil. After mixing several samples, 21% of the organic content was settled due to its clear effect on the engineering properties of the soil without affecting its behavior.

2.3 Experimental Program

The experimental program adopted in this study includes:

a) Physical and classification tests. The results of these tests are shown in Table 1. When maximum dry density (MMD) is 1.335 g/cm^3 and Optimum moisture content (O.M.C) is 26.5%. The soil is classified in the USCS method, and the result was (OH) organic clay with silt of medium to high plasticity. Figure 1 shows the grain size distribution.

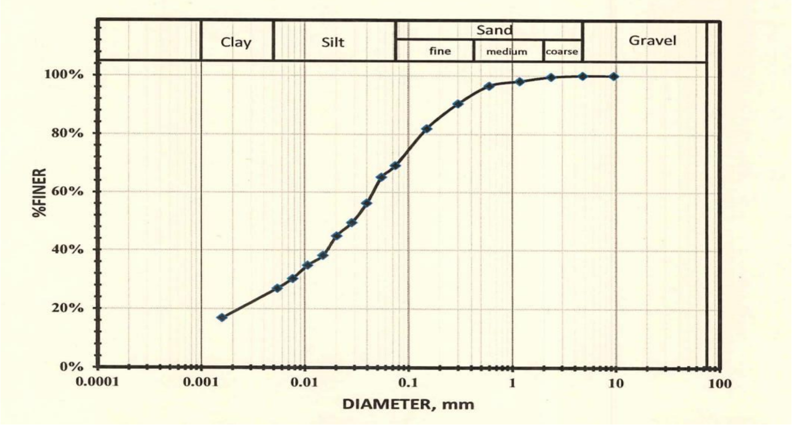

Figure 1: Sieve analysis test.

Table 1: Physical and classification properties of natural organic soil.

Property	Value	Standard	Property	Value	Standard
Specific Gravity (Gs)	2.24	ASTM D854	Standard Compaction Test Maximum dry unit weight $\gamma_{d.max}$ (kN/m^3) Optimum moisture content (%)	13.10 26.5	ASTM D698
Liquid Limit (LL) %	59	ASTM D423			
Plastic Limit (PL) %	34	ASTM D424			
Plasticity Index (PI) %	25	ASTM D4318			

b) Chemical tests on the soil and organic material. The results are presented in Tables 2 and 3.

Table 2: Chemical composition of natural organic soil.

Chemical Compound	CaO	Na_2O	SO_3	TDS	CO_3	Fe_2O_3	SiO_2	Al_2O_3	L.O.I
Percent (%)	20.8	0.66	0.31	0.61	0.17	6.2	23.9	41.37	5.36

Table 3: Chemical composition of the organic material.

Chemical Compound	O.M	SO_3	TDS	CO_3	Fe_2O_3	K_2O	Al_2O_3	CaO
Percent (%)	35	0.3	Turbid	0.28	2.7	29	5.9	31

c) The ignition test method is used to determine the actual organic content of prepared samples. The process was repeated several times to reach 21% of the organic content of the natural soil.
d) Compaction tests: The standard compaction effort is used according to ASTM D689-78. Samples with organic content approximately equal to 21% are compacted to 80 % of compaction strength to obtain the density to be improved.

2.4 Test Procedure

The following is how the model tests were conducted based on the testing program:

1) The Bed of Soil: Soil samples are put in the form of aggregates, each group consisting of 15 kg. For each group of these aggregates, 30% water was used to obtain a weak shear resistance, which was previously calculated at 18 kPa. After the soil and water mixing process, the soil is placed inside the iron box, arranged in a manner of layers, and then stacked to obtain the required density of 1.068 g/cm^3.
2) Construction of Sand Column: The crushed concrete is prepared, and the specified percentage of sodium silicate is added and mixed well and homogeneously. After the mixing is completed, the length and diameters of the columns that will be fixed in the soil are prepared and excavated using metal tubes inserted into the soil and then pulled out. The diameter of the column is 25 mm, while the length of one column is 150 mm, and the length-to-diameter ratio is 6. The mixture is placed inside the pits, then covered with a nylon cover, and left for 12 days, which is the treatment period and the consistency of the mixture to give the highest value for the shear resistance of the soil.
3) Three soil models were made so that the first is unimproved soil without any additions, while the second is by adding 9% of sodium silicate to crushed concrete and the end of the columns is floating and not based on a strong layer, while the last model is with the same properties and additions, but that the soil is based on a layer Strong and end bearing.
4) A piece of metal with dimensions of (100×100×6) mm was used as a basis for conducting the test.
5) Two dial gauges are mounted in positions to measure the settlements.
6) Then, loads are applied through a hydraulic jack. The loading rate was kept constant at 1 mm/min, and the load was evaluated by the load cell, logged by load indicator during loading increments. Dial gage was read at the end of the period of each incremental loading or until the reading of settlement became constant, see Figure 2.

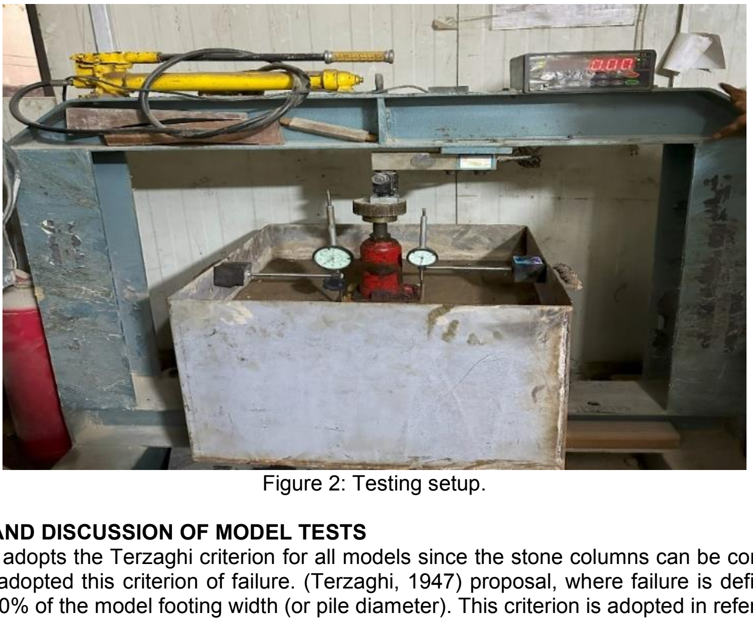

Figure 2: Testing setup.

4. RESULTS AND DISCUSSION OF MODEL TESTS

This study adopts the Terzaghi criterion for all models since the stone columns can be considered piles. ASTM-D1143 adopted this criterion of failure. (Terzaghi, 1947) proposal, where failure is defined as a load equivalent to 10% of the model footing width (or pile diameter). This criterion is adopted in reference [16].

 https://doi.org/10.1051/e3sconf/202342701030

4.1 Model Tests on Untreated Organic Soil

The test was carried out on a sample of organic soil that was previously mobilized, and the foundation was installed in the middle of the box until failure occurred in the soil. Figure 3 shows the bearing ratio qu/cu versus settlement ratio $S/B_{footing}$. The bearing ratio at failure is 0.91 was adopted.

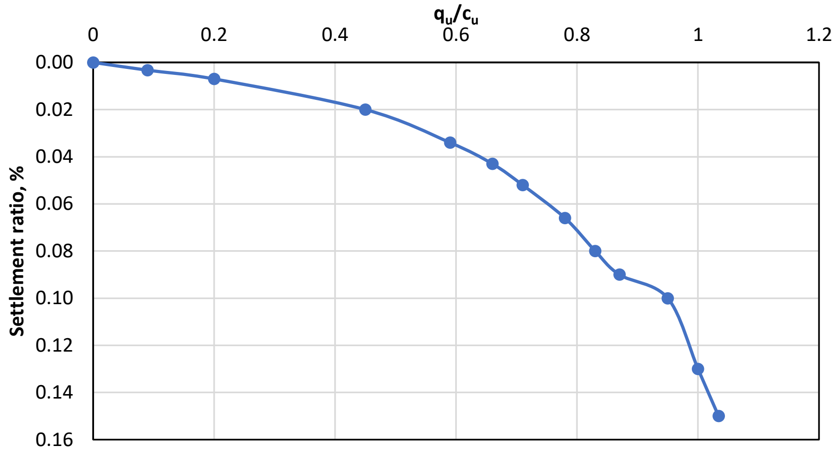

Figure 3: Bearing ratio versus settlement ratio of untreated soil.

4.2 Floating Type / 12 Days Curing

The soil model was reinforced with four concrete columns, and sodium silicate was added to it to increase cohesion. The ratio was obtained through previous practical experiments and the treatment period in which the columns are left to increase their cohesion. Figure 4 presents the q/cu against $S/B_{footing}$ for crushed concrete columns with 6% sodium silicate. It is noted that at the beginning of the examination for both tests, the prospective behavior of the improved and unimproved soils is below 0.5 from q_u/c_u. While this value exceeds the amount of stress, it will clearly show the amount of improvement in the soil. As the value of q_u/c_u reached 1.5, this indicates an improvement in the shear stress of this soil.

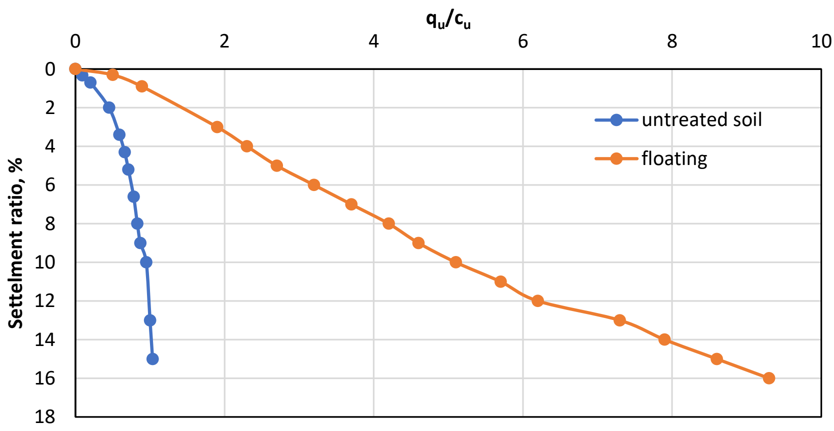

Figure 4: Bearing ratio versus settlement ratio of crushed concrete column treated with 6% SS (Floating type).

4.3 End Bearing Type / 12 Days Curing

As was previously done in the previous experiment, it is to install four columns inside the soil of crushed concrete after mixing them with sodium silicate, then shedding loads on the soil until failure is complete. Figure 5 shows the difference between the unimproved soil and the soil that the two methods have improved, as it is clear that the soil improved by the end bearing gains more hardness and durability than the soil improved by the floating method, as well as the unimproved soil. Table 4 shows the type and amount of failure and the amount of improvement. The value of the Bearing ratio at the point of failure, according to the Terzaghi hypothesis, reached 9.4, and this number is considered very good for improving weak soils.

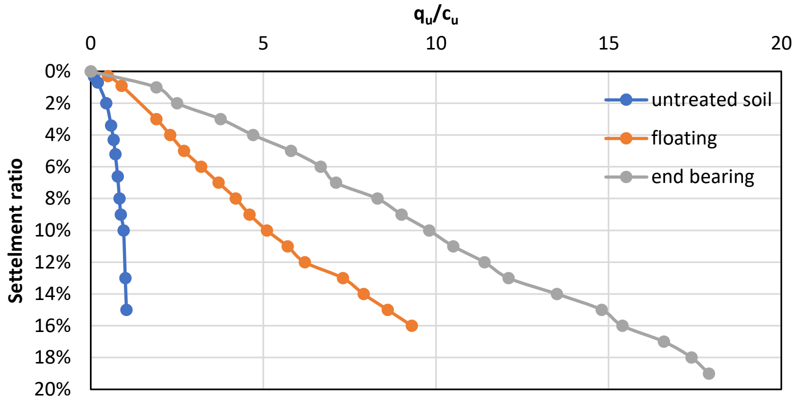

Figure 5: Bearing ratio versus settlement ratio of crushed concrete column treated with 6% SS (End bearing type).

Table 4: Summary of crushed concrete columns stabilized with 6% SS of both cases floating and end bearing.

item	type	q_u/c_u at failure	Improvement ratio (%)
Untreated soil	---	0.91	---
Crushed concrete +9% SS. columns	Floating	4.86	423
Crushed concrete +9% SS. columns	End bearing	9.4	710

5. CONCLUSIONS

- The bearing capacity improvement and settlement decrease were achieved with acceptable results when liquid sodium silicate was used to strengthen broken concrete. The strength of crushed concrete increases as the percentage of sodium silicate increases until it reaches its maximum strength at 9%; however, after 9%, the strength decreases as the percentage of sodium silicate increases, possibly because sodium silicate has switched from being a cementing agent to a lubricant.
- The ability of columns to increase soil's bearing capacity demonstrated that end-bearing columns always produce the greatest degree of improvement.
- After 12 days of curing, crushed concrete columns stabilizing with 9% sodium silicate in the floating type gave an improvement ratio of 4.23 compared to unimproved soil, while in the end bearing type, the improvement ratio was 7.1 compared to unreinforced soil.
- Because sodium silicate acts as a cementing agent and increases the stiffness of the column, using 9% sodium silicate as a stabilizing agent with crushed concrete columns often gave advantages in terms of improvement ratio and bearing capacity ratio.

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