Effect of installing columns from different solid waste materials on the soft clay bearing capacity

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Abstract. Soft clay deposits cause many problems due to low bearing capacity and high deformation. This paper presents the results of laboratory model tests for studying the improvement of soft clay-bearing capacity using two kinds of soil columns, the first is slag-cement dust columns and the second is bentonite column. Three columns from SCC (slag-cement dust columns) encased by Woven Geotextile are installed beneath a steel plate representing a footing. Four bentonite Columns (BC) encased with non-woven geotextile are installed around the steel plate at a distance of 1 B, where B is steel plate width. The research aims to assess the increase in the SCC length effect on clay-bearing capacity. A series of 4 experimental tests were performed. The results show that, the clay bearing capacity increased with the increase of column length because slag and bentonite can absorb the clay water content, leading to an increase clay shear strength. Floating columns gives better improvement than the end bearing columns. The slag partially replaced with cement dust is weak enough to transfer the total applied stress to a strong soil layer.

1. Introduction

A wide range of various improvement techniques is implemented to improve the clay-bearing capacity and reduce excess settlement such as stone columns[1], grouting with lime, lime silica [2], and [3]. Some techniques depend on using lime, fly ash, and cement, as presented by [4], [5],[6], [7]. Further improvement to the soft ground by introducing the soil-cement column method as reported by [8]. Alternative methods to enhance the load-bearing capacity of soft soil by soil reinforcement technique are presented by [9]. The bearing capacity of footings on soft clay can considerably be improved by placing a layer of compacted granular fill of limited thickness without/with geotextile or geogrid reinforcement at the sand-clay

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interface [10]. Some of these techniques are very expensive because of raw material and installation expenses, columns using waste material are one of the most are one of the most effective and economic techniques. Soil columns are installed in the field with the same methods. Although the columns method is widely used, the interaction between the soft soils and the column is not well - understood, but it proved to give excellent results. There are different solid waste materials produced in Egypt due to the industrial factories, and these materials cause environmental pollution. Slag & cement dust are solid waste materials produced from steel and cement production. In this study, Slag – cement dust columns (SCC) are installed in soft Clay beneath a steel plate as isolated footing with dimensions 200 mm * 200 mm * 20 mm. Bentonite columns (BC) are installed around the steel plate. Soft Clay used in this research was brought from Mahmoudia city – Alexandria government. SCC is encased by woven geotextile, while a non-woven geotextile encasement was used for the BC. The proposed research studies the effect of floating columns and end-bearing columns on soft clay-bearing capacity and settlement. The columns length was 60%, 80% & 100% from the clay layer thickness.

2. Experimental material.

2.1 Soft Clay

The soft soil used in this research was natural deposit soft clay from Alexandria**.** The physical and mechanical properties of the clay under study are listed in Table 1. The tests were carried out According to Egyptian Code for Soil Mechanics and Executing the Foundation 2009, Part 2

Table 1. Laboratory Tests for Soft Clay

Test	Property	Value
Atterberg limit	Liquid limit	151.5%
	Plastic limit	42.5%
	Plasticity index	109%
	Soil classification	CL
Water Content	Moisture Content	79 %
Consolidation test	Cc	0.5
	Cr	0.09
	OCR	2.47
	K (m/day)	$1.0*10^{-7}$

2.2 Slag

Slag material is considered as a solid waste material from the manufacture of steel. The slag type used in this research was water-cooled Blast furnace slag because, that type can absorb water. Slag mixed with a small amount of cement dust to form the final mixture material was used to form columns beneath the footing. Table 2 shows the laboratory tests for slag.

Table 2. Slag Properties Analysis Results

Property	**Property**	**Value**
Relative Density	Minimum Density (Ɣ min.)	1.36
	Maximum Density (Ɣ max.)	1.75
Absorption (%)		30.14

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2.3 Cement dust

Cement dust is a solid waste material from the Tora factory in Egypt. A chemical analysis test was performed to determine the cement dust components, as shown in Table 3.

Table 3. Chemical Analysis Results for Cement Dust

Component	Tio2	Sio2	Al2o3	Fe2o3	MgO	Cl-	So3	L.O. I	moisture
Percentage	N. D	0.97	2.4	0.8	1.7	19	7.1	12	0.03

2.4 Encasement material

Woven geotextile and non-woven geotextile were used to wrap columns. Woven geotextile was used to confine the SCCs, providing strength against the lateral pressure due to the stress applied. It can interlock with Clay because the openings' sizes are slightly oversized. Non-Woven geotextile was used to confine the bentonite columns, preventing the mixing between Clay and bentonite and allowing the excess water to enter the column to be absorbed by bentonite. Table 4 shows the Geotextile properties.

Table 4. Geotextile Properties [11]

Test	Reference	Woven Geo. Result	Non-Woven Geo. Results
Fabric weight (kN/m2)	ASTM D-5261	1.2	4.38
Tensile strength (kN/m)	ASTM D-4595	25	5.86

2.5 Trial mixes from slag & cement dust

Different percentages of cement dust & slag were mixed and submerged in water for seven days to determine the optimum mix for using it to form SCC. After seven days, samples were extracted from water and tested. The optimum percentage is corresponding to the maximum compressive strength after seven days. The results in
Fig. **1** showed that the optimum percentage for cement dust and slag was 17 % & 83 % slag, respectively. These percentages will be used to form the SCCs.

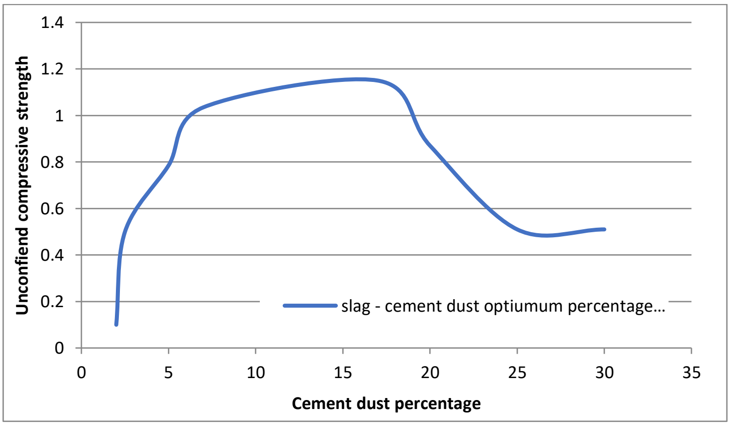

Fig. 1. The Cement Dust Optimum Percentage

3. Physical model setup

3.1 Model component

A three-dimension steel model with dimension of 1.0 m * 2.0 m * 1.0 m was used to perform tests on soft Clay. Fig. **2** show the model schematic view.
The model consists of:

1- Steel tank is placed on a reinforced concrete pad with dimensions of 2.0 m * 3.0 m * 0.5 m.
2- I-beam with length of 4.00 m is responsible for transferring and magnifying the imposed load.
3- A steel box that carries a counterweight to the beam was installed as shown in Fig. **3**.

The model is similar to a large consolidation device. All tank sides were painted with non-erosion paint.

Fig. 2. Photo Shows The Lab Model

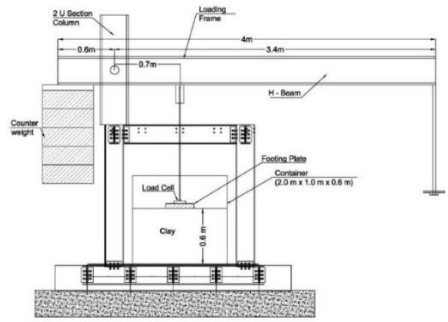

Fig. 3. Large Scale Odometer

3.2 Test preparation

The following procedures were performed before conducting the experimental tests:

1- The base filter consists of gravel wrapped by non-woven geotextile. The purpose of the installation is to decrease the test consolidation time. The filter is wrapped with geotextile to prevent mixing gravel and Clay.
2- Soft Clay was placed in layers and mixed with water until the clay cohesion reached 12 kPa to reach the initial cohesion. The clay bed thickness is 55 cm.
3- SCC & BC were installed by the displacement method using a 5.0 cm diameter PVC pipe. The geotextile is wrapped around the outer pipe face and installed in Clay. Then the mix was placed inside the pipe using a funnel and compacted until the column material reached the maximum density. During the compaction, the pipe was extracted, and the geotextile is remained in Clay to form SCC and BC columns. after compaction, the density of Slag- cement dust material was density 1.7 t/m3 (Fig. 4).
4- A sand layer with a thickness of 5.0 cm was placed above the SCC to work as a sand filter to decrease the consolidation time during the test. (Fig. 5)
5- After columns installation, a steel plate with dimension 200 mm * 200 mm * 20 mm was used as a footing above SCC. The measuring system is as follow:
 - a load cell was used for measuring the applied loads on footing.
 - LVDT was used for recording the footing settlement during a test.
 - A strain gauge was used for observing the geotextile hoop strain during the test.

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Finally, the test configuration was ready to perform the proposed tests.

Fig. 4. After Columns Installation

Fig. 5. Loading Configuration Installation

3.3 Loading procedure

After the test configuration was ready, different loads were applied to the clay bed for each test. An I-beam is responsible for transferring and magnifying the loads on Clay. The beam transfers the load to the load applier rod and magnifies it by a factor of 4.

4. Experimental program

The main testing program consisted of 4 tests. Table 5 shows the experimental test configuration.

Table 5. Experimental Test Program.

Test No.	Footing size	Column Length	Column Diameter	Spacing	Area Ratio
T 0 E	200 mm * 200 mm	Control Test			
T 1 E		60%	50 mm	122 mm	15%
T 2 E		80%	50 mm	122 mm	15%
T 3 E		100%	50 mm	122 mm	15%

5. Experimental tests results and discussions

5.1 Clay failure shape

After gradual applying of the load., the clay yield failure shape as shown in Fig. 6. During and after the tests, some cracks were created in the clay surface due to the drying process as the installed columns absorbed the clay water content from the surrounding area. These cracks proved that SCCs and BC did their function to absorb water from the surrounding soil. Fig. 7& Fig. 8 show the bentonite and slag-cement dust soil after the test.

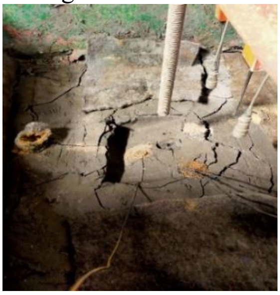

Fig. 6. Clay Failure Shape

Fig. 7. Bentonite Soil After the Test

Fig. 8. Slag – Cement Dust Soil Mixture After the Test

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The soil columns were observed to be in saturated case. The slag-cement dust seems to be as gravelly soil, because the cement dust material cemented the slag particles with each other, due to the hydration process in the presence of water. Samples from bentonite and slag – cement dust mixture were taken before and after the test. Fig. 9 & Fig. 10 &. For slag-cement dust soil, the water content before the test was almost 0%, but the water content varied from 15 to 20 % after the test. The soil's ability to absorption depends on the surrounding water content as the clay water content varies vertically and horizontally. The moisture content of SCCs after the test was nearly around 35% compared to a value of about 13 % before the test.

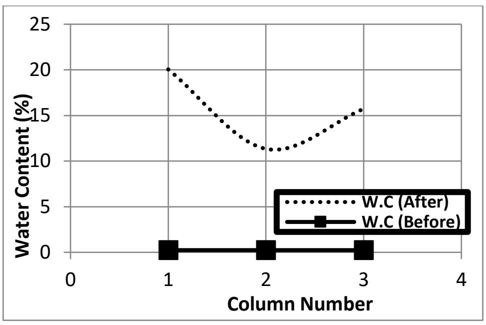

Fig. 9. Water Content for SCCs before and after Test (T 2 E)

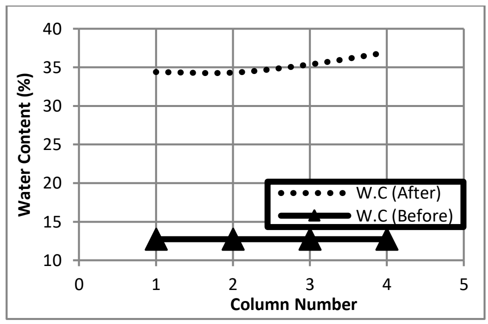

Fig. 10. Water Content for BC columns before and after test

5.2 Effect of column length on bearing capacity

From the test results it was found that, the installation of SCCs and BC in soft clay increase the clay bearing capacity because the installed columns accelerate the exit of water from clay so, the consolidation rate and clay shear strength increased. In case of increasing the columns length, the surface exposed to the columns became greater thus, the treated area become larger. In addition, the friction surface between the columns and the clay increased so the clay bearing capacity increased. In case of end bearing columns (columns length equal 100 % from the clay bed thickness), the clay treated with end bearing columns was enhanced more than clay treated with floating columns but with small difference as the columns soil cannot transfer the total stress to the deeper soil as the column soil is not very hard to transfer loads [13]. Fig. 11 shows the comparison between all tests.

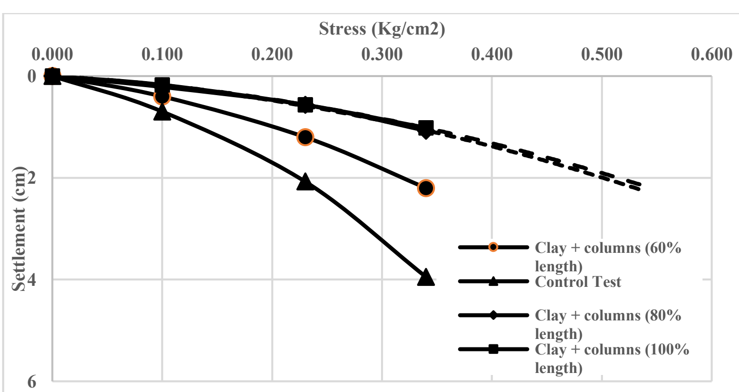

Fig. 11. Load Settlement Curves For Experimental tests

5.3 Bearing capacity and improvement percentage

Table 6 shows the soil bearing capacity in each test according to the Terzaghi method & De Beer's (1967) method and shows the improvement percentage. According to the De Beer method, the ultimate bearing capacity can be taken at the breakpoint between two straight lines with a different slope. Bearing capacity corresponds to the 10% settlement of the footing width according to Terzaghi methods. The improvement percentage can be calculated from equation (1).

$$\mathrm{I.P} = \frac{\mathrm{Qtreated}}{\mathrm{Quntreated}} * 100 \quad (1)$$

Table 6. Shows the Ultimate Bearing Capacity for Each Test and The Improvement Percentage.

Test No.	Q Untreated (Kg/cm²)		Q treated (Kg/cm²)		I.P (%)	
	Terzaghi Method	De Beer Method	Terzaghi Method	De Beer Method	Terzaghi Method	De Beer Method
T 0 E	0.24	0.22	Control Test			
T 1 E			0.32	0.25	133.3	113.63
T 2 E			0.5	0.4	208.3	181.81
T 3 E			0.58	0.53	241.67	240.9

5.4 Variation in geotextile hoop strain

As a result of loading soft clay treated with SCCs and BCs, the cross-section of the column was changed because of bulging. The bentonite column volume changed due to swelling. At the end of the test, the SCC's & BC's cross-sections were measured using strain gauges along their lengths, to deduce the difference in cross-section. Fig. 12 shows the horizontal deformation in the SCCs cross-section. The results show that the maximum bulging nearly occurred at the column mid-height. Fig. 13 shows the difference in BC's cross-section. The BCs cross-sections increased because the clay water absorption offset the volume change for BC whole volume.

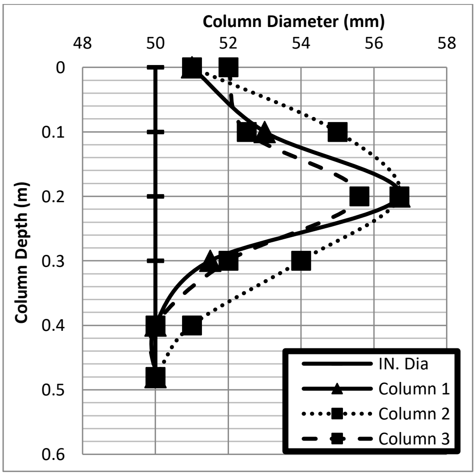

Fig. 12. Hoop Strain For S-C Columns for Test T 2 E

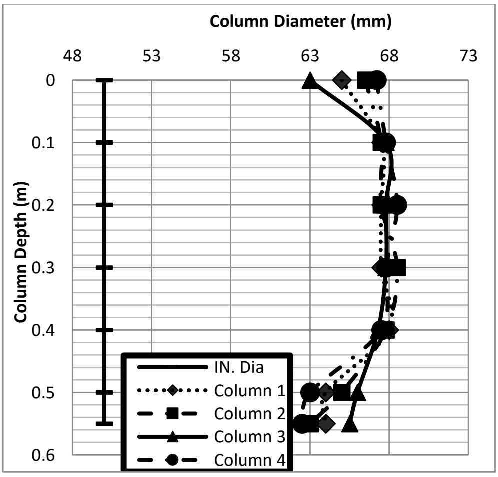

Fig. 13. Hoop Strain For Bentonite Columns for T 2 E

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6. Conclusions

Depending on the Experimental & Laboratory tests performed, it can be concluded that:

- SCCS & BCs enhanced the soft clay ultimate bearing capacity by 241 % because the installed columns absorbed the water content from the surrounding area so, the consolidation rate and clay shear strength increased, and also, the SCCs act as a friction pile due to the interaction between the columns soil and Clay in the presence of woven geotextile.
- The increase in column length led to an increase in clay ultimate bearing capacity as the surrounding soil between columns and Clay increased, so the friction surface also increased.
- Bentonite and slag have an excellent effect for absorbing clay water content, leading to an increase in hear strength, and consequently the composite ground bearing capacity.
- The encasement material provides the SCCs with strength towards lateral loads.

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