Diyala Journal of Engineering Sciences

ISSN 1999-8716
Printed in Iraq

First Engineering Scientific Conference
College of Engineering –University of Diyala
22-23 December 2010, pp. 310-326

IMPROVEMENT OF SOFT CLAYS BY END BEARING STONE COLUMNS ENCASED WITH GEOGRIDS

Mohammed Y. Fattah[1] and Emad Y. Khudhair[2]
(1)Building and Construction Engineering Department, University of Technology
(2)Engineering College , Diyala University

ABSTRACT:- In this paper, the finite element method is utilized as a tool for carrying out different analyses of stone column–soil systems under different conditions. A trial is made to improve the behaviour of stone column by encasing the stone column by geogrid as reinforcement material .

The program CRISP2D is used in the analysis of problems. The program adopts the finite element method and allows prediction to be made of soil deformations considering Mohr–Coulomb failure criterion for elastic-plastic soil behaviour.

A parametric study is carried out to investigate the behaviour of ordinary and encased floating stone columns in different conditions. Different parameters were studied to show their effect on the bearing improvement and settlement reduction of the stone column. These include the length to diameter ratio (L/d), end support of the stone column and the area replacement ratio (a_s).

It was found that the effect of encasement length ratio on bearing improvement and settlement reduction increases with the increase in the end bearing soil undrained shear strength.

The encasement of the stone column should be extended to the full stone column length to make the stone column take the full benefit of the end bearing soil support especially for long columns with (L/d) more than 4.

***Keywords*:-** Stone columns, Encased, Geogrid, End bearing, Finite elements.

INTRODUCTION

Stone columns were well known in 1830 to French military engineers to support the heavy foundation of iron work at the artillery arsenal that was founded on soft soil. The columns were (2 m) long and (0.2 m) in diameter constructed by driving stakes into ground withdrawing them then backfilling the hole with crushed stone, but they are not ideal for behaviour of foundation stone column system. Stone columns were then forgotten until the 1930's when they were rediscovered as by product of the technique of vibroflotation for compacting granular soils. In the last part of 1950's, the use of compacted stone column in soft clay deposits was started in Germany, and the construction of sand compaction pile was developed in Japan by Murayama in 1957 (Tanimoto, 1973).

In recent years, a new kind of sand/gravel column appeared and called geotextile or geogrid encased sand/gravel column. It is primarily used for improvement of foundation in many countries around the world; they are placed in regular patterns through the soft soil down to lower bearing stratum (Kempfert and Gebreselassi, 2006).

BASIC CONSIDERATIONS

Unit Cell Concept

Since granular columns are installed in group, in general they are installed on a regular grid. There are three possible regular arrangements; the columns may lie on the vertices of an equilateral triangle, a square or hexagon. To analyze the load carrying capacity and settlement of the stone column, it is assumed to have an equivalent area of soil surrounding each stone column. Although this area forms different regular shape according to stone column pattern, it can be closely approximated as a circle having the same total area, having an equivalent diameter or effective diameter (de), (Goughnour and Bayuk, 1979; Balaam and Booker, 1981). It follows from consideration of symmetry that the area surrounding column corresponding to spacing on vertices of equilateral triangles is regular hexagon of side equal to ($s/\sqrt{3}$). The area based on square pattern is itself square of a side (s), and that based on regular hexagon is an equilateral triangle of side equal to ($\sqrt{3}\,s$). It also follows that de for triangular is (de =1.05s) and (de =1.13 s) for square and (de=1.29 s) for hexagonal pattern symmetry that the sides of the domains of influence are shear free and undergo normal displacement. In order to reduce the complexity of analysis, each domain is approximated by circle of effective diameter (de), the perimeter of which is shear free and undergoes no radial movement which has the same area as the actual domain (Balaam and Booker, 1981).

STRESS CONCENTRATION RATIO

According to the assumption of the unit cell that both stone and surrounding soil will settle vertically with same magnitude when it is loaded, because of the difference of stiffness of stone and soil, it will give different deformation behavior with the development of loading, there will be concentration in stresses in stone as it is stiffer than the native soil (Balaam and Boker, 1985). The ratio of the stresses in the column to the stresses in the surrounding native soils is called a stress concentration ratio (Aboshi et al., 1979). The stress concentration ratio (η) is defined by

$$\eta = \frac{\sigma_s}{\sigma_c} \qquad \text{……………………..………………. (1)}$$

Where:

σ_s = stress in stone column,

σ_c = stress in clayey soil.

From the concept of equilibrium of vertical stress in unit cell, the average stress (σ) in the unit cell is equal to:

$$\sigma = \sigma_s . a_s + \sigma_c (1 - a_s) \qquad \text{…………………….. (2)}$$

$$\sigma_c = \frac{\sigma}{1 + (\eta - 1) . a_r} = \mu_c . \sigma \qquad \text{……………………………. (3)}$$

$$\sigma_s = \frac{\eta . \sigma}{1 + (\eta - 1) . a_r} = \mu_s . \sigma \qquad \text{…………………………. (4)}$$

Where:

μ_c and μ_s are the ratio of stress in clay and stone column, respectively to the average loading intensity (σ) and (a_s) is the area replacement ratio.

AREA REPLACEMENT RATIO

Area replacement ratio (a_s) or reinforcement ratio is defined as the ratio of stone column area to total unit cell area **(Bergado et al., 1996)**:

$$a_s = \frac{A_s}{A_s + A_c} \qquad \text{..............................} \; (5)$$

Where:

As = area of stone column cross-section,

Ac = area of clay in unit cell surrounding stone column.

GEOGRID ENCASED STONE COLUMN

The foundation system with geotextile / geogrid encased sand or gravel columns (GEC) is a new soil improvement method and it is primarily used for improvement of foundations of road embankments in Germany, Sweden and the Netherlands since the last decade (Kempfert and Gebreselassi, 2006). Basically, this method is an extension of the well known stone column and sand compaction pile foundation improvement techniques. The only difference is that the column in this new method is encased with geotextile of high tensile strength. Recently, it is also used in dike constructions and land reclamation such as the dike of robust Airbus A380 in Hamburg, Germany which was founded on over 60,000 getextile-encased sand columns of diameter of (0.8 m) and (4 to 14 m) length below the base of the dike foot reached up to the relatively load bearing sand layer.

Murugesan and Rajagopal (2006) investigated the qualitative and quantitative improvement in load capacity of the stone column by encasement through a comprehensive parametric study using the finite element analysis. It is found from the analyses that the encased stone columns have much higher load carrying capacities and undergo lesser compressions and lesser lateral bulging as compared to conventional stone columns. The results have shown that the lateral confining stresses developed in the stone columns are higher with encasement.

Gniel and Bouazza (2009) discussed the results of a series of small-scale model column tests that were undertaken to investigate the behavior of geogrid encased columns. The tests focused on studying the effect of varying the length of encasement and investigating whether a column that was partially encased with geogrid would behave similarly to a fully-encased column. In addition, isolated column behavior was compared to group column behavior. The results of partially encased column tests indicated a steady reduction in vertical strain with increasing encased length for both isolated columns and group columns. Bulging of the column was observed to occur directly beneath the base of the encasement. A significant increase in column stiffness and further reduction in column strain was observed for fully-encased columns, with strain reductions in the order of 80%. This range of performance may lend the techniques of partial and full geogrid encasement to a series of potential site applications.

Yoo (2010) presented the results of a numerical investigation into the performance of geosynthetic-encased stone columns installed in soft ground for embankment construction. A three-dimensional finite-element model was employed to carry out a parametric study on a number of governing factors such as the consistency of soft ground, the geosynthetic encasement length and stiffness, the embankment fill height, and the area replacement ratio. The results indicated among other things that additional confinement provided by the geosynthetic encasement increases the stiffness of the stone column and reduces the degree of embankment load transferred to the soft ground, thereby decreasing the overall settlement. It was also shown that the geosynthetic encasement has a greater impact for cases with larger stone column spacing and/or weaker soil.

Pulko et al. (2010) presented a newly developed design method for non-encased and encased stone columns. The developed analytical closed-form solution is based on previous solutions, initially developed for non-encased columns and for non-dilating rigid-plastic column material. In this method, the initial stresses in the soil/column are taken into account, with the column considered as an elasto-plastic material with constant dilatancy, the soil as an elastic material and the geosynthetic encasement as a linear-elastic material. To check the validity of the assumptions and the ability of the method to give reasonable predictions of settlements, stresses and encasement forces, comparative elasto-plastic finite element analyses have been performed.

The agreement between the two methods is very good, which was the reason that the new method was used to generate a parametric study in order to investigate various parameters, such as soil/column parameters, replacement ratio and load level and geosynthetic encasement stiffness on the behavior of the improved ground.

In this paper, geogrid reinforced stone columns are analyzed using the finite element method.

COMPUTER PROGRAM USED

CRISP is a 2D finite element program. CRISP Windows interface is currently restricted to 2D plane strain and axisymmtric problems. The program can deal with untrained, drained or fully coupled (Biot) consolidation analysis of two-dimensional plane strain or axisymmtric (with axisymmtric loading) solid bodies.

FINITE ELEMENT GEOMETRY

The basic axisymmtric finite element mesh used for geogrid encasement parametric study is shown in Figure (1).

Eight-node isoperimetric elements were used to model the soil and stone column. The reinforcement material (geogrid material) is modelled by three-node bar elements which mobilize axial loads only. Due to symmetry, only half of the axisymmtric problem is considered.

The boundary conditions of the axisymmtric problem domain are shear free with no radial movement at the lateral sides and prevent the bottom boundary from both radial and vertical movement. The thickness of soil below the tip of the stone column was taken according to the bulb of stresses which disappear at a distance equal to (6d) below the column tip (where d is the diameter of the stone column), therefore the thickness of the soil below the tip of the stone column is (10 m), for more safety, (Majeed, 2008).

According to (2:1) stress distribution method, the stress reaching the lateral distance from the center of the stone column equals to (d+L)/2, thus for a length (L) equal to (12 m) and (d) equals (1m), the lateral distance is taken to be (18 m), for more safety. The water table is assumed to be at the ground level. An isolated concrete footing of (0.5 m) thickness was placed at the top of the stone column and a uniform load was applied on the footing gradually.

The settlement is calculated at the top of footing at node number (479) for the mesh used to study the effect of geogrid encasement as shown in Figure (1).

MATERIAL CHARACTERISTICS AND MODELING

Elastic-perfectly plastic, Mohr-Coulomb model for undrained condition has been assumed to model the behaviour of the soil and stone column materials, while linear elastic bar element was used for geogrid material modelling.

The stone column material properties are given in Table 1. The geogrid used in this study is warp knitted fiberglass geogride (FGG 140). The geogrid properties are given in Table 2.

The study was carried out using Poisson's ratio (0.45) for clay. The modulus of elasticity E of the clay is assumed to be equal to Cu × 250 (E = 200 to 500 × Cu) (Bowles, 1996). The unit weight, $\gamma = 16$ kN/m^3, the angle of internal friction (ϕ) of clay = 0.

Effect of L/D and (A_S)

The area replacement ratio of stone column plays an effective part in improving the strength of soft clay treated by stone column; also the length of stone column affects directly stone column strength.

Figures (2) to (7) shows the relation between L/d (length of stone column / diameter of stone column) and the bearing improvement ratio (q treated /q untreated) for L/d (3-12), for ordinary floating stone column and encased floating stone column. In these figures, Cu = 20 kPa of surrounding soft soil was adopted. These figures show that for ordinary stone column, the strength of column increases with the increase in the length of stone column. The effective length to diameter ratio of stone column is found to be L/d = (7-8) for all area ratios and after L/d of 8, there is no effect on (q treated /q untreated) value. It can also be seen that for encased stone column, the bearing improvement ratio increases with the increase of (L/d) even when (L/d) ratio becomes more than 8 for all area replacement ratios. This means that in case of encased stone column, there is no limitation on the effective (L/d) ratio.

The figures also indicate that the strength of stone column increases when encased with geogrid compared with ordinary stone column and the increasing in (q treated /q untreated) is higher when (L/d) increases.

Figures (2), (3) and (4) reveal that the stone column is not improved when it is encased by geogrid when L/d =3, actually the improvement is starting from L/d = 6 for a_s=

0.1 and 0.15, while the increasing in (q treated / q untreated) for a_s= 0.25 is starting from L/d = 5. On the other hand, the improvement in stone column when it is encased started from L/d = 4 for a_s = 0.3 and L/d = 3 for a_s= 0.35.

Stone Column Based on Stiffer Soil

A number of figures are drawn to display the relation between the bearing improvement ratio and encasement length ratio for a_s = 0.25. These cases are studied when the surrounding soil has Cu = 20 kPa, and the end bearing soil has Cu= 50 and 150 kPa for different (L/d) ratios.

Figures (8) and (9) are for L/d = 3 and 4, respectively. It can be seen that for end bearing soil with Cu = 50 kPa, the increase in (q treated / q untreated) is uniform and small with increase in encasement length ratio, while for end bearing soil with Cu=150 kPa, the increase in (q treated /q untreated) value is much higher due to increase of encasement length ratio.

Figures (10) and (11) are drawn for encased end bearing stone column with L/d = 5 and 6, respectively. The end bearing soil Cu has a small effect on (q treated /q untreated) at encasement length ratio below 0.4, but after this limit, the value of (q treated /q untreated) becomes higher for Cu = 150 kPa than for Cu = 50 kPa.

Figures (12) and (13) are drawn for L/d = 8 and 10 respectively, of encased end bearing stone column. It can be noticed that when the value of encasement length ratio is below 0.5, (q treated /q untreated) is the same for end bearing soil with Cu = 50 ana 150 kPa. When encasement length ratio is above 0.5 for end bearing soil with Cu =150 kPa, (q treated / q untreated) increases rapidly and continues increasing at this rate till reaching the encasement length ratio 1 (full encasement), while for end bearing soil Cu = 50 kPa, the increase in (q treated /q untreated) is uniform.

Figure (14) is drawn for encased end bearing stone column with L/d =12. In this Figure, the value of (q treated /q untreated) is the same for 50 and 150 kPa end bearing soil strength when the encasement length ratio is less than (0.6), which means that for encasement length ratio below 0.6, the strength of end bearing soil has no effect on increasing the stone column bearing capacity. When the encasement length ratio is greater than 0.6, the increase in the shear strength of the end bearing soil leads to great improvement in (q treated /q untreated).

The previous figures demonstrate that for encased stone column based on stiffer soil than the surrounding soil, the encasement should be extended to full length of the stone column to ensure that the stone column is resting on the hard soil to give the column the active support which increases (q treated /q untreated) value.

CONCLUSIONS

From the finite element analysis carried out in the previous sections, the following conclusions can be drawn.

Ordinary End Bearing Stone Columns

1. The effective (L/d) ratio is between (7-8).
2. The bearing improvement ratio increases when the end bearing soil undrained shear strength(Cu) increases and the increase in bearing improvement ratio is higher for L/d' = 3 and 4 than for L/d = 5 and 6.
3. The failure mode is bulging for all stone column lengths.

Encased End Bearing Stone Columns

1. The increase in undrained shear strength (Cu) of the end bearing soil leads to increase in the strength of the encased stone column for all surrounding soil undrained shear strength values.
2. The bearing improvement ratio and the settlement reduction ratio are increased with decrease in undrained shear strength of the surrounding soil for all end bearing soil undrained shear strengths.
3. The effect of encasement length ratio (length of geogrid encasement along the stone column / total stone column length) on bearing improvement and settlement reduction increases with the increase in the end bearing soil undrained shear strength.
4. The encasement of the stone column should be extended to the full stone column length to make the stone column take the full benefit of the end bearing soil support especially for long columns with (L/d) more than 4.

REFERENCES

1. Aboshi, H., Ichimoto, E., Enoki, M., and Harada, K., (1979), “The Compozer: A Method to Improve Characteristics of Soft Clays by Inclusion of Large Diameter Sand

Columns,” Proceedings International Conference on Soil Reinforcement; Reinforced Earth and Other Techniques, Paris, E.N.P.C. , Vol. 1, pp. 211–216.

2. Balaam, N.P., and Poulos, H.G., (1978), “Method of Analysis of Single Stone Column”, Proceedings Symposium on "Soil Reinforcing and Stabilizing Techniques", Sydney, Australia, pp.497-512.
3. Balaam, N.P. and Booker, J.R., (1981), “Analysis of Rigid Rafts Supported by Granular Piles”, International Journal for Numerical and Analytical Methods in Geomechanics, Vol.5, pp. 379-403.
4. Balaam, N.P., and Booker, J.R., (1985), “Effect of Stone Column Yield on Settlement of Rigid Foundations in Stabilized Clay”, International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 9, No. 4, pp. 331 – 351.
5. Bergado, D. T., Anderson, L. R., Miura, N., and Balasubramaniam, A. S., (1996), “Soft Ground Improvement in Lowland and Other Environments”, ASCE Press, New York, USA, pp. 186–232.
6. Bowles, J.E., (1996), “Foundation Analysis and Design”, 5th. Edition, McGraw-Hill Book Company, p. 1175.
7. Gniel, J. and Bouazza**, A.,** (2009), **“**Improvement of soft soils using geogrid encased stone columns”, Geotextiles and Geomembranes, Vol. 27, No. 3, pp. 167-175.
8. Gniel, J. and Bouazza**, A.,** (2010), **“**Construction of Geogrid Encased Stone Columns: A New Proposal Based on Laboratory Testing”, Geotextiles and Geomembranes, Vol. 28, No. 1, pp. 108-118.
9. Goughnour, R.R., and Bayuk, A.A., (1979), “Analysis of Stone Column-Soil Matrix Interaction under Vertical Load”, Proceedings International Conference on Soil Reinforcement; Reinf. Earth and other Techniques, Vol. 1, Paris 1979, pp. 271 – 278.
10. Kempfert, H., and Gebreselassi, B., (2006), “Excavations and Foundations in Soft Soils”, Springer-verlay Germany Berlin.
11. Lee, D., Yoo, C., Park, S., Jung, S., (2008), “Field Load Tests of Geogrid Encased Stone Columns in Soft Ground”, Proceedings of the Eighteenth International Offshore and Polar Engineering Conference, Vancouver, BC, Canada, July 6-11, 2008.
12. Majeed, Q. G., (2008), "Assessment of Load Capacity of Reinforced Stone Column Embedded in Soft Clay", M.Sc. thesis, Building and Construction Engineering Department, University of Technology, Baghdad.

13. Murugesan, S. and Rajagopal, K., (2006), "Geosynthetic-encased Stone Columns: Numerical Evaluation", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 136, No. 8, pp. 1148-1160.
14. Murugesan, S. and Rajagopal, K., (2009), "Performance of Encased Stone Columns and Design Guidelines for Construction on Soft Clay Soils", Journal of Geosynthetics in Civil and Environmental Engineering, Part 10, pp. 729-734.
15. Pulko, B., Majes, B., Logar, J., (2010), "Geosynthetic-encased stone columns: Analytical calculation model", Geotextiles and Geomembranes, Vol. 28, No. 9.
16. Shenzhen Ktyu Insulation CO., Ltd. (*www.geogrid.biz*).
17. Tanimoto, K., (1973), "Introduction of the Sand Compaction Pile Method as Applied to Stabilization of Soft Foundation Grounds", Common Wealth Scientific Industrial Research Organization, Australia.
18. Yoo, C., (2010), "Performance of Geosynthetic-Encased Stone Columns in Embankment Construction: Numerical Investigation", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 136, No. 8, pp. 1148-1160.

Table (1): Material Properties of Stone Column Used in the Parametric Study of the Problem.

Value	Parameter
40	Angle of internal friction, ϕ (degrees)
17	Unit weight, γ (kN/m^3)
0.30	Poisson's ratio, υ
100000	Modulus of elasticity (kN/m^2)

Table (2): Geogrid Properties Used in Stone Column Encasement

(Shenzhen Ktyu Insulation CO., Ltd.)

Value	Parameter
140	Tensile strength (kN/m)
4	Elongation (%)
5	Weft diameter (mm)
25.4 × 25.4	Hole size (mm × mm)
76	Elastic modulus (GPa)

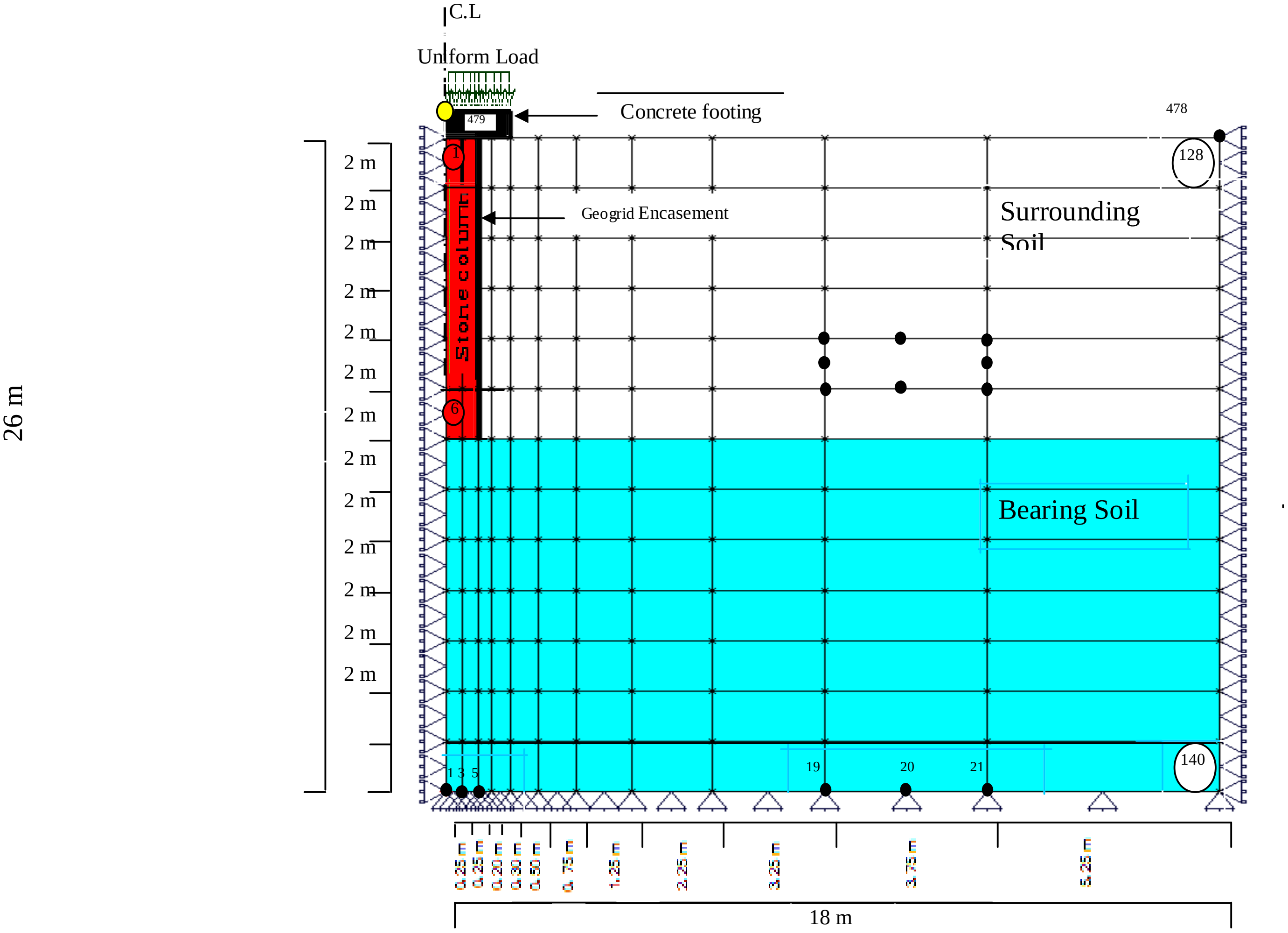

Fig.(1): Basic Axisymmetric Finite Element Mesh Used for the Parametric Study.

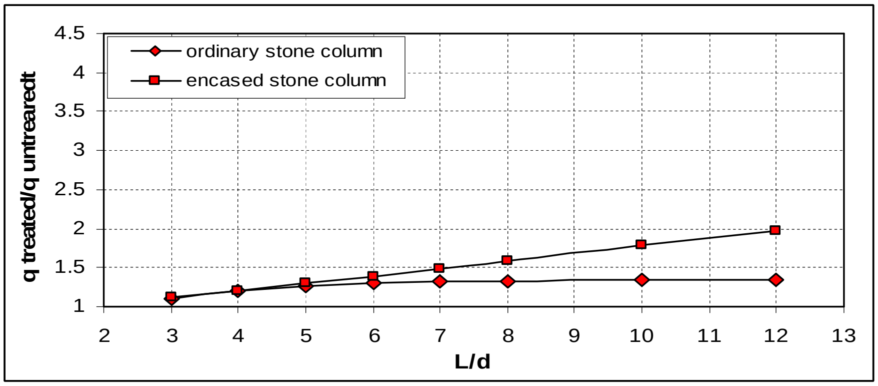

Fig.(2): Relationship between the Bearing Improvement Ratio and Length to Diameter Ratio of Floating Stone Column (Cu=20 kPa, a_s= 0.1).

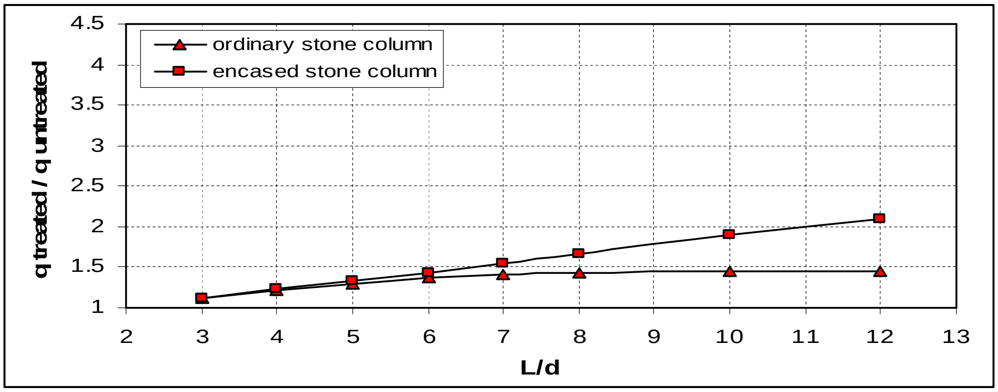

Fig. (3): Relationship between the Bearing Improvement Ratio and Length to Diameter Ratio of Floating Stone Column (Cu=20 kPa, a_s= 0.15).

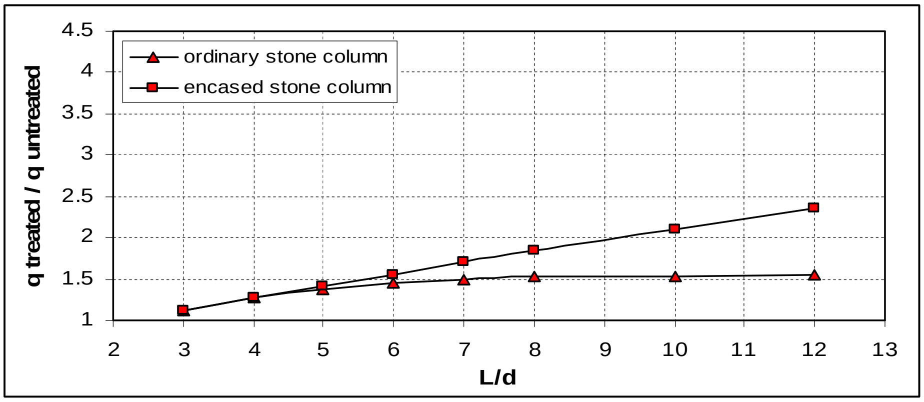

Fig. (4): Relationship between the Bearing Improvement Ratio and Length to Diameter Ratio of Floating Stone Column (Cu=20 kPa, a_s= 0.2).

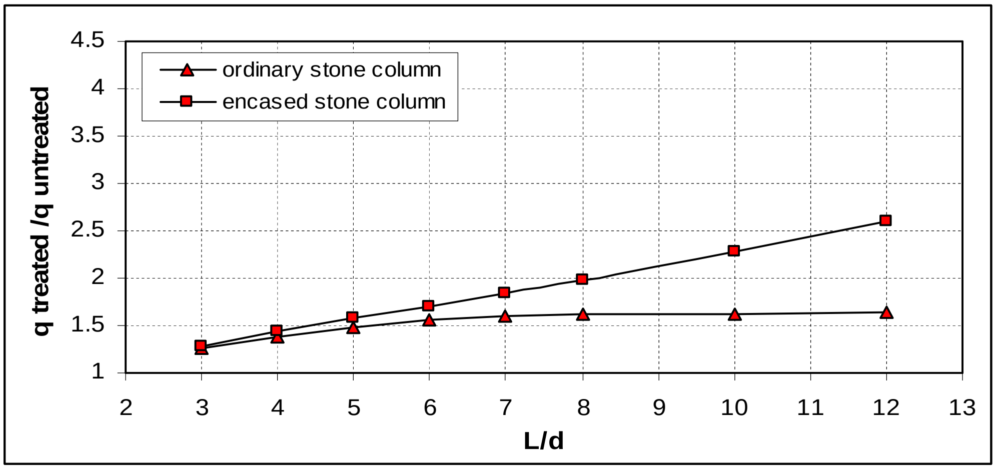

Fig.(5): Relationship between the Bearing Improvement Ratio and Length to Diameter Ratio of Floating Stone Column (Cu=20 kPa, a_s= 0.25).

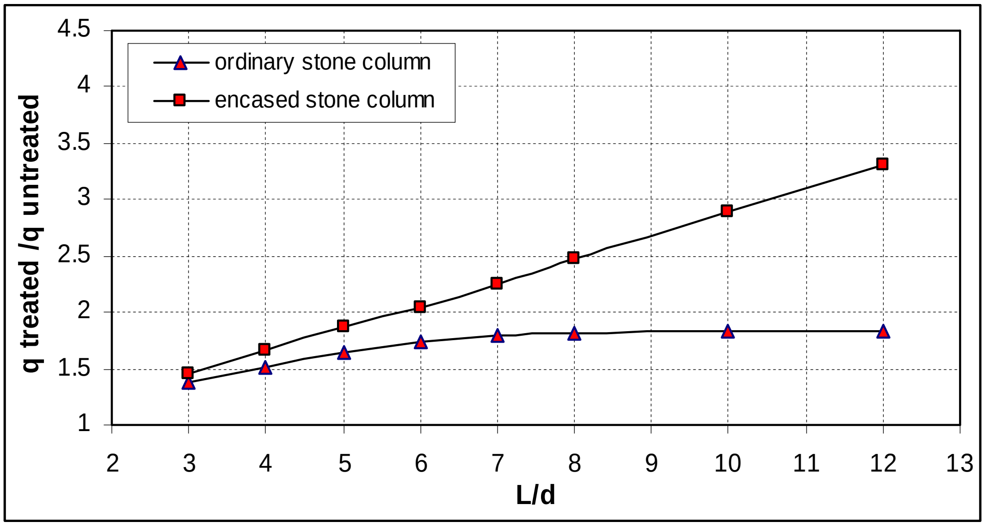

Fig.(6): Relationship between the Bearing Improvement Ratio and Length to Diameter Ratio of Floating Stone Column (Cu=20 kPa, a_s= 0.3).

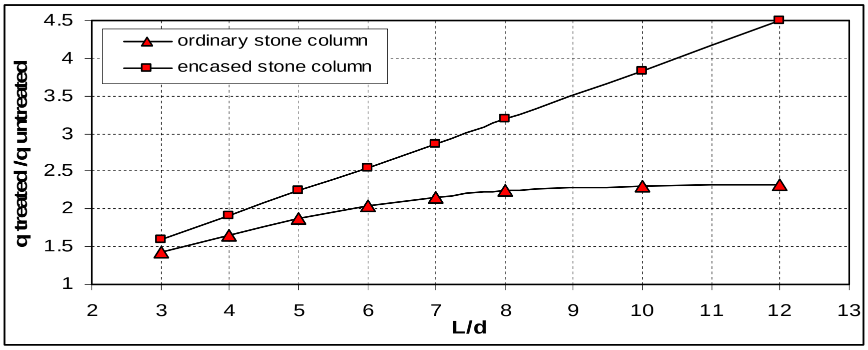

Fig. (7): Relationship between the Bearing Improvement Ratio and Length to Diameter Ratio of Floating Stone Column (Cu=20 kPa, a_s= 0.35).

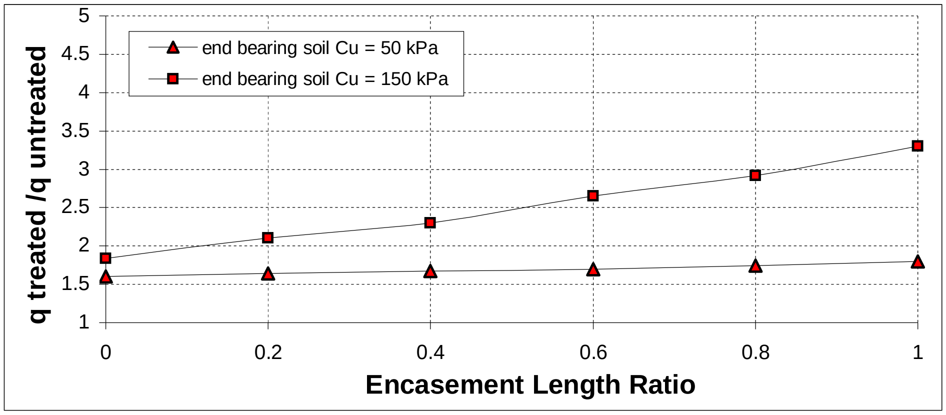

Fig.(8): Relation between the Encasement Length Ratio with Bearing Improvement Ratio of End Bearing Stone Column, (Cu=20 kPa for Surrounding Soil, L/d=3, a_s=0.25).

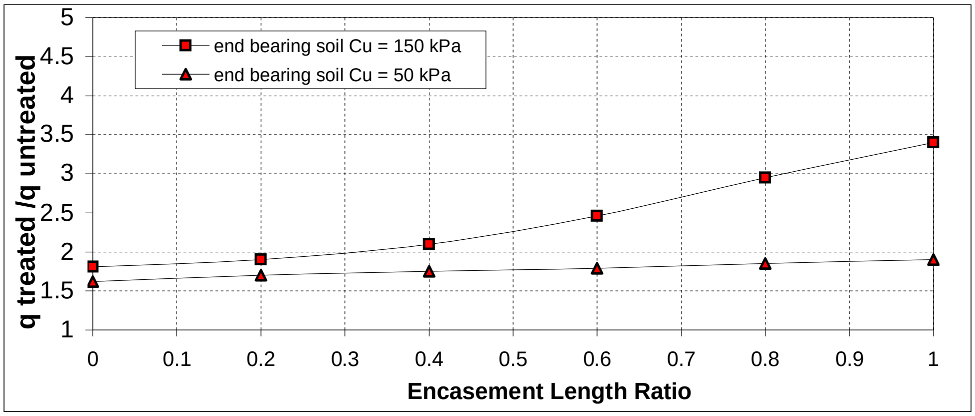

Fig. (9): Relation between the Encasement Length Ratio with Bearing Improvement Ratio of End Bearing Stone Column, (Cu=20 kPa for Surrounding Soil, L/d=4, a_s=0.25).

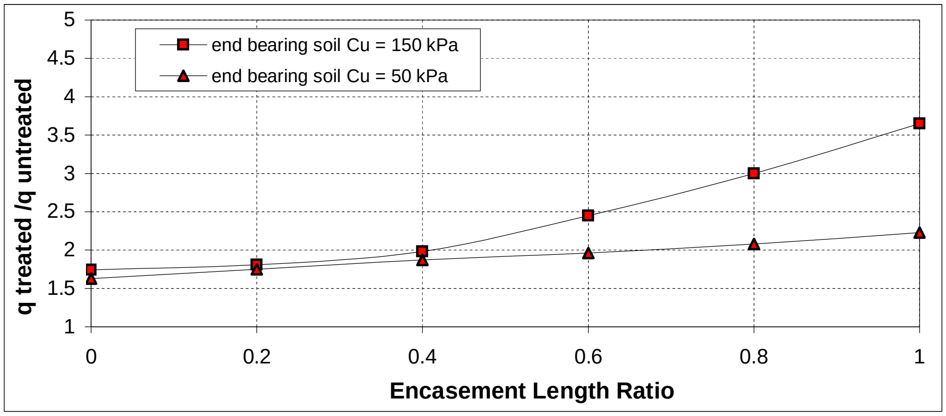

Fig. (10): Relation between the Encasement Length Ratio with Bearing Improvement Ratio of End Bearing Stone Column, (Cu=20 kPa for Surrounding Soil, L/d=5, a_s=0.25).

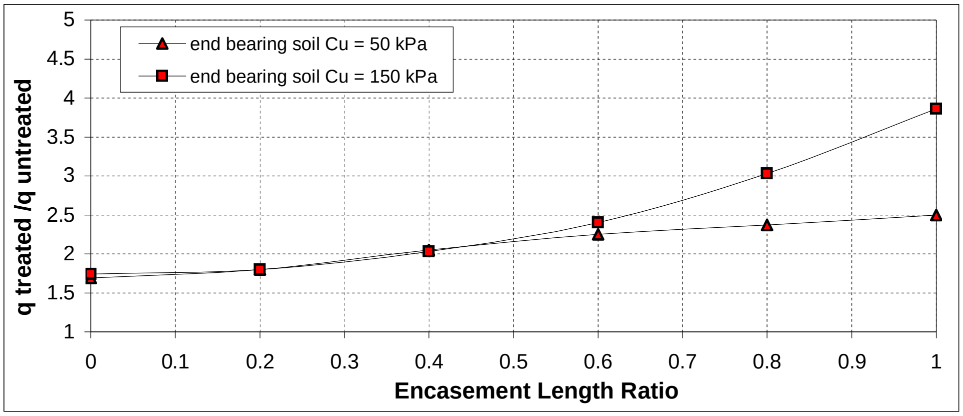

Fig. (11): Relation between the Encasement Length Ratio with Bearing Improvement Ratio of End Bearing Stone Column, (Cu=20 kPa for Surrounding Soil, L/d=6, a_s=0.25).

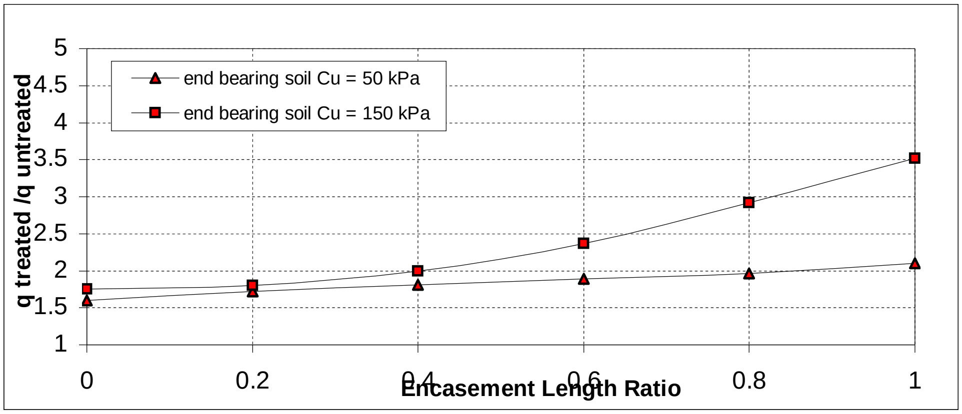

Fig. (12): Relation between the Encasement Length Ratio with Bearing Improvement Ratio of End Bearing Stone Column, (Cu=20 kPa for Surrounding Soil, L/d=8, a_s=0.25).

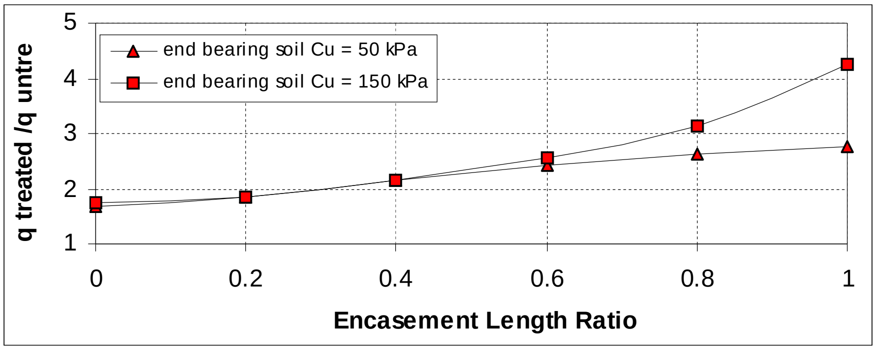

Fig. (13): Relation between the Encasement Length Ratio with Bearing Improvement Ratio of End Bearing Stone Column, (Cu=20 kPa for Surrounding Soil, L/d=10, a_s=0.25).

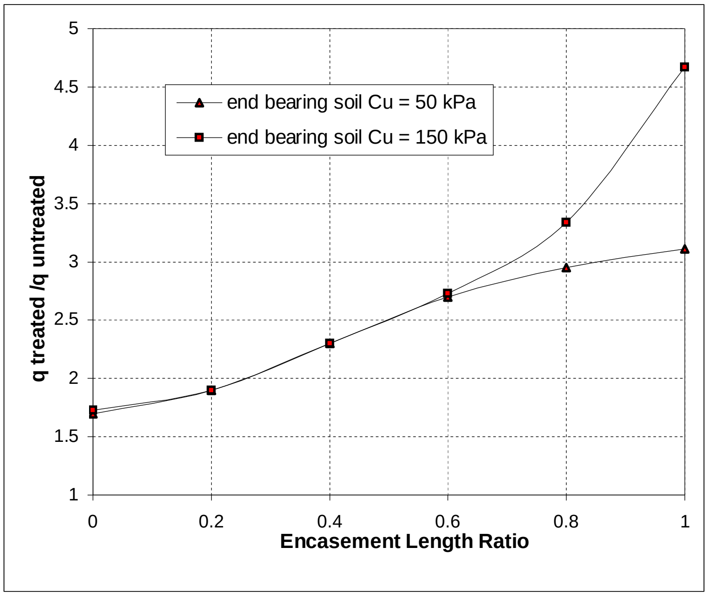

Fig. (14): Relation between the Encasement Length Ratio with Bearing Improvement Ratio of End Bearing Stone Column, (Cu=20 kPa for Surrounding Soil, L/d=12, a_s=0.25).

تصرف الأعمدة الحجرية محملة النهايات المغلفة

د.محمد يوسف فتاح
أستاذ مساعد
قسم هندسة البناء والإنشاءات _الجامعة التكنولوجية

عماد ياسين خضير
مدرس مساعد
كلية الهندسة . جامعة ديالى

الخلاصة

في هذا البحث تم استخدام طريقة العناصر المحددة كوسيلة لأجراء تحليلات مختلفة على منظومة الأعمدة الحجرية-التربة بظروف مختلفة. أجريت محاولة لتحسين تصرف الأعمدة الحجرية بواسطة تغليف الأعمدة باستخدام المشبكات (geogrid) كمادة تسليح. تم استخدام برنامج CRISP2D لإجراء هذه التحليلات و الذي يعتمد طريقة العناصر المحددة ويمكن من خلاله الحصول على التشوه المتوقع من خلال اعتماد معيار فشل Mohr–Coulomb لتصرف التربة المرن - اللدن.

أجريت دراسة للمعاملات لتحري تصرف الأعمدة الحجرية لظروف مختلفة. تمت دراسة عدة معاملات لبيان تأثيرها على تحسين قابلية التحمل والهبوط للأعمدة الحجرية وهذه المعاملات هي نسبة طول الركيزة إلى قطرها (L/d), وإسناد النهاية للعمود الحجري وكذلك نسبة المساحة التعويضية (مساحة العمود الحجري/مساحة الأساس الكلي) لكل من الأعمدة الحجرية العادية والمسلحة.

وقد وجد أن تأثير نسبة طول التغليف للأعمدة الحجرية (طول التغليف بالمشبك على طول العود الحري / الطول الكلي للعمود) على كل من تحسن التحمل و تقليل الهبوط يزداد مع زيادة مقاومة القص للطبقة التي تستند إليها نهاية العمود. إن تغليف العمود الحري يجب أن يمتد إلى الطول الكلي للعمود الحجري لجعل العمود يستفيد استفادة قصوى من التربة التي تستند إليها نهايته و خاصة للأعمدة الطويلة ذات نسبة (L/d) أكثر من 4.