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Bearing Capacity of Soft Clay Soil Improved By Sand Bed Over Geosynthetic Encased Stone Columns, Case of Study

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ABSTRACT: One of the biggest challenges faced by geotechnical engineers is the construction on soft clay soil. It is being one of the most erratic soils with very low bearing capacity and high compressibility. Many techniques, such as stone columns and geosynthetic reinforced sand bed, are effective means of performance improvement of foundations on soft clay soil. Although their individual applications have been studied extensively, the combined application of both has limited studies. Stone columns develop their load carrying capacity from the circumferential confinement provided by the surrounding soils. In very soft soils, an important problem which should be taken into account for designing stone column is bulging as the circumferential confinement offered by the surrounding soft soil may not be sufficient to develop the required load carrying capacity. Hence a confinement by geosynthetics would yield a better result and prevents squeezing of stones into the surrounding clay. The load carrying capacity is further increased and settlement is decreased with the addition of a sand bed over the stone columns, also this layer of sand is used to let the foundation distribute its load uniformly. In the current research, a series of numerical model tests for a case of study on an unreinforced sand bed (USB) and a geogrid reinforced sand bed (GRSB) placed over a vertically encased stone column (ESC) floating in soft clay. Soil samples were taken form Oncology Hospital 2020 site at Assiut University, Assiut City, Egypt and a laboratory tests were conducted at the Soil Mechanics and Foundations Laboratory on triaxial device and some other devices. Three dimensional finite difference numerical models were performed using a finite difference package FLAC3D. For all different improvement cases, the results indicate that the bearing capacity ratio, BCR, increases to reach 1.83, 2.58, 3.59 and 8.07 fold, as compared to unimproved clay bed, for the cases of ordinary stone column (OSC), (ESC), (USB+ESC) and (GRSB+ESC) respectively.

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Keywords: Soft clay; Ground improvement; Stone column; Geosynthetic; Sand Bed.

1. INTRODUCTION

Due to the ever increasing demand for land space because of increased construction activity worldwide, there is an increasing need to improve soft soil grounds which otherwise are unsuitable for adopting the conventional shallow foundations. Using deep foundations, such as pile, to bypass the weak soil is often costly. Ground improvement technique is a potential alternative to mitigate this problem. Amongst the various ground improvement techniques used for improving the in-situ ground conditions, geosynthetics reinforcement and stone column technique are probably the most versatile ones. This is primarily due to their simplicity, ease of construction and overall economy that finds favor with the practicing engineers.

Historically, research studies have been designed to investigate the behavior of ordinary and encased stone column-reinforced clay systems in the laboratory tests and numerical studies that are conducted by (Bergado et al. 1987, El Sawwaf 2007, Elsawy et al. 2009, Black et al. 2011, Ramadan et al., 2015, 2016, Ghazavi et al. 2017 and Ramadan et al. 2018 (a & b)). The concept of using geosynthetics reinforced sand bed has been acknowledged by several researchers (Guido et al. 1989, Latha et. al. 2009, Azzam and Nazir 2010, Laman et. al. 2012, 2014, Das et. al. 2015, 2016 and Infante et. al. 2019). There are very limited experimental investigations or three- dimensional numerical studies to show the combined effect of geogrid reinforced sand bed (GRSB) with encased stone columns (ESC) such as (Thakare and Tanveer 2016, Debnath and Dey 2017, Wu et al. 2019, Ramadan et al., 2021).

The present research main aim is to show the beneficial use of unreinforced or geosynthetic reinforced sand bed over encased stone columns in terms of increasing in bearing capacity and minimizing the settlement. The analysis is carried out using a three dimensional finite difference numerical model FLAC3D and the results of the numerical study conducted for the effect of multilayer geosynthetic-reinforced granular fill over soft soil with encased stone columns on settlement response, bearing capacity and bulging of the stone column were reported.

2. PROPERTIES OF THE USED MATERIALS

A case study of the Oncology Hospital 2020 site at Assiut University,Assiut City, Egypt. In the site under study, it was noticed that a layer of backfill about 3.0 m deep had been removed. A number of boreholes were carried out at the previously mentioned site, Figure 1, and it was found that it contains a soft clay layer with a depth of about 10 m. Soil samples were taken and a laboratory tests were conducted at the Soil Mechanics and Foundations Laboratory, Faculty of Engineering, Assiut University, Egypt, on triaxial device and some other devices.

Figure 1: Oncology Hospital 2020 site, Assiut University, Egypt

According to the results from the laboratory tests, the water content of the natural clay is found to be W_C = 63% and the saturated unit weight is equal 17 kN/m^3. Also liquid limit, plastic limit and plasticity index of the clay soil are found to be 72%, 26% and 46% respectively. According to the Unified Soil Classification System (USCS) the soil can be classified as clay with high plasticity (CH), Figure 2. Undisturbed cylindrical specimens of the soft clay soil (38 mm x 76 mm) were extracted from the soil sample extractor and tested by triaxial compression tests, Figure 3. The properties of the used soft clay soil are given in Table 1.

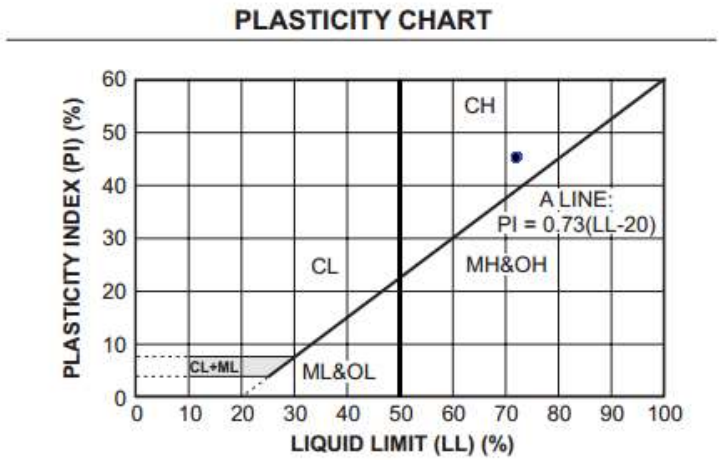


Figure 2. Plasticity chart for the used soft clay soil

Figure 3. Triaxial test equipment

The used sand in this case of study was obtained from a site near Assiut city. The sand was sieved using sieve No. 7, which has opening of equivalent diameter equal to 2.4 mm. The portion passed from sieve No. 7 was used in the laboratory tests. The sand was clean, dry and free from any impurities and large particles. Triaxial compression tests were conducted on sand specimens (50 mm in diameter and 76 mm in height). The sand was sieved using vibrating sieve machine and grain size distribution is shown in Figure 4. The different particle sizes D_{10}, D_{30} and D_{60} are found to be 0.20 mm, 0.31 mm and 0.43 mm respectively. The Coefficient of uniformity (Cu) and Coefficient of curvature (Cc) are obtained as 2.15 and 1.12 respectively. As per Unified Soil Classification System (USCS), the soil is classified as poorly graded sand (SP). The properties of the used sand are given in Table 2. All tests were carried out according to the Egyptian code of soil mechanics and foundation design, part 2.

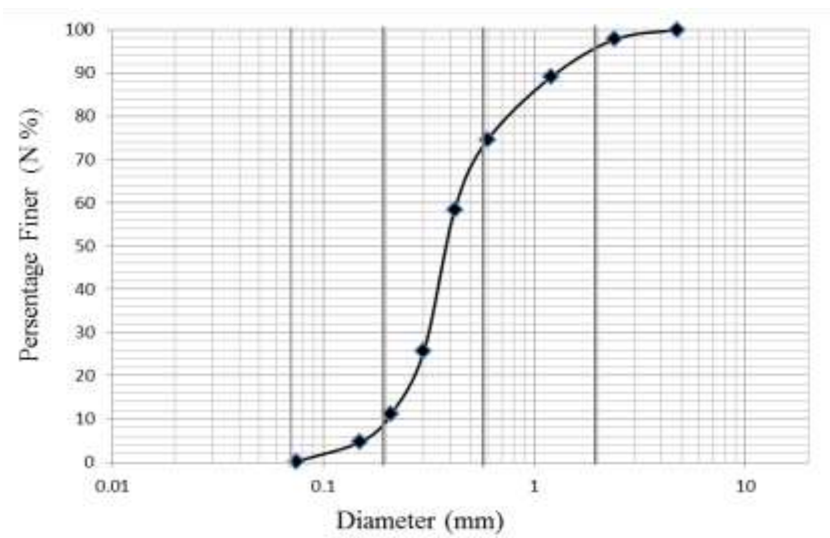


Figure 4. Grain size distribution of the tested sand

Table 1: Material properties of the Soft clay soil

Parameter	***value***	***Unit***
Saturated unit weight, γ_{sat}	17.0	kN/m^3
Dry unit weight, γ_d	10.3	kN/m^3
Natural water content, W_c%	60	%
Void ratio, e	1.59	-
Liquid limit, L.L	72	%

Plastic limit, P.L	26	%
Plasticity index, PI	46	%
Specific gravity, G_s	2.65	-
USCS classification system	CH	-
Young's modulus, E_s = (200 c_u)	4000	kPa
Poisson's ratio, υ	0.45	--
Undrained cohesion, c_u	20	kPa
Friction angle, φ	0.0	Degree
Dilatancy angle, ψ	0.0	Degree

Table 2: Material properties of the used sand

Parameter		value		Unit
		Stone Column	Sand bed	
Dry unit weight, γ_d		16.82	16.82	kN/m^3
Bulk unit weight, γ_b at w_c%=10%,		19.0 , at w_c%=13%	18.0 , at w_c%=7%	kN/m^3
saturated unit weight, γ_{sat}		20.6	20.6	kN/m^3
Specific Gravity, G_s		2.70	2.70	-
Void ratio. e		0.605	0.605	-
Young's modulus, E_s		55000	32000	kPa
Poisson's ratio, υ		0.30		-
Undrained cohesion, c_u		0.0		kPa
Friction angle, φ		40º	30º	degree
Dilatancy angle, $\psi=(\varphi-30)$		10º	0º	degree
Grain size distribution	Mean grain size, D_{50}	0.39		mm
	Effective grain size, D_{10}	0.20		mm
	Uniformity coefficient, $C_u = \frac{D_{60}}{D_{10}}$	2.15		-
	Curvature coefficient, $C_c = \frac{(D_{30})^2}{D_{10}\, D_{60}}$	1.12		-
	USCS classification	SP		-

3. NUMERICAL MODEL AND ITS VERIFICATION

Numerical analyses were carried out by the FLAC3D software (version 5.0) to create a three-dimensional finite-difference model of foundation on soft clay soil improved by adding sand bed over geosynthetics encased stone columns. This software program uses an explicit finite difference technique to solve problems with initial and boundary conditions. The solutions are reached through a process known as time-marching, which is simply adjusting the values of each node in the mesh through a series of cycles or steps. The adjustment continues until the error (e.g., unbalanced force in the system) becomes very small. The displacements in the x, y and z directions were set to zero on the boundary of the soft soil zone. FLAC3D was validated by analyzing the pressure-settlement behavior from laboratory tests of a single stone column by (Ghazavi and Afshar 2013). In this analysis, the soft clay soil was created using brick zones extending radially from a circular hole into which the pile was inserted later. Before inserting the stone column, interface elements were attached to the soil elements where the stone column comes into contact with the soil. A circular column has 100 mm diameter and 500 mm height was created separately and moved into contact with the interface elements. Concerning circular footing has 200 mm diameter and 30 mm thickness was rested on soil and stone column. It is connected to the soil via interface elements. Figure 5 compares the results obtained from FLAC3D analysis and that from the model tests by (Ghazavi and Afshar 2013), where the results match closely.

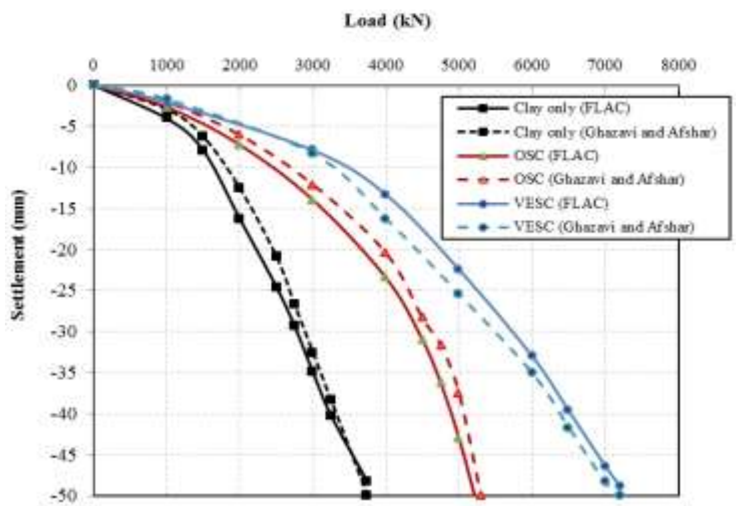


Figure 5. The comparison between results from FLAC3D and model test by Ghazavi and Afshar [7]

4. MODEL DETAILS

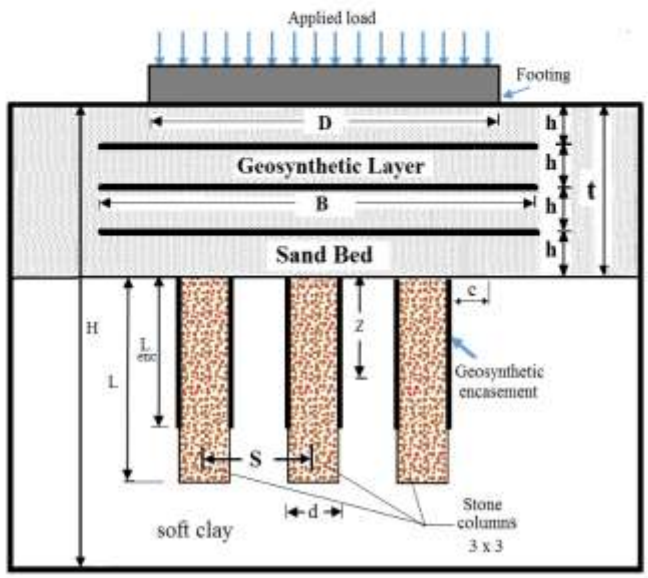
A model was developed containing soil, sand bed, stone columns, footing and geosynthetic encasement as shown in Figure 6. Both the infill material used for the sand bed, encased stone columns and the weak surrounding soil, which was soft clay, were modeled as a linear elastic perfectly plastic material using Mohr-Coulomb criterion. Brick elements were used to model the soil. The stone column is modeled as a massive circular element with outside interface with soil. The column was divided in the radial direction to four parts. It is modeled to behave as a conventional elastic-perfectly plastic model based on Mohr-Coulomb failure criterion in FLAC3D software. The square footing is modeled as square brick elements with 0.7 m thickness, its side length depend on the stone column diameter. The groundwater table was located at the foundation level. Interfaces element is used to represent the connection between footing, sand bed, column, geosynthetics and soil. In FLAC3D, the Mohr Coulomb constitutive model requires wet density (γ), angle of internal friction (φ), cohesion (c), bulk modulus (K) and shear modulus (G). The bulk and shear moduli are both functions of the Young’s modulus (E) and Poisson’s ratio (ν) and are calculated using the following equations:

$$K = \frac{E}{3(1-2\nu)} \qquad (1)$$

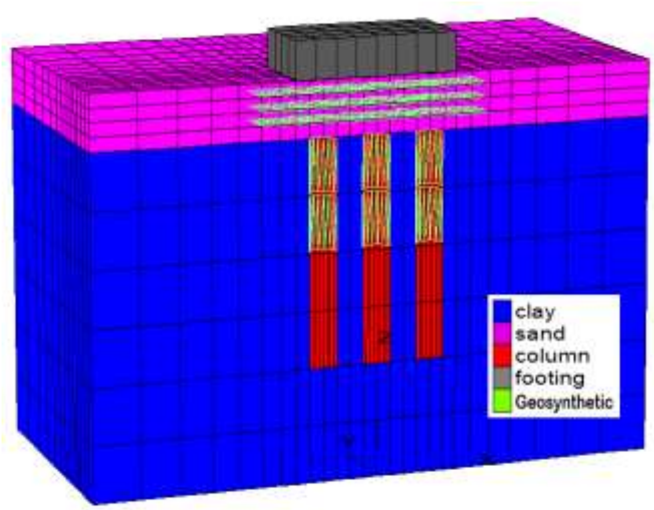
$$G = \frac{E}{2(1-\nu)} \qquad (2)$$

5. CASES OF STUDY

The main factors taken into consideration were: side length of square footing (*D*), stone column diameter (*d*), length of stone column (*L*), encasement length (L_{enc}), axial stiffness of grotextrile encasement for the stone column (J_{sc}), internal friction angle of stone column material (φ_{sc}), thickness of unreinforced sand bed (*t*), vertical distance between geosynthetic layers (*h*), friction angle of sand bed material (φ_{SB}), number of geosynthetic layers (*N*), length of geosynthetic (*B*), axial stiffness of geogrid in the sand bed (J_{SB}) and spacing between stone columns (*S*). The soft clay soil has a depth (*H*) =10 m according to the case study and undrained cohesion (C_u) = 20 kN/m^2. In all cases, the footing is supported by sand bed over single or group of stone columns. The effective stone column length (*L*) to diameter (*d*) ratio was (*L/d*) = 10 (Malarvizhi et al., 2007; Fattah et al., 2012; Ramadan et al., 2015). The effective projection of the footing was (*C*) = 0.5d (Ramadan et al., 2015). The optimum encasement length to diameter ratio (L_{enc}/d) = 5.0 (Ramadan et al., 2018b). The effective vaslue of encasement axial stiffness of stone column (J_{sc}) = 2000 kN/m (Chungsik Yoo 2015 and Ramadan et al., 2018b). The general plan of the parametric study is given in Table 3.



(a) Geometry Model



(b) Finite difference mesh for the model

Figure 6. FLAC3D model.

Table 3: The general plan of the parametric study

Case of study	D (m)	d (m)	L (m)	L_{enc}/d	φ_{SC}	J_{SC} kN/m	t/D	h/D	φ_{SB}	N	B/D	J_{SB} kN/m
Clay Only	1.2	-	-	-	-	-	-	-	-	-	-	-
OSC		0.6	6.0	-	40°	-	-	-	-	-	-	-
ESC				5.0		2000	-	-	-	-	-	-

USB + ESC							1.5	-	30°	-	-	-
GRSB + ESC							-	0.30		3	2	1500

6. RESULTS AND ANALYSIS

A model was run to simulate the construction of footing rests on soft clay without any improvements and then it was run with stone column with and without encasement installed in soft clay. Also, the model was run with unreinforced and geosynthetic reinforced sand bed over encased stone column. Figure 7 shows a typical axial stress versus settlement of footing relationship for different improvement cases. Settlement was calculated at the top of the soft clay at the center of footing under applied axial stress. For comparing and expressing results to show the effect of using ordinary, encased stone columns, unreinforced and geosynthetic reinforced sand bed to increase the bearing capacity of soft clay, a dimensionless parameter called *BCR* (Bearing Capacity Ratio) is used. The *BCR* was defined as:

$$(3) BCR = \frac{\text{Ultimate bearing capacity of improved soil}}{\text{Ultimate bearing capacity of soft soil only}}$$

Figure 8 shows the variation of *BCR* with different improvement cases. As compared to unimproved clay bed, a 1.83 fold increase in bearing capacity was observed with the provision of ordinary stone column (*OSC*) and 2.58 fold increase in bearing capacity with the provision of encased stone column (*ESC*). Also, in case of clay bed provided with combination of unreinforced (*USB+ESC*) and geosynthetic reinforced sand bed (*GRSB+ESC*) over encased stone column, 3.59 and 8.07 fold increase in bearing capacity, respectively. The benefit of using geogrid layers in the sand bed is to increase the stiffness of the sand bed to resist the vertical settlement and reduces the stresses that reach to the soft clay layer. Also, the stone columns being at a larger depth away from the base of the footing and transmit stresses relatively less to the stone columns lying below. The values of the BCR for different improvement cases are presented in Table 4.

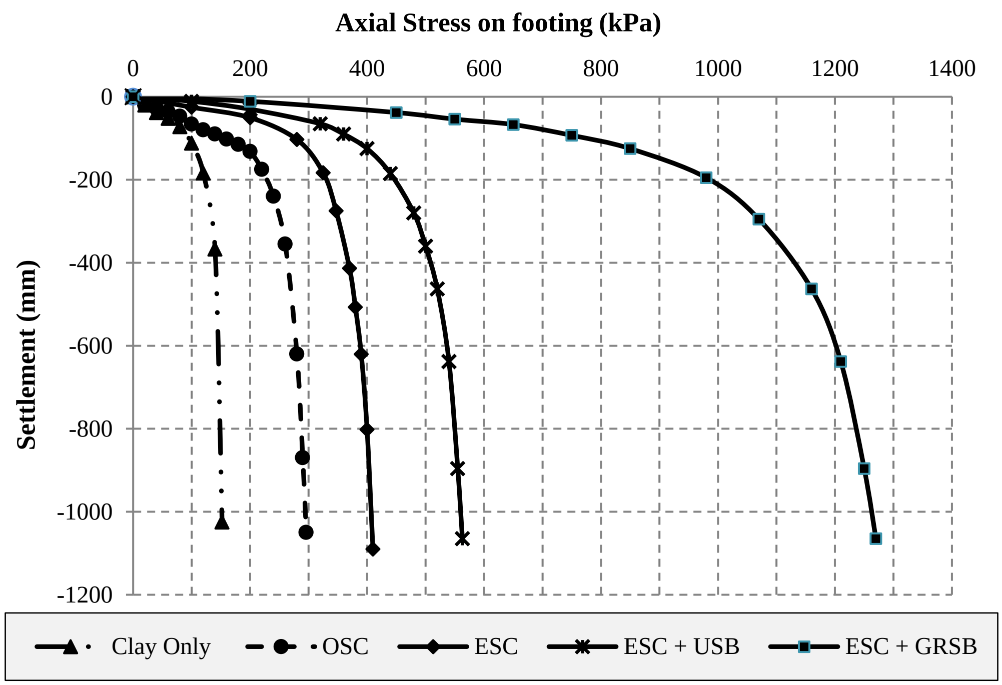


Figure 7. Axial stress on footing versus settlement for different improvement cases

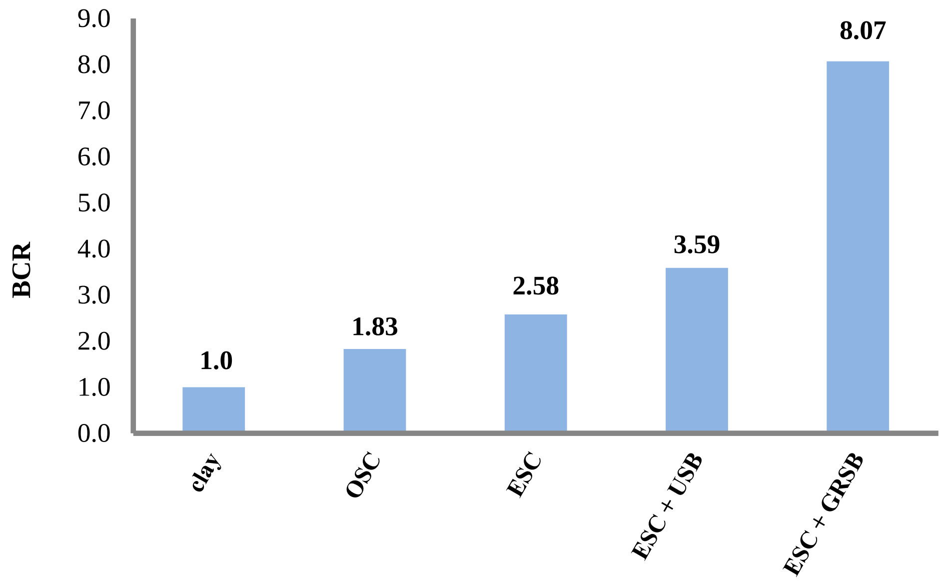


Figure 8. BCR for different improvement cases

Table 4: Values of the BCR for different improvement cases

Case of study	q_u (kPa)	BCR	BCR increased by
Soft Clay	145	1.00	-
OSC	265	1.83	83 %
ESC	374	2.58	158 %
USB+ESC	520	3.59	259 %
GRSB+ESC	1170	8.07	707 %

Where:

- $$\% \text{ of the increase in BCR} = \frac{[\, q_{u \text{ for the improved soil}} - q_{u \text{ for the unimproved soil}} \,]}{q_{u \text{ for the unimproved soil}}} \text{ x } 100$$

Figure 9 shows the lateral displacement to diameter of stone column ratio, *Ux/d*, at different improvement cases. The lateral deformation increased as the depth from the top of soft clay layer (*Z*) increases to reach the maximum lateral deformation then decreasing to reach small value of deformation. The maximum bulge has been observed at a depth of 2, 2.5 and 3.0 times the diameter of stone column in case of soil improved by stone column alone and by placing of unreinforced and geosynthetic reinforced sand bed over encased stone column, respectively.

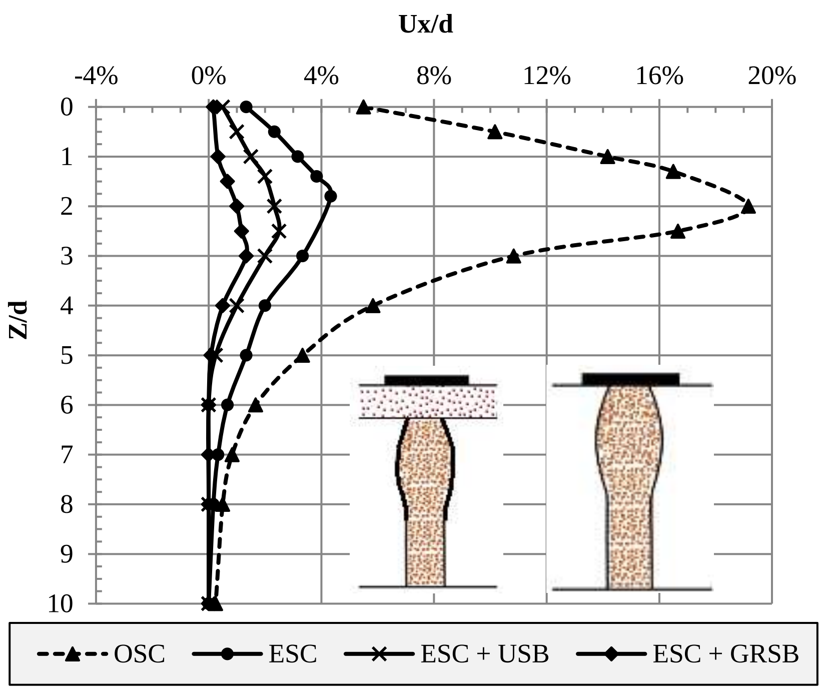


Figure 9. Lateral displacement to diameter ratio vs. Z/d for different improvement cases

Influence of Spacing between Stone Columns

A series of finite-difference model footing tests were conducted on the unreinforced sand bed (USB)/ geosynthetic reinforced sand bed (GRSB) placed over a group of nine (3 x 3) encased stone columns. These columns are installed at different values of the spacing ratio, *S/d*=1.5, 2.0, 3.0 and 4.0, which is defined as the ratio of the spacing between stone columns to stone column diameter. Figure 10 shows the typical footing stress-settlement curves were obtained at *S/d*=2.0, as example, for different improvement cases of OSC, ESC, USB+ESC and GRSB+ESC.

The effect of changing the spacing ratio between stone columns on the BCR was investigated at *t=1.5D* and φ_{SB}=30˚ for the case of USB+ESC also at the vertical distance between geosynthetic layers (*i.e. h=0.3D*), the number of geosynthetic layers (*i.e. N=3*), the length of the geosynthetic layers (*i.e. B=2.0D*) and the axial stiffness of geosynthetic layers (i.e. J_{SB}=1500 kN/m) for the case of GRSB+ESC. Figure 11 depicts the comparisons between the BCR values obtained from changing the spacing ratio (*S/d*) for the different improvement cases of (OSC), (ESC), (USB+ESC) and (GRSB+ESC). The results presented that a decrease of spacing ratio (*S/d*) from 4.0 to 1.5 increases the BCR, as compared to unimproved clay, from 1.18 to 1.70 fold for the case of OSC and from 1.62 to 2.35 fold for the case of ESC. Also, the decrease of spacing ratio (*S/d*) from 4.0 to 1.5 increases the BCR from 2.59 to 3.26 fold for the case of USB+ESC and from 6.21 to 7.50 fold for the case of GRSB+ESC. The ultimate load for single stone column is bigger than that for a stone column in a group at the same conditions because of the high confining stresses from surrounding soil compared to single stone column. The effect of changing the spacing ratio on the maximum bulging of stone columns is shown in Figure 12. It was observed that the decrease of spacing ratio from 4.0 to 1.5 decreases the maximum values of Ux/d ratio from 18% to 13% for the case of OSC, from 6.7% to 3.2% for the case of ESC, from 4.67% to 1.83% for the case of USB+ESC and finally from 2.33% to 1.15% for the case of GRSB+ESC.

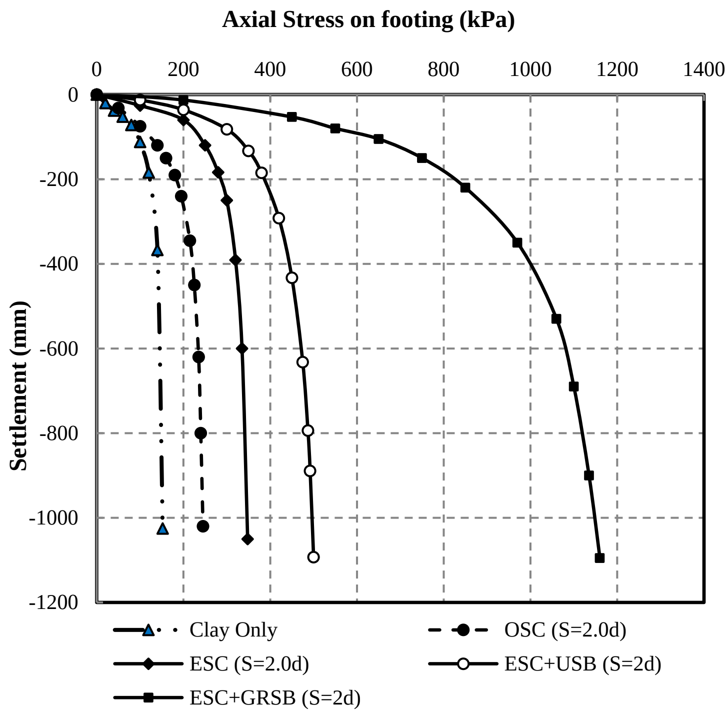
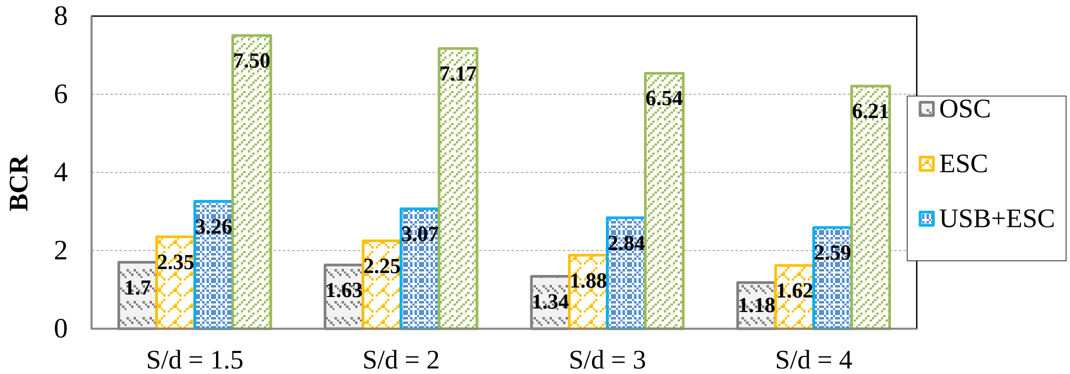


Figure 10. Axial stress on footing versus settlement for group of stone columns at S/d=2.0



(a)

Figure 11, a. Variation of BCR with different values of spacing ratio (S/d) for different improvement cases

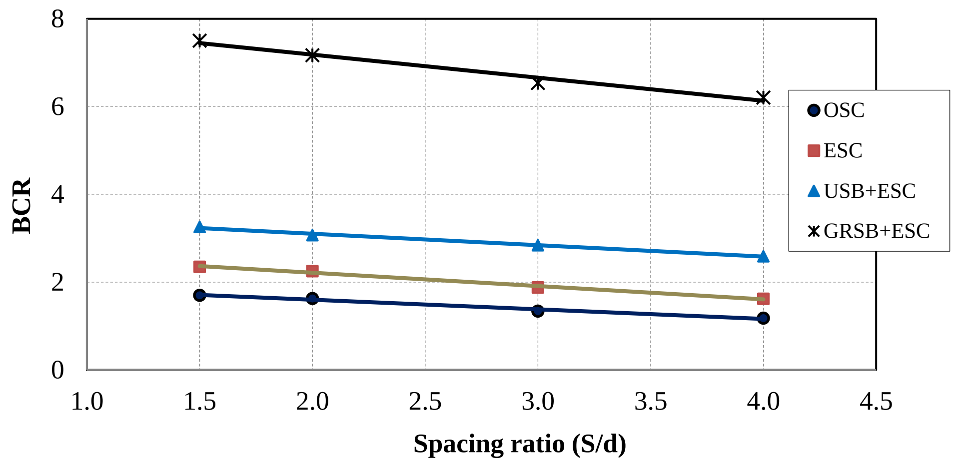


Figure 11, b. Variation of BCR with different values of spacing ratio (S/d) for different improvement cases

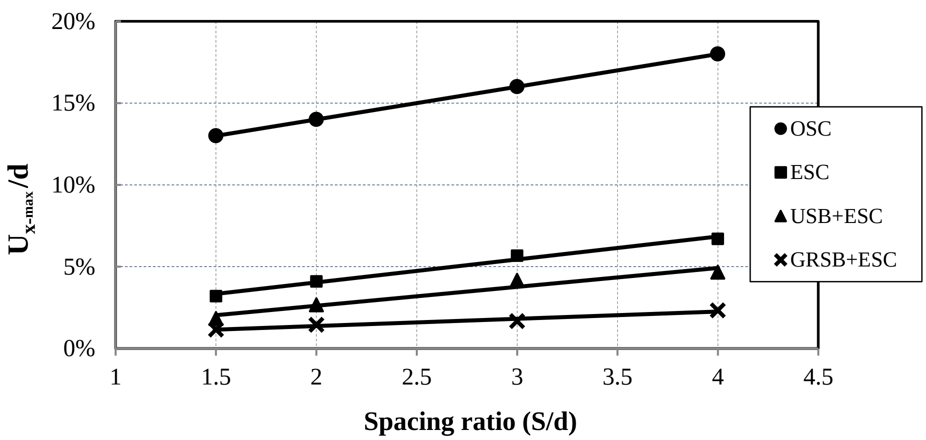


Figure 12. Variation of maximum lateral displacement to diameter of stone column ratio (U_x/d) for different values of spacing ratio (S/d):

7. CONCLUSIONS

Based on the results the following conclusions can be drawn**:**

- When encasing the stone column, the lateral bulging is considerably decreased due primarily to the added confinement by the encasement**.**
- With provision of ordinary stone column, *OSC*, the bearing capacity of soft clay bed can be increased by 1.83 fold as compared to unimproved clay bed and with encased stone column, ESC, it is of the order of 2.58 fold**.**
- It has been observed that the placement of unreinforced sand bed over encased stone column-improved soft clay (*USB+ESC*) increases the load carrying capacity by 3.59 fold as compared to unimproved clay bed.
- The stiffness and load carrying capacity of the clay bed with composite reinforcement (*GRSB+ESC*) is much higher as compared to that with the (*ESC*) alone. It is noted that BCR increased by 8.07 fold with combination of geosynthetic reinforced sand bed over encased stone column (*GRSB+ESC*)**.**
- Decrease in bulge diameter and increase in depth of bulge have been observed due to placement of sand bed over encased stone column improved soft clay. Further decrease in maximum bulge diameter and increase in depth of bulge have been observed due to application of geosynthetic reinforced sand bed.
- The maximum bulge has been observed at a depth of 2, 2.5 and 3.0 times the diameter of stone column in case of soil improved by stone column alone and by placing of unreinforced and geosynthetic reinforced sand bed over encased stone column, respectively.
- For a group of stone columns, a decrease of spacing ratio (S/d) from 4.0 to 1.5 increases the BCR, as compared to unimproved soft clay bed, from 1.18 to 1.7, from 1.62 to 2.35, from 2.59 to 3.26 and from 6.21 to 7.5 for the cases of OSC, ESC, USB+ESC and GRSB+ESC respectively and the suitable spacing to diameter ratio, S/d is 2.0 for all different improvement cases**.**

8. REFERENCES

[1]. Azzam, W. R. & Nazir, A. K. (2010) “Improving the bearing capacity of footing on soft clay with sand pile with/without skirts”. Alexandria Engineering Journal , 49, 371–377

[2]. Bergado D. T., Huat S. H. and Kalvade S. (1987) “Improvement of soft Bangkok clay using granular piles in subsiding environment”, In: Proceedings, 5th international geotechnical seminar on case histories in soft clay, Singapore, pp 219–226.

[3]. Black J. V., Sivakumar V. and Bell A. (2011) “The settlement performance of stone column foundations”, Geotechnique 61(11):909–922.

[4]. Das, B. M., Sahu, R., Patra, C. R. & Sivakugan, N. (2015). “Ultimate bearing capacity of rectangular foundation on geogrid-reinforced sand under eccentric load”. International Journal of Geotechnical Engineering, 10(1), 52-56 .

[5]. Das, B. M., Sahu, R., Patra, C. R. & Sivakugan, N. (2016). “Bearing capacity of shallow strip foundation on geogrid-reinforced sand subjected to inclined load”. International Journal of Geotechnical Engineering, 10(2), 183-189.

[6]. Debnath, P., & Dey, A. K. (2017). “Bearing capacity of geogrid reinforced sand over encased stone columns in soft clay”. Geotextiles and Geomembranes, 45(6), 653-664.

[7]. “Egyptian Code of Soil Mechanics and Foundation Design”, 2001, Part 2, Laboratory Tests"

[8]. El Sawwaf, M. A. (2007). “Behavior of strip footing on geogrid-reinforced sand over a soft clay slope”. Geotextiles and Geomembranes, 25(1), 50-60.

[9]. Elsawy M., Lesny K., and Richwien W. (2009) “Behavior of ordinary and encased stone columns studied by FEM analysis”, Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering, Alexandria.

[10]. Fattah, M. Y. & Majeed, Q. G. (2012). “Finite element analysis of geogrid encased stone columns”. Geotech Geol Eng. Vol. 30, pp. 713-726.

[11]. Ghazavi M. and Afshar J. N. (2013). "Bearing capacity of geosynthetic encased stone columns," Geotextiles and Geomembranes, 38: 26-36.

[12]. Ghazavi, M., Yamchi, A. E., & Afshar, J. N. (2017). “Bearing capacity of horizontally layered geosynthetic reinforced stone columns”. Geotextiles and Geomembranes, 46(3), 312-318.

[13]. Guido, V. A., Sobiech, J. P., & Christou, S. N. (1989). “A comparison of texturized and non-

texturized geoweb reinforced earth slabs". Proceedings of Geosynthetics-1989, 215-230.
[14]. Infante, D., Aiassa Martinez, G., Arrúa, P. & Eberhardt, M. (2019). "Experimental study of behaviour of circular footing on geogrid-reinforced sand". Geomechanics and Geoengineering, 1-19
[15]. Latha, G. M., & Somwanshi, A. (2009). "Bearing capacity of square footings on geosynthetic reinforced sand". Geotextiles and Geomembranes, 27(4), 281-294.
[16]. Laman, M., Yildiz, A., Ornek, M., & Demir, A. (2012). "Field test of circular footings on reinforced granular fill layer overlying a clay bed". Geotechnical Testing Journal, 35(4), 575-585.
[17]. Laman, M. & Keskin, M. S. (2014). "Experimental and numerical studies of strip footings on geogrid-reinforced sand slope". Arabian Journal for Science and Engineering, 39(3), 1607-1619.
[18]. Malarvizhi, & Ilamparuthi, (2007). "Comparative study on the behavior of encased stone column and conventional stone column". Soils and Foundations Vol. 47, No. 5, pp. 873-885.
[19]. Megally A. A. 2018. Behavior of Footing Rested on Soft Clay Soils Reinforced with Geosynthetic-Encased Stone Columns. M.Sc. thesis, Dept. of Civil Engineering, Assiut University, Assiut, Egypt.
[20]. Ramadan E. H., Senoon A. A., Hussein M. M. and Kotp D. A. (2015) "Numerical analysis of footing on Soft clay reinforced with stone columns", Proceedings of International Conference on Advances in Structural and Geotechnical Engineering ICASGE'15, Hurghada.
[21]. Ramadan E. H., Senoon A. A., Hussein M. M. and Kotp D. A. (2016) "Effect of Stone Density and Stone Cushion on the Behavior of Soft Soils Improved by Stone Columns", Life Science Journal: 13 (4).
[22]. Ramadan, E. H., Senoon, A. A., Abdel-Naiem, M. A. & Megally, A. A. (2018a). "Improving the Behavior of Soft Clay Soil Using Ordinary and Geosynthetic Encased Stone Columns", Proceedings, 7th Annual international conference of ASU, Cairo, Egypt, pp 108–115.
[23]. Ramadan, E. H., Senoon, A. A., Abdel-Naiem, M. A. & Megally, A. A. (2018b). "Effect of Geosynthetic-Encased Stone Columns on Behavior of Footing Rested on Soft Clay Soils", Proceedings, the international conference on geotechnical engineering, Saint Petersburg, Russia, pp 217–224 .
[24]. Ramadan, E. H., Senoon, A. A. Abdel-Naiem, M. A. and Megally, A. A. (2021). "Effect of Adding Unreinforced Sand Bed over Encased Stone Columns on the Bearing Capacity of Soft Clay Soil", Proceedings, 2nd International Conference on Civil Engineering, Hurghada, Egypt.
[25]. Ramadan, E. H., Senoon, A. A. Abdel-Naiem, M. A. and Megally, A. A. (2021). "Stone Columns and Reinforced Sand Bed for Performance Improvement of Foundations on Soft Clay", Proceedings, the international conference on advances in structural and geotechnical Engineering, Hurghada, Egypt.
[26]. Thakare, S. W., & Tanveer, A. (2016). "Performance of Footing on Clayey Soil with Encased Stone Columns and Geocell Mattress ." Geotextiles and Geomembranes, 46(4), 392-398.
[27]. Wu, P. C., Yin, J. H., Feng, W. Q., & Chen, W. B. (2019). "Experimental study on geosynthetic-reinforced sand fill over marine clay with or without deep cement mixed soil columns under different loadings". Underground space, 4(4), 340-347.
[28]. Yoo C. (2015) "Settlement behavior of embankment on geosynthetic-encased stone column installed soft ground-A numerical investigation", Geotextiles and Geomembranes 43: 484-492.

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