ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 1, No. 51 Jan 2022, pp.73-79
Journal Homepage: erj.bu.edu.eg

Experimental Assessment of Stone Columns on Embedded Retaining Walls Behavior

Amani G. Salama(1), Waleed S. Abdallah (2), Nasser M. Saleh(3), Waleed A. Dawood(4)

[1]AssistantProfessor, Geotechnical Engineering Department of civil engineering, Shubra Faculty Benha University.
[2]Teaching Assistant, Geotechnical Engineering Department of civil engineering, Shubra Faculty Benha University.
[3]Professor, Geotechnical Engineering Department of civil engineering, Shubra Faculty Benha University.
[4]Assistant Professor, Geotechnical Engineering Department of civil engineering, Shubra Faculty Benha University.

Abstract : Stone column is one of the most effective techniques used in soil enhancement. Inserting stone columns under strip footing in the active zone of a retaining wall embedded in soft soils enhances the allover behavior of the retaining wall. Stone columns improve the bearing capacity under the footing, decreases the settlement of the footing, and decreases the lateral movement of the retaining wall. Increasing area replacement ratio of stone columns improves the bearing capacity under the footing, reduces settlement, and decrease the lateral movement of retaining wall.In this resaerch an experimental study was carried out on changing the area of replacement ratio of stone columns inserted in very soft clay in the active zone of embedded retaining wall with strip footing load at the top of backfill.Increasing stone columns area replacement ratio improves the bearing capacity under the footing, reduces settlement, and decrease the lateral movement of retaining wall.

KEYWORDS: Stone Column;Soft Clay;Embedded Retaining Wall;Strip Footing, Lateral Displacement; Vertical Settlement.

Introduction

Nowadays, geotechnical engineers face many challenges and risks to construct on weak soils that they natively are not suitable for construction on them due to their adverse properties. Soft and very soft clay soils are considered one of the most problematic soils owing to high compressibility, low shear strength, global or local instability, and low bearing capacity [1]. Construction on such poor soils will be an expensive and time-consuming operation using traditional methods. Therefore, engineers should use one of the soil improvement methods to enhance the weak soil and make it valid for constructions such as compaction, preloading, soil stabilization using lime, fly ash, cement, lime-cement, soil reinforcement and stone columns.

Stone columns are one of the most effective techniques used in soil improvement. They are ideally suited to improve soft clays, silts, and loose silty sands. The stone column has proven a great success in many applications such as improving the slope stability, improving the bearing capacity of the soil, decreasing the total and differential settlement of the soil, reducing the potential of liquefaction of loose sands and increasing the settlement time rate [2].

Patel Paresh [3]used a PLAXIS to determine the factor of safety for slopes reinforced with single & multi-rows of stone columns. He approved that the effective location of a single row of stone column is at 0.25L from the slope crest where L is the slope length; and that for two rows of stone column is 0.25L & 0.50L from the slope crest; also, internal friction angle and column diameter have a great effect on slope stabilization; and a gentle slope provides a higher factor of safety than a steeper slope.

1. LABORATORY MODEL

The used apparatus is shown in Figure 1. It was used by Saleh, Shalaby, Salama, and Hamoda[4]. It consists of a tank containing the soil model, retaining system, loading system, and somedifferent measurement tools.

1.1 The Test Tank

The test tank is a box of rectangular cross section. Its faces are four wooden plates of 18mm thickness. The inner dimensions of the box are 200cm long, 50cm wide, and 110cm high. The four wooden plates are stiffened by vertical and horizontal steel bracing systems. The front longitudinal side has a transparent glass plate between two wooden plates. This front longitudinal side was stiffened by seven vertical box sections (60*40*4) 110cm long spaced at a horizontal distance of 25cm.

2.2 Loading System

This system used to apply static load incrementally on loading plate of dimensions (495*250*25mm)simulating strip footing was loaded with a manual gear box connecting to a pre-calibrated proving ring of 10 kN capacity. The configuration of the system of loading and its components are shown in Figure 2.

2.3 Soil layers.

The soil model was consisted of two layers. The lower one is a sand layer of thickness 30 cm overland by a very soft clay layer of thickness of 60cm.

2.4 Retaining System.

A steel plate is used to simulate the retaining wall embedded in very soft clay. The plate dimensions are 700*496*100 mm as shown in Figure 3.

2.5 Instrumentation.

- Pre-calibrated proving ring of capacity 10KN.
- Stopwatch.
- Two dial gauges (50mm range, 0.01mm precious) for measuring the vertical and horizontal displacement of the footing and the retaining wall respectively.

Fig 1. Apparatus Setup

Fig 2. Loading System

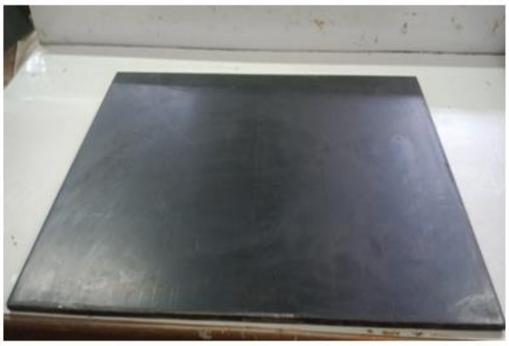


Fig 3. Retaining Wall Plate.

2. Materials Properties

2.1 Clay Properties

The clay used in this research was brought byElleboudy, Saleh, and Salama, [5] from Benha city from depth ranging from 1.0m to 1.5m below the ground surface during open excavation. Figure 4 shows the grain size distribution curve. The clay properties extracted from different laboratory tests are listed in table 1.

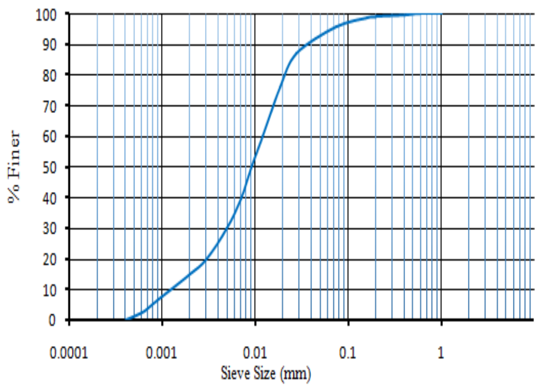


Fig 4. Grain Size Distribution Curve for Clay

Table 1: Properties considered for clay in testing program.

Parameters	Value
Specific gravity (Gs)	2.70
Liquid limit, LL (%)	65
Plastic limit, PL (%)	31
Plasticity index, IP (%)	34
Bulk density in test, γ_b(kN/m^3)	15.6
Water content in test, wc (%)	59
Undrained Cohesion, Cu(kN/m^2)	(6-8)
% Sand	7
% Silt	63
% Clay	30
Unified soil classification system	CH

3.2 Sand Properties

Thesandused inthisstudywas taken fromasiteat6th of October City. It was left to dry well inopenair.Figure 5shows the grainsize distributioncurve for the sand.The sand properties are listed in table 2.

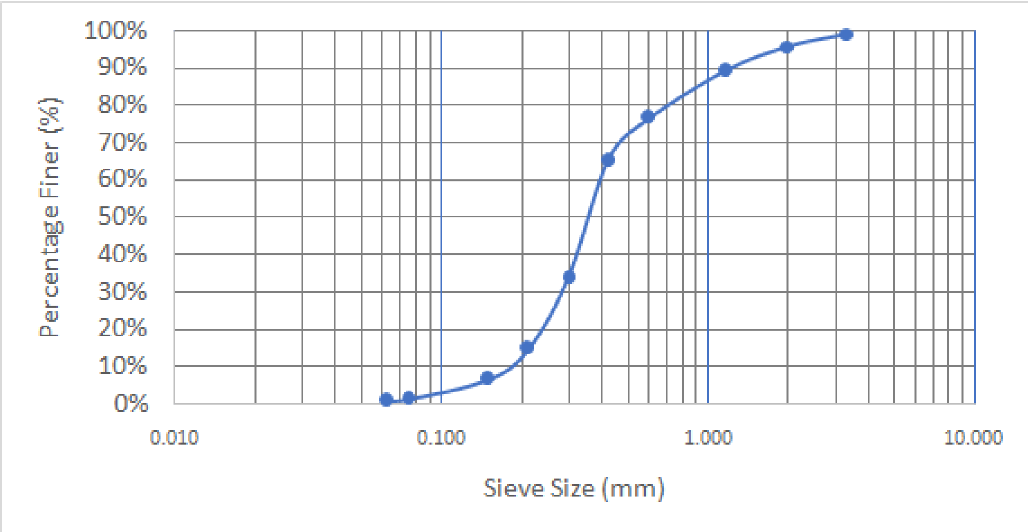


Fig 5. Grain Size Distribution Curve for Sand

Table 2: Properties considered for sand in testing program

Parameter		Value
Maximumdrydensity(γ_d) max(kN/m^3)		19.3
Minimumdrydensity (γ_d) min(kN/m^3)		15.5
Specificgravity of solids (G_s)		2.66
Maximumvoid ratio (e_{max})		0.72
Minimumvoid ratio(e_{min})		0.38
Grainsizedistribution	Coefficientof Uniformity(c_u)	2.22
	Coefficientofcurvature (c_c)	1.09
	EffectiveDiameter(D_{10}) (mm)	0.18
Unifiedsoilclassification system		SP
Angle of internalfriction (∅)in the test		35

3.3 Crushed Stones Properties (Stone Columns)

The crushed stones were brought fromasite near to Shoubra faculty of engineering. First It was shaked on 2mm sieve and the soil particles less than 2mm were omitted. The grainsize distribution curve of the stones is shown in figure 6.The crushed stones properties used in the test are listed in table 3.

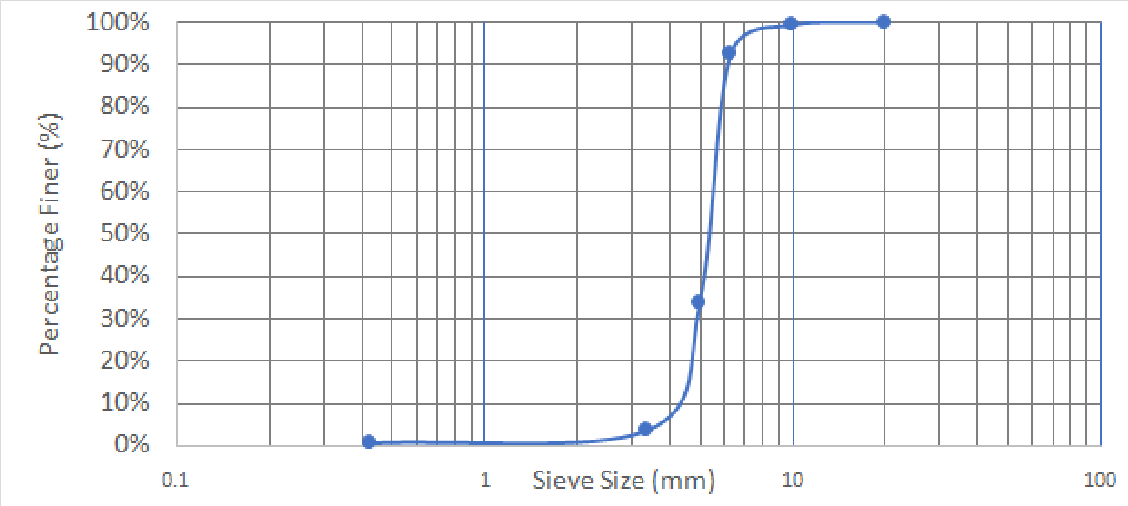


Fig 6. Grain Size Distribution Curve for Crushed Stones.

Table 3: Properties considered for crushed stones in testing program.

Parameter		Value
Maximumdrydensity(γ_d) max(kN/m^3)		17.4
Minimumdrydensity (γ_d) min(kN/m^3)		13.4
Specificgravity of solids (G_s)		2.64
Maximumvoid ratio (e_{max})		0.97
Minimumvoid ratio(e_{min})		0.52
Grainsizedistribution	Coefficientof Uniformity(c_u)	1.29
	Coefficientofcurvature (c_c)	1.06
	EffectiveDiameter(D_{10}) (mm)	4.20
% Gravel		80%
% Sand		20%
Unifiedsoilclassification system		GP
Angle of internalfriction (∅)in the test		45

4. Experimental Program

4.1 Parametric Study

The experimental program was summarized in table 4.

Table 4: Tests carried out in the experimental program.

Test ID	Test Description	Installation zone	Area Replacement Ratio	Stone column length to clay layer depth %
PC	Pure Clay (Base Case)	***	***	***
A25%F	Active 25% Fully	Active	25%	100%
A30%F	Active 30% Fully	Active	30%	100%
A35%F	Active 35% Fully	Active	35%	100%

4.2 Testing Procedures

➢ The experimental test of pure clay case was carried out as the following steps:

1. The sand layer of 30cm was placed into the tank on lifts and compacted to a relative density of 65%.
2. The clay layer of 60cm was placed above the sand layer on lifts, compacting it using steel tamper to avoid creating voids.

3. Theretaining wall was inserted into the clay and rested on the sand layer forming an excavation of 35cm and embedded 25cm into the clay.
4. The plate simulating the strip footing was placed on the top of clay layer in the active zone. This plate introduces an initial stress of 2 kN/m^2.
5. The load was applied by a handle gear box in a rate of 1.2mm/min till the retaining wall (vertical steel plate) exhibited failure.
6. The vertical displacement of the center of the plate and the horizontal displacement of the top of retaining wall were recorded.

- The experimental tests of stabilized clay with stone columns were carried out as previous, but the stone columns were executed by inserting a steel casing and making a hole using a hand auger and then the crushed stones were inserted into the hole compacted to 61% relative density.

  The following figure shows the geometric models for tests different cases.

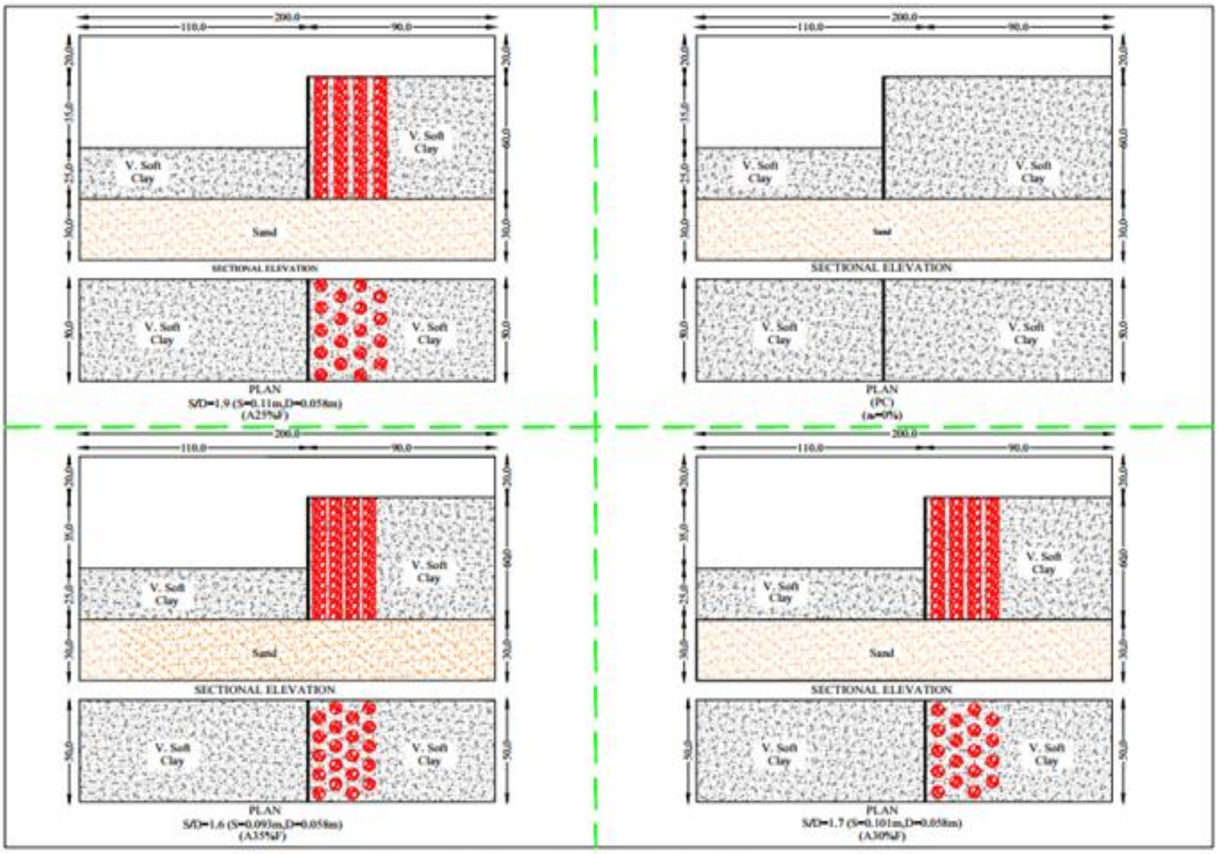


Fig 7: Geometric Models for different tests

5. Results.

5.1Testing results.

The area replacement ratio of stone columns is one of the most significantparameters controlling the response of the stone column stabilized soil. The effects of the area replacement ratios on horizontal and vertical displacement of the stone column stabilized soil have been investigated and showed in the followingsubsections. The tests in active zone of the retaining wall are conducted using area replacement ratios of 25, 30, and 35%.

The results are presented in this section using figures that shows the relation between the applied stress(kpa) and the vertical and horizontal displacements(cm).

- **Vertical Displacement Results**

  Figure 8 shows the relation between the external applied stress on the strip footing and the vertical settlement of the footing in case of the pure clay and the stone columns stabilized clay in active zone with different percentages of area replacement ratios of stone columns.

- **Horizontal Displacement Results**

Figure 9 shows the relation between the external applied stress on the strip footing and the horizontal displacement of the top of the retaining wall in case of the pure clay and the stone columns stabilized clay in active zone with different percentages of area replacement ratios of stone columns.

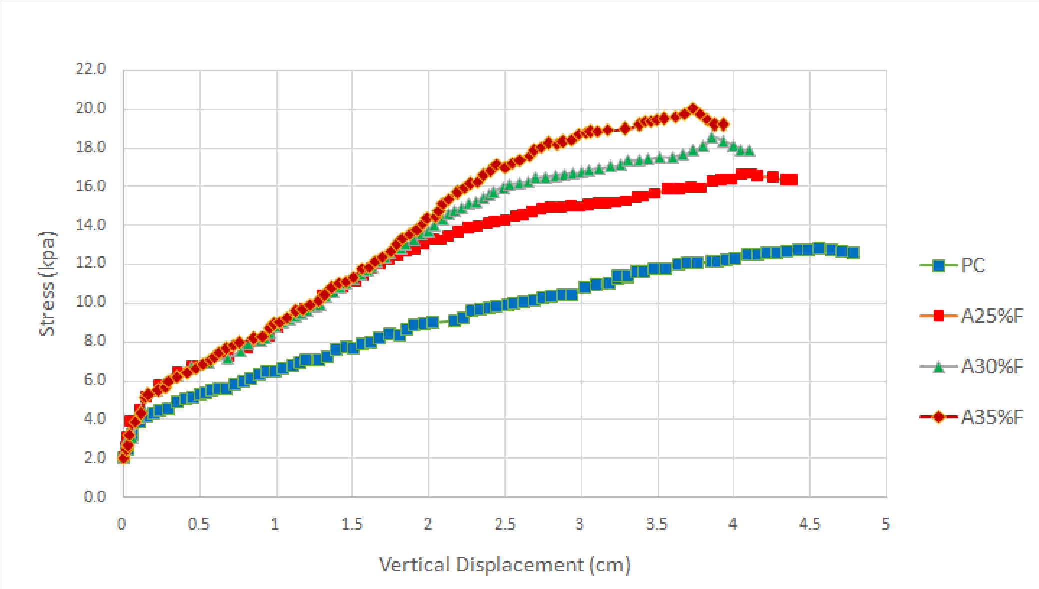
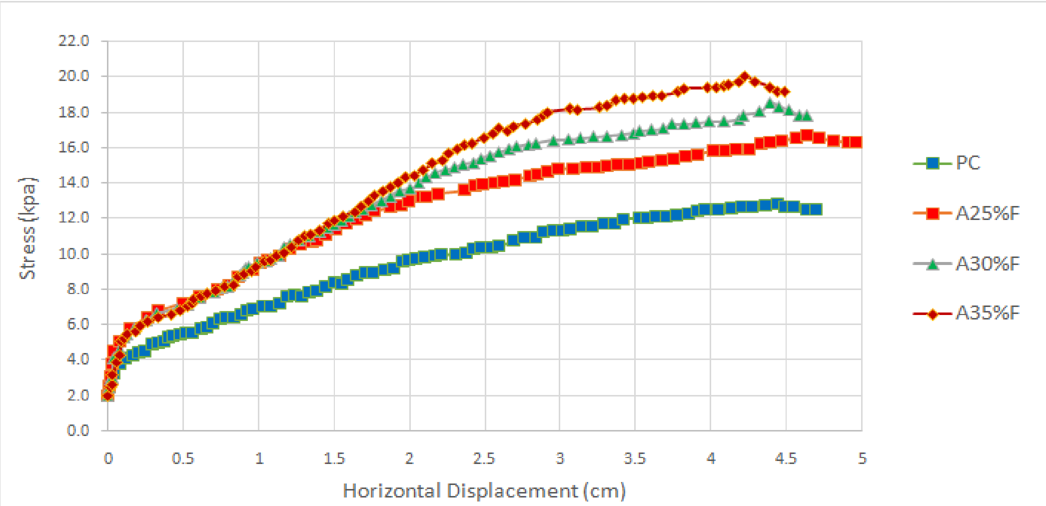


Fig 8. Applied Stress vs Vertical Displacement for Strip Footing.



. Figure 9.

Fig .9 Applied Stress vs Horizontal Displacement of Retaining Wall

Test ID	Max. Vertical Stress (kpa)	Max. Vertical Settlement (cm)	Max. Horizontal Displacement (cm)	Increase in Vertical Stress (%)	Decrease in vertical Settlement (%)	Decrease in HorizontalDisplacement (cm)
PC	12,6	4,56	4,44	***	***	***
A25%F	16,5	4,12	4,64	31%	10%	-5%
A30%F	18,3	3,86	4,39	45%	15%	1%
A35%F	19.8	3,73	4,22	57%	18%	5%

Note that: the stresses in the previous table include the initial stress exerted by the loading plate that simulate the strip footing

.

5.2 Conclusions

The following points can be concluded from the previous table and from the experimental tests performed on the strip footing placed on the surface of the active zone of a retaining wall embedded in very soft clay soil.

1- Inclusion of stone columns in soft soils increases bearing capacity of soil.
2- Inclusion of stone columns in soft soil decreases the footing settlement.
3- Inclusion of stone columns in soft soil decreases the horizontal displacement of the retaining wall.
4- Increasing area replacement ratio increases the bearing capacity and decreases both horizontal and vertical displacements.
5- It is economically not recommended to use stone columns with area replacement ratio more than 35%.
6- The enhancement of soil is not significant for very soft clay with very low shear strength, so it is not recommended to use stone columns in soft soil with very low undrained cohesion.

6. References

[1] Han, J. and Gabr,M.A. (2002)"Numerical Analysis of Geosynthetic-Reinforced and Pile-Supported Earth Platforms over Soft Soil"*Journalof Geotechnical and Geoenvironmental Engineering,* vol. 128, no. 1, Pp. 44–53.

[2] Barksdale, R.D. and Bachus,R.C. (1983)"Design and Construction of Stone Columns Vol. I ",*FHWA/RD-83/026, Federal Highway Administration, Washington, D.C*. vol. I,Pp.1-5.

[3] Paresh, P. and Vasanwala, S. (2012). "Numerical analysis of slope reinforced with stone column" *InternationalJournal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development,* vol. 2(2), Pp10-16.

[4] Saleh, N.M.,Hassan,A.S., Salama, A.G., and Hamoda,A.S.(2019)"Performance of soft clay stabilization using geocells under shallow footings"*Engineering Research Journal.*

[5] Salama, A.G.,Saleh,N.M. and Elleboudy,A.M. (2017)"Assessment of geogrids in gravel roads under cyclic loading"*Alexandria Engineering Journal*, vol. 56, no. 3, Pp. 319–326.