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Ground improvement using stone column construction encased with geogrid

Улучшение грунта с использованием конструкции каменного столба с георешеткой

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КЛЮЧЕВЫЕ СЛОВА

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несущая способность;
каменные колонны;
георешетка;
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АННОТАЦИЯ

Использование каменного столба является экономически и технически рентабельным для строительных проектов на слабом грунте. В соответствии с историей, установлено, что это лучший способ успешного применения для создания такой структуры, как резервуары для хранения нефти, фундамент плота, земляные набережные. Следует отметить, что при установке каменной колонны внутри почвы боковое удержание грунта вокруг камня может оказаться недостаточным для образования каменной колонны; в этом случае используется облицовка каменного столба георешеткой для необходимого бокового удержания. Экспериментальные исследования в настоящей работе проводятся для исследования поведения каменной колонны, заключенной в георешетку. Испытания проводятся на одной установленной каменной колонне (обычной и облицованной георешеткой), чтобы оценить ее несущую способность и осадку. Было обнаружено, что помещение каменной колонны с помощью георешетки приводит к увеличению грузоподъемности и сокращению осадки по сравнению с корпусом без георешетки. Используя георешетку, предельная несущая способность увеличилась на 60%, а грузоподъемность увеличилась на 20% для расчета 10 мм. Помимо опытов планируется провести численный анализ в программе PLAXIS 3D для тестирования и сравнения каждого опыта.

ABSTRACT

Using stone column to improve weak soil can be considered as an economic and technical viable for construction projects on the soft soil. According to the case history of the stone column it was provided that it is the best way of successful application for foundation of the structure such as, oil storage tanks, raft foundation, earth embankments. It should be noted that through the installation of the stone column inside the soil the lateral confinement offered by the soil around the stone may not be adequate to form the stone column; in this case encasing the stone column by the geogrid can induce the required lateral confinement. Experimental studies in the present work are carried out to investigate the behaviour of the stone column encased with Geogrid, Tests are carried out on a single installed stone column (ordinary and encased) in order to evaluate the effectiveness of the single column on bearing capacity and settlement. It was found that encasing the stone column with geogrid results in an increase in load carrying capacity and reduction in a settlement in comparison with the case without geogrid. By using geogrid, the ultimate bearing capacity increased by 60% compared to that without geogrid and load-bearing capacity increased by 20% for 10 mm settlement. Numerical analysis will be carried out by using PLAXIS 3D to validate the test and to make comparison between them

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1. Introduction

There are a lot of methods for improving the soil condition like (lime pile, stone column jet grouting and compaction). Before using any of these methods, the detail of improvement should be known. The ground improvement does not only include improving the soil layers but it's also in some cases improving the rock layer. It is a technique which is used by a geotechnical engineer for (solving) the problems of weak soil when the weak soil existing at the site [1].

The main regions with soft clay are the Nordic countries (except Denmark), Canada and northern United States (Chicago and Boston), where deposits of soft glacial and post glacial clays are often more than 100 m thick. Clays in these regions often have a high sensitivity and low shear strength; they are called quick in the Scandinavian countries when the sensitivity ratio, Sv (i.e. the ratio of undisturbed and remolded shear strengths) exceeds 50. Most regions of soft clays in Iraq are concentrated in the middle and southern parts of Iraq. Random data collected from several site investigation reports demonstrated values of undrained shear strength less than 30 kPa in Basrah governorate and less than 40 kPa in Missan and Nasirya governorates, also compression indices as high as 0.3 were also reported. The textures of these soils consist of fine silty clay loams, silty clay and clay fraction with up to 50-70%. These constituents with high water table throughout most of the southerly of the basins revealed a fair to poor soft deposit.

The soft clay soil exhibits low compressibility and strength as shown in figure 1,The stone column consists of a material compacted in the cylinder that is used as a technique for improving the strength and the characteristic of weak soft soil because the load capacity of the stone column is coming from:

1. The friction properties of the stone column.
2. Cohesion and frictional properties between the soil and stone column.
3. Flexibility characteristics of the foundation that are transmitting stresses to the improved soil.

The interaction between different elements of the system coming from the magnitude of lateral pressure which is developed in the surrounding soil mass and acting on the sides of the stone columns.

Figure 1. Main problems of soft clay

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The increase in the resistance of lateral deformation under surcharge load and the bulging effect of the stone column will cause passive earth pressure, which is the main parameter that the stone column takes its axial capacity from. Several kinds of research found that the estimated bearing capacity and settlement was the first proposed way in the theory of load transfer of the stone column. [2, 3] Found that the improvement of the clay soil by stone column is due to three factors:

- The modulation of stiffer material of the stone column like stones, or other) in the clay soil.
- Through the installation of the stone column, densification of the surrounding soft soil.
- Stone column can change the material characteristics of soil and the stresses in the soil mass and that includes the stone column, not just a replacement operation [4].

Soft clays soils are recently alluvial deposits possibly formed in the last 10000 years on the flat and featureless ground surface. They are identified by their high compressibility cc from 0.19 to 0.44 and low undrained shear strength cu< 40 kPa, with high natural water content ranging from 40-60% and plasticity index from 45-65%. Soil with these characters has a serious problem for geotechnical engineering connected with stability and the settlement problems [5].

Many ways are usually used to improve soils based on decreased the moisture content by several mechanisms such as (sand drain, wicks, thermal treatment and electric osmosis), also there are some techniques are utilized to improve the engineering properties of these clays soil like (piles or stone columns) by making holes with specific depth & diameter in the soil in a grid shape and backfilled with granular material, the stone column has been used in many places in Iraq in simple ways like small holes filled with non-uniform pieces of gravel or rocks. These holes had been reported in old Babylon city and in the old city of Ur, small holes also were found filled with pieces of baked clay and covered with the isolated sheet from the asphaltic material. The main idea of using columns is not well understood as mentioned by the detection mission, it was reported that the old civilization found in the Mesopotamians land could be the first pioneers of using the stone columns, probably in its rudimentary concepts

In the recent history, [8] the use of the stone column has become a traditional method, similarly the stone column was limited in 0.2 m diameter and 2 m length, and then this technique was developed [20] in increasing diminution of the stone columns from 0.5-1.5 m diameter and 15m length. The construction method of the stone column was also improved from manual method to Vibro flotation and rammed methods, the concept of the stone column was first applied to improve the soil in France by military engineers, and then in Germany and Japan by utilizing aggregate column it was started to reinforce soft soil for foundation support, finally it has become wide spread around the entire world including the United States. Geotechnical engineers emphasized more on improving the performance of the stone column by modifying the backfill material with additives or introducing several patterns of reinforcements such as hollow discs, geomesh, etc. [6].

When geotechnical engineering tried to encase the stone column with geogrid, a new kind of soil improvement has been found, which has been used primary in Germany, Sweden and the Netherlands since the last decade. Generally, this method is an extension of a used stone column or piles techniques for improving the foundation. The geogrid/geotextile system can be used in very soft clay (Cu < 15 kPa) because the stone column has many limitations when being used in weak sensitive clay soil. There is an increase in settlement of the bed because of the absence of resistance. The soil particles get filled around the stone columns that way reducing radial drainage to conquer these limitations, and for increasing the efficiency of the stone column with respect to strength and compressibility of the soil, also the stone columns are encased via utilizing geogrids to improve lateral support [7].

Fattah et al. (2016) investigated the behavior of embankment models resting on soft soil reinforced with ordinary and encased stone columns (ESCs). Model tests were performed with different spacing distances between stone columns and two length-to-diameter ratios L/d of the stone columns, in addition to different embankment heights. A total number of 39 model tests were performed on soil with the undrained shear strength of 10 kPa. The system consisted of the stone column–supported embankment at different spacing-to-diameter ratios of stone columns. For embankment models constructed on soft clay reinforced with ESCs, [11] [12] it was found that whether a column was floating or end bearing (resting on a rigid stratum), encasement of the column by a geogrid was most effective in improving the bearing ratio of reinforced soil by approximately 1.29, 1.39, and 1.63 times and 1.4, 1.57, and 1.83 times that of untreated soil, reducing the settlement by 0.71, 0.67, and 0.62 times & 0.63, 0.6, & 0.45 times that of untreated soil for 200, 250, & 300 mm embankment heights with L/d = 5 & 8, respectively, and spacing s = 2.5d.

The objective of this paper is to investigate experimentally the difference in behavior of ordinary and geogrid encased stone columns.

2. Methods

2.1 Experimental investigation

2.1.1 Material characterization

- ***Clay soil***

The used clay is natural clay that is brought from a place called Al-Nahrawan near Baghdad city in Iraq. And the tests were carried out at the University of Technology in Baghdad.

The collected samples have been pulverized and air dried, the pulverized sample was sieved through 4.75 mm (sieve No. 4) for quicker hydration and easy mixing. The engineering properties of the site soils are identified based on some of laboratory tests. Standard tests were performed to determine the physical and chemical properties of the soil, all these details are given in Table 1. The soil consists of 4% sand, 28% silt and 68% clay as shown in the table below, the tests, which were performed, along with the utilized relevant standards are listed below:

1. Water content (ASTM D-2216)
2. moisture limits (ASTM D-4318)
3. Sieve analysis (ASTM D-421)
4. Specific gravity (ASTM D-854)
5. Soil classification (ASTM D 2487-11)

According to the sieve analyses tests, more than 50% of the soil passed No. 200 sieve and Atterberg limit tests show that the plasticity index is 10%, whereas the range of the liquid limit is between 37% and 40% with an average of 38.5%. According to USGS, the soils are classified as clays (CL) with low plasticity and high plasticity (CH). Water content varied within a range between 30% and 31%. Dry unit weight (γ dry) is 15.5($\frac{\mathrm{kN}}{\mathrm{m}^3}$) the properties of clay are given below:

Table 1: The physical and chemical properties of the soil

Index	**Natural water content % (wc)**	**Liquid limit % (LL)**	**Plastic limit % (PL)**	**Shrinkage limit % (SL)**	**Plasticity index % (PI)**	**Activity (At)**
Value	31	37	27	20	10	0.6
Index	**Specific gravity (Gs)**	**Gravel (larger than 4.75 mm)%**	**Sand (0.075 to 4.75 mm)%**	**silt (0.005 to 0.075 mm)%**	**Clay (less than 0.005 mm)%**	**Classification (USCS**
Value	2.68	0	4.2	27.7	68	CL

- ***The crushed stone column***

The crushed stone materials were obtained from a private mosaic factory. They were produced as a result of crushing big stones, the crushed stone is of white color with angular shapes. The assessment of mechanical properties of the stone columns, internal friction angle of the constructed and the relative density of columns are estimated according to the past studies. The engineering properties of the stone columns are estimated based on the sieve analysis.

Physical and chemical properties of crushed stone are: -

Max Dry unit weight,$\gamma\mathrm{d}_{\max}$, $(\frac{\mathrm{kN}}{\mathrm{m}^3})$ =18.3

Min. dry unit weight, $\gamma\mathrm{d}_{\min}$, $(\frac{\mathrm{kN}}{\mathrm{m}^3})$ =13.8, D10 (mm) =5.2, D30 (mm) =5.1, D60 (mm) =5.22, Specific gravity (Gs) =2.64, effective internal friction angle, ø's=25, internal friction angle, ø'=25, Coefficient of curvature (Cc) =0.95, Coefficient of uniformity (Cu) =1.04

- ***Geogrid encasement***

The geogrid used in the tests has engineering properties as follows: size 8*8, Weight per unit area (g/m^2) = 296, thickness=11.35mm, Roll width (m) =1, Roll length =25m, according to ISO 9864

2.1.2 Stone column inistallation

A PVC pipe of the required diameter was placed at the center of the cylindrical tank, and the clay bed was formed around the pipe via stamping the clay layer by wooden tamper frequently to drive out the air during the process of the filling. The column was carefully charged in 3 layers, each one was compacted by using12 mm diameter rod to achieve the required density for reinforced the stone column by geogrid. The reinforcement was stitched and placed around the pipe. After preparing the clay, charging and compacting the tube with stones along with, the PVC tube was withdrawn carefully. The operations of the charging of stone, the compaction and withdrawal of pipes were carried out simultaneously. Further, the prepared bed was left for 2 days to achieve a uniform bed and also to ensure a proper contact between the stone columns and clay soil

2.1.3 Experimental setup for the load test

Tests were conducted on a single stone column with a diameter of 100 mm for different proportions of the stone column on the standard loading frame as a strain-controlled test. Figure 3 shows the schematic sketch of the test set up.

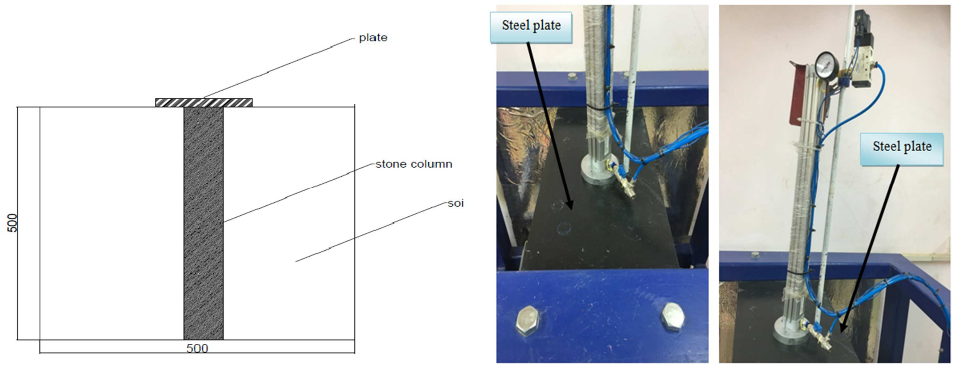


Figure 2. Small sketch about the stone column-soil system

The load test was carried out on a single stone column with diameter 100 mm. The load was applied to a plate 240 mm which is about 2.2 times. The single column diameter, which was placed over the clay that is filling the tank, is with size 500*500 mm. The loading was done over clay without the stone column, stabilized with the stone column that was encased within geogrid with the same diameter as that of the stone column alone. The settlement of the plate was reported by means of two dial gauges set diametrically opposite to each other and the load was applied through a ring at a maintained rate of 1.2 mm/min.

After completing the final layer, the top surface was scraped and leveled to get as near as possible a flat surface, then covered with polythene sheet to prevent any loss of moisture. A wooden board of similar area to that of the surface area of soil bed (600 x 600) mm was placed on the bed of soil. The bed of soil was subjected to seating pressure of 5 kPa for 24 hours to regain part of its strength. The bed of soil was covered and left for a period of curing time of (five days) before the testing time

2.2 Numerical analysis

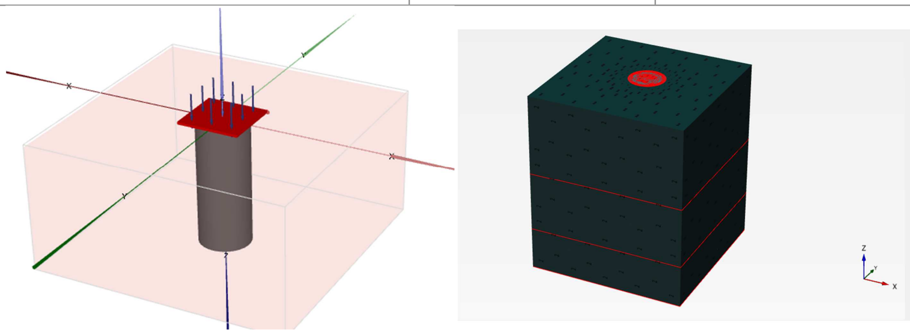
The numerical analysis was carried out by using PLAXIS 3D software (finite element method) to compare the load-settlement of experimental investigation and model test. The boundary condition was carried out as well via employing Mohr-coulomb for the stone column and Hardening soil for clay, A drained behavior was assumed for the column, the un drained B for the clay fourteen nodded triangular was used for the process of meshing. Medium deformation was restricted to all these boundary conditions that were used to represent the behavior of the stone column surrounding by the soil and typical deformation and mesh for the stone column shown in figure 3 (a, b)

In PLAXIS 3D program, several phases of analysis must be defined, in each phase, the program makes the required calculations. The second phase of the present work included calculation of initial stresses and limit stress in the soil

The calculation consists of three phases except the initial phase for generating the initial stresses with active groundwater table. The process of setting the stone columns was chosen in phase one. Phase two was to simulate the elements of the stone columns. The load was selected in phase three to consider settlement and stresses in the stone columns and surrounding soil. Calculations in Phase 1 include estimating the initial stresses, in this phase, the effective stresses of the soil are calculated by using K_o procedure where K_o=1-sin □; where K_o is the lateral earth pressure coefficient at rest which defines the relationship between horizontal and vertical stresses in the soil.

Table 2 Parameter of the soil, stone column and geogrid

Properties	Soft clay	Stone column
Unsaturated unit weight ,γ_{unsat},($\frac{kN}{m^3}$)	13.8	15
Saturated unit weight, γ_{sat},($\frac{kN}{m^3}$)	18.3	16.6
Material model	Hardening soil	Mohr-coulomb
Drainage type	Undrained (B)	Drained
E (kPa)	-	30000
E_{50} ref (kPa)	600	-
E_{oed} ref (kPa)	1425	-
E_{ur} ref (kPa)	1800	-
Power (m)	1	-
Cohesion ,Cu (kPa)	10	1
Friction angle, $\emptyset_u$ (deg)	-	41.5
Geogrid stiffness, J($\frac{kN}{m}$)	-	68



(a) (b)

Figure 3. (a) 3D finite element modeling of the stone column reinforced clay soil (L/d=5)

(b) Finite-element method discretization for the stone column, typical deformed mesh

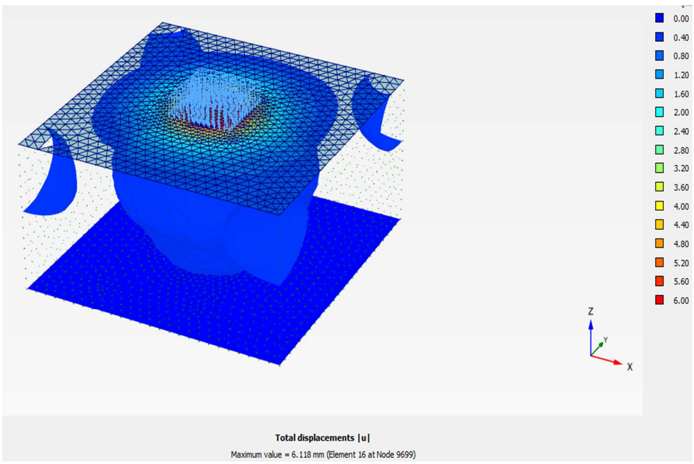


Figure 4. 3D finite element modeling of the stone column reinforced clay soil (L/d=5) under stress 5 KPa

Ква С.Ф., Колосов Е.С,, Фаттах М.Ю., Земное улучшение с использованием конструкции каменного колонка, обработанного георадом, Строительство уникальных зданий и сооружений, 2018, №3(66). С. 49-59.

3. Results and discussion

3.1 Effect of ordinary stone column without geogrid

Pressure settlement response of clay bed and the stone column without geogrid increases the bearing capacity of the clay by about 51%. As shown in Figure 4, the load bearing capacity of clay is increased by 73% when the stone has been installed, considering that the failure load corresponds to 10% of the column diameter: 10 mm settlement. Initially, the stone column bears the load and after bulging, the settlement increases rapidly.

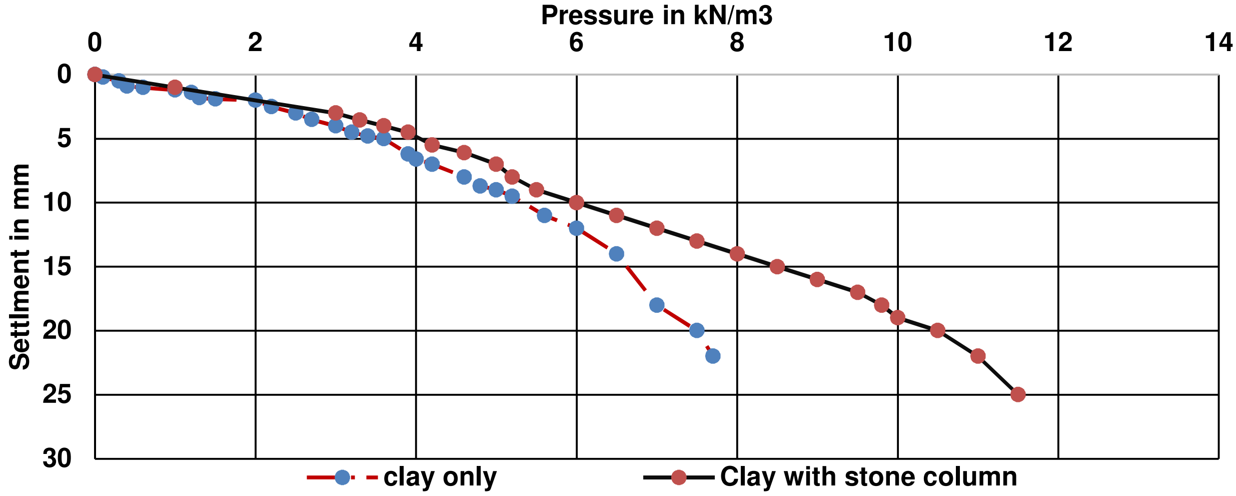


Figure 5. Pressure-settlement relationship of soil reinforced with the stone column

3.1.1 Calculating the Bulging failure of individual stone column

Below is the method of calculating the stresses of individual stone column

$$K_{pg} = \tan^2(45+\varphi/2) = 4.8 \quad (1)$$

$$K_p = \tan^2(45+\varphi_s/2) = 4.4 \quad (2)$$

Where:

φ_s : Effective internal friction angle

K_p : Coefficient of passive earth pressure of the surrounding soil

$$z_b = df + 0.5 * \tan^2(45+41/2) = 0.119\ m^2 \quad (3)$$

Where:

df : The depth of the foundation

z_b : The failure of a single stone column due to the bulging

$$\sigma_{vo} = Zb * \gamma_s = 3.0\ kPa \quad (4)$$

$$\sigma_{ro} = \sigma_{vo} * k_p + u = 13.0\ kPa \quad (5)$$

Where:

σ_{vo} : Initial vertical effective stress

σ_{ro} : Total radial stress, where bulging failure will occur

$$\sigma_{limit} = \sigma_{ro} + cu\,[\ln \frac{E_s}{2*cu\,(1+v)}] = 160.0\ \text{kPa} \tag{6}$$

Where:

σ_{limit} : Limit radial stress where the bulging failure will occur

φ: Internal friction angle

K_{pg} Coefficient of passive earth pressure of the stone column

3.2 Effect of geogrid encasement

The columns were covered with geogrid to keep the stones of the column intact, and the stone column was encased with geogrid. Figure 5 shows the pressure-settlement relation for soft clay reinforced with ordinary and geogrid encased stone columns. It can be noted that the pressure- settlement response of the clay bed with the stone column encased by geogrid exhibits greater improvement in bearing capacity as compared to ordinary stone columns.

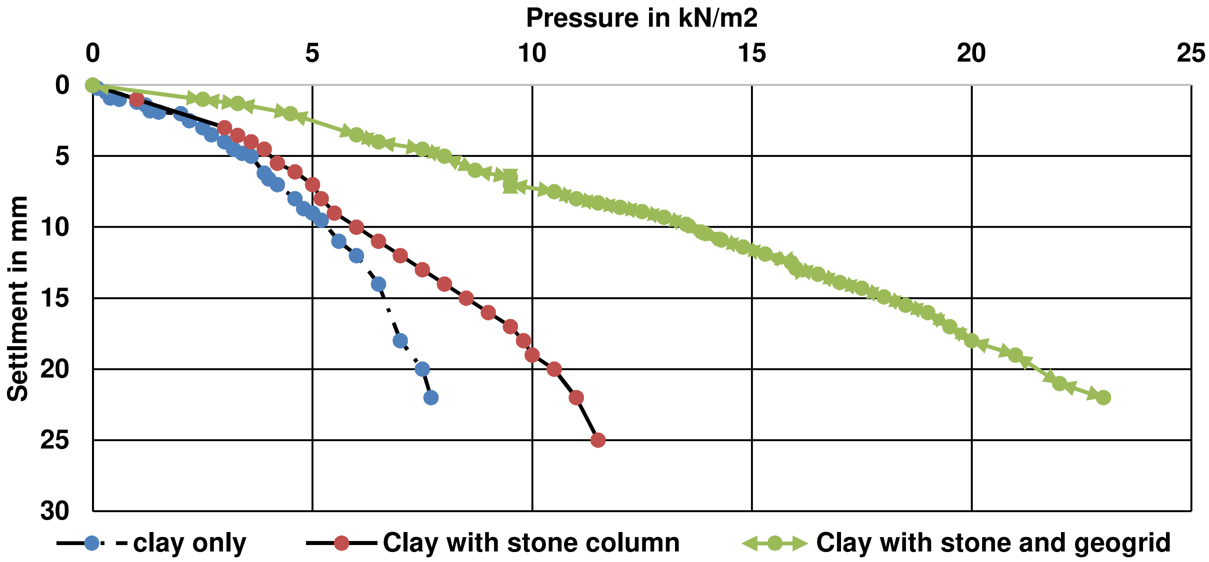


Figure 6. Pressure-settlement relationship of soil reinforced with ordinary and geogrid encased stones

By using geogrid, the ultimate bearing capacity increased by 60% as compared to that without geogrid and load bearing capacity increased by 20% for 10 mm settlement. Generally, as the load increases, the bulging occurs in the stone column, however, in case of the encapsulated stone column, bulging reduces, hence settlement and ultimate load got improved. Table 4 summarizes the results for different cases. In the classical theory for footings on homogeneous soil, the main effect of the surcharge is to restrain the soil from moving upward and causing a larger volume of soil to move at the limit load. However, in the reinforced ground around a group of the stone columns, the surcharge contributes to the confining pressure of the stone columns. Thus, the failure modes of this type of ground are more complex.

The present results are compatible with the finding of [8] that carried out finite element analyses on ordinary and geogrid encased stone columns and found that the geogrid encasement of the stone column greatly decreases the lateral displacement in comparison with ordinary stone column. The effective encasement length ratio (length of geogrid encasement along the stone column/total stone column length) was found to be about (0.6). The encasement did not provide an important increase in bearing improvement when L/d = 3 for area replacement ratio less than (0.3), for undrained cohesion Cu is between (20–40) kPa because the bulging problem is small in short columns.

With increasing of (L/d), the bearing improvement ratio increases and continues to increase at same rate even when (L/d) becomes more than 8, which means that the encasement increases the effective L/d ratio in Geosynthetic encased column (GEC) due to existence of geosynthetic casing which largely prevents lateral deformation and rupture in the stone column. For approximately up to 1000 kPa pressure, no impact of failure is expected as it was concluded by[9] [10] who commented that because improving of stiffness and soil resistance, the materials practically prevents the deformation in stone column, and the need for reinforcement around the stone columns is elevated[11][12]. However, the encased condition increases the bearing capacity for at least 57%.

Table 3: Summary of results

Properties of column	Pressure at 5 mm settlement (kN/m²)	Pressure at 10 mm settlement (kN/m²)	Ultimate load capacity (kN/m²)
Clay only	3.4	6	7.6
Clay with ordinary stone column	5	7.1	9.07
Clay with the stone column and geogrid	8	13	15.75

3.3 Validation of the model with numerical analysis

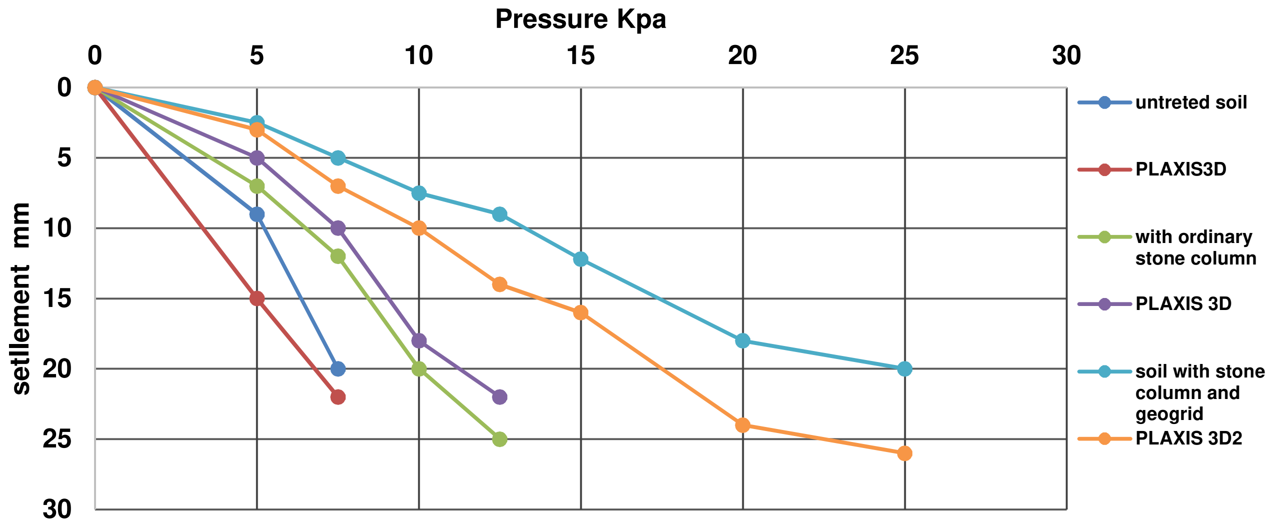


Figure 7. Comparison of PLAXIS 3D modelling results and real load -displacement the behaviour for a field test

The differences between the experimental and numerical results can be related to the test conditions which could not be simulated exactly in addition to soil parameters required in the finite element model. Some parameters require special tests which were not carried out in this study.

4. Conclusions

The use of the stone column is accepted as a means of ground improvement in soft clayey soils. The following observations could be made in this study;

- Stone column improves the settlement behavior and bearing capacity of soft soil [18] [19].
- Encasing the stone column with the geogrid results in an increase in load carrying capacity and reduction in a settlement in comparison with the case without geogrid. By using geogrid, the ultimate bearing capacity increased by 60% as compared to that without geogrid and load bearing capacity increased by 20% for 10 mm settlement.
- It was found that the results of using finite element method with software PLAXIS 3D are the same as of the experimental results, so this method can be applied to enhance the buildings' foundation in real projects.

Литература

[1]. Rudrabir, G and Kashliwal A., 2008,(Ground Improvement Techniques / with a Focused Study on Stone Column, VIT University, Dept. of Civil Engineering

[2]. Malarvizhi, S.N. and Ilamparuthi, K. (2004),"Load Versus Settlement of Clay-Bed Stabilized with Stone and Reinforced Stone Columns", Proceedings of the 3rd Asian Regional Conference on Geosynthetics, GEOASIA, Seoul, Korea, pp. 322-329.

[3]. Guetif, Z., Bouassida, M., & Debats, J.M., 2003. Parametric study of the improvement due to vibro-compacted columns installation in soft soils.

[4]. G. Ya. Bulatov, N. B. Kolosova, E. S. Kolosov, A. B. Teplov, Dependence the bearing capacity of the pile on the shapes of cross-section, Construction of unique buildings and structures, 10 (15),15-24, (2013)

[5]. Brand, E.W. and Brenner, R.P. (1981),"Soft Clay Engineering", Elsevier Scientific Published Company, Amsterdam.

[6]. Hughes, J.M.O. and Withers, N.J. (1974),"Reinforcing of Soft Cohesive Soils with Stone Columns", Ground Engineering Journal,Vol. 7, No. 3, pp. 42-49.

[7]. Kempfert H., Gebreselassi B. (2006), "Excavations and Foundations in Soft Soils", Springer, Germany

[8]. Fattah, M. Y., Majeed, Q. G., (2012), "A Study on the Behaviour of Geogrid Encased Capped Stone Columns by the Finite Element Method", Int. J. of GEOMATE, Sept., 2012, Vol. 3, No. 1 (Sl. No. 5), pp. 343-350, Geotec., Const. Mat. & Env., ISSN:2186-2982(P), 2186-2990(O), Japan.

[9]. Annual Book of ASTM Standard, Vol.4, No.8, (2000). American Society of Testing and Materials International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States

[10]. Fathi, E., Mohtasham, R., (2016), " Numerical Analysis of the Reinforced Stone Column by Geosynthetic on Stability of Embankment", Proceedings of the World Congress on Civil, Structural, and Environmental Engineering (CSEE'16), Prague, Czech Republic – March 30 – 31, 2016, ICGRE, Paper No. ICGRE 112.

[11]. Ambily, A. P. and Gandhi, S. R., (2007), "Behavior of stone columns based on experimental and FEM analysis," Journal of Geotechnical and Geoenvironmental Engineering, ASCE, vol. 133, pp. 405-415.

[12]. Fattah, M. Y., Zabar, B. S., Hassan, H. A., (2016), "Experimental Analysis of Embankment on Ordinary and Encased Stone Columns", International Journal of Geomechanics, ASCE, Vol. 16, No. 4, DOI 10.1061/(ASCE)GM.1943-5622.0000579 , 04015102.

[13]. A. K. Bugrov, E. S. Kolosov, Practical methods of taking into account the nonlinear deformation of soils, IV International scientific-practical conference, COLL Actualproblems of modern Foundation with energy saving technologies Penza, 14-21 (2014)

[14]. Rashid D., Kolosov E.S., Kolosova N.B., Soldatenko T.N. Evaluation's methods ofthe seismic stability of buildings and structures in the Gaza Strip. Advances and Trends in Engineering Sciences and Technologies II Proceedings of the 2nd International Conference on Engineering Sciences and Technologies. 2016. S. 237-242.

[15]. Vatin N.I., Kolosova N.B., Tokareva E.E. Tteaching professional cycle with overlap in a foreign language as a method of training specialist at international level (preparing a civil engineer). Construction of unique buildings and structures. 2017. No. 5 (56). C. 7-16.

[16]. Kolosova N., Kolosov E., Agishev K. Systematization

References

[1]. Rudrabir, G and Kashliwal A., 2008,(Ground Improvement Techniques / with a Focused Study on Stone Column, VIT University, Dept. of Civil Engineering

[2]. Malarvizhi, S.N. and Ilamparuthi, K. (2004),"Load Versus Settlement of Clay-Bed Stabilized with Stone and Reinforced Stone Columns", Proceedings of the 3rd Asian Regional Conference on Geosynthetics, GEOASIA, Seoul, Korea, pp. 322-329.

[3]. Guetif, Z., Bouassida, M., & Debats, J.M., 2003. Parametric study of the improvement due to vibro-compacted columns installation in soft soils.

[4]. G. Ya. Bulatov, N. B. Kolosova, E. S. Kolosov, A. B. Teplov, Dependence the bearing capacity of the pile on the shapes of cross-section, Construction of unique buildings and structures, 10 (15),15-24, (2013)

[5]. Brand, E.W. and Brenner, R.P. (1981),"Soft Clay Engineering", Elsevier Scientific Published Company, Amsterdam.

[6]. Hughes, J.M.O. and Withers, N.J. (1974),"Reinforcing of Soft Cohesive Soils with Stone Columns", Ground Engineering Journal,Vol. 7, No. 3, pp. 42-49.

[7]. Kempfert H., Gebreselassi B. (2006), "Excavations and Foundations in Soft Soils", Springer, Germany

[8]. Fattah, M. Y., Majeed, Q. G., (2012), "A Study on the Behaviour of Geogrid Encased Capped Stone Columns by the Finite Element Method", Int. J. of GEOMATE, Sept., 2012, Vol. 3, No. 1 (Sl. No. 5), pp. 343-350, Geotec., Const. Mat. & Env., ISSN:2186-2982(P), 2186-2990(O), Japan.

[9]. Annual Book of ASTM Standard, Vol.4, No.8, (2000). American Society of Testing and Materials International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States

[10]. Fathi, E., Mohtasham, R., (2016), " Numerical Analysis of the Reinforced Stone Column by Geosynthetic on Stability of Embankment", Proceedings of the World Congress on Civil, Structural, and Environmental Engineering (CSEE'16), Prague, Czech Republic – March 30 – 31, 2016, ICGRE, Paper No. ICGRE 112.

[11]. Ambily, A. P. and Gandhi, S. R., (2007), "Behavior of stone columns based on experimental and FEM analysis," Journal of Geotechnical and Geoenvironmental Engineering, ASCE, vol. 133, pp. 405-415.

[12]. Fattah, M. Y., Zabar, B. S., Hassan, H. A., (2016), "Experimental Analysis of Embankment on Ordinary and Encased Stone Columns", International Journal of Geomechanics, ASCE, Vol. 16, No. 4, DOI 10.1061/(ASCE)GM.1943-5622.0000579 , 04015102.

[13]. A. K. Bugrov, E. S. Kolosov, Practical methods of taking into account the nonlinear deformation of soils, IV International scientific-practical conference, COLL Actualproblems of modern Foundation with energy saving technologies Penza, 14-21 (2014)

[14]. Rashid D., Kolosov E.S., Kolosova N.B., Soldatenko T.N. Evaluation's methods ofthe seismic stability of buildings and structures in the Gaza Strip. Advances and Trends in Engineering Sciences and Technologies II Proceedings of the 2nd International Conference on Engineering Sciences and Technologies. 2016. S. 237-242.

[15]. Vatin N.I., Kolosova N.B., Tokareva E.E. Tteaching professional cycle with overlap in a foreign language as a method of training specialist at international level (preparing a civil engineer). Construction of unique buildings and structures. 2017. No. 5 (56). C. 7-16.

[16]. Kolosova N., Kolosov E., Agishev K. Systematization modern devices for the protection of buildings and structures due to seismic impacts. MATEC Web of Conferences Editors: J.Melcer and K. Kotrasova. 2017. S. 00065.

[17]. Rechinsky A.V., Strelets K.I. Refresher training on designing and construction of high-risk,technically complex and unique objects.

modern devices for the protection of buildings and structures due to seismic impacts. MATEC Web of Conferences Editors: J.Melcer and K. Kotrasova. 2017. S. 00065.

[17]. Rechinsky A.V., Strelets K.I. Refresher training on designing and construction of high-risk,technically complex and unique objects. Construction of unique buildings and structures. 2012. No. 1. C. 74-76.

[18]. Ahmed, A. A. (1998) "Performance of Stone Columns in Soft Soils" Ph.D. Thesis, Civil Engineering Department, University of Baghdad, Iraq.

[19]. Al-Mohamadi, F.H. (1999), "Substitute of Pile by Using Stone Column", M.Sc. Thesis, Civil Engineering Department, University of Baghdad,Iraq.

[20]. Al-Saidi, A.A. (2000), "The Use of Stone Columns to Improve Soft Soils", M.Sc. Thesis, Civil Engineering Department, University of Baghdad, Iraq

[21]. Sinyakov,L.N. (2016), "strengthening and stabilization of the weak water saturated soil using stone columns" , MATEC web of conference ,T.73,DOI ,C.73

[22]. Kwa Sally,Kwa,S.F and E.S Kolosov, 'IMPROVED THE CHARECTERISTIC OF WEAK SOIL BY ENCASED STONE COLUMNS UNDER CYCLIC AND STATIC LOAD ' Thesis ,Peter the great St.petersburg Polytechnic University , Institute of Civil Engineering, 2018

Construction of unique buildings and structures. 2012. No. 1. C. 74-76.

[18]. Ahmed, A. A. (1998) "Performance of Stone Columns in Soft Soils" Ph.D. Thesis, Civil Engineering Department, University of Baghdad, Iraq.

[19]. Al-Mohamadi, F.H. (1999), "Substitute of Pile by Using Stone Column", M.Sc. Thesis, Civil Engineering Department, University of Baghdad,Iraq.

[20]. Al-Saidi, A.A. (2000), "The Use of Stone Columns to Improve Soft Soils", M.Sc. Thesis, Civil Engineering Department, University of Baghdad, Iraq

[21]. Sinyakov,L.N. (2016), "strengthening and stabilization of the weak water saturated soil using stone columns" , MATEC web of conference ,T.73,DOI ,C.73

[22]. Kwa Sally,Kwa,S.F and E.S Kolosov, 'IMPROVED THE CHARECTERISTIC OF WEAK SOIL BY ENCASED STONE COLUMNS UNDER CYCLIC AND STATIC LOAD ' Thesis ,Peter the great St.petersburg Polytechnic University , Institute of Civil Engineering, 2018

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