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Performance of Stone Column in Soft Clay-Numerical Evaluation

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Abstract: *Stone columns are an efficient ground improvement technique for treating problematic soils. The confidence in the prediction accuracy of bearing capacity remains unsatisfactory. Soil samples were collected from vellayani paddy field and basic laboratory experiments were done. This paper aims to investigate the bearing capacity of single stone column using three-dimensional numerical analysis. Failure modes were observed and the effect of key parameters such as column's friction angle, undrained shear strength of surrounding soil and modular ratio were investigated. Numerical results showed bulging and a combination of bulging and punching are two dominant failure modes for the single stone column. Ultimate bearing capacity is mainly influenced by the column's friction angle and the undrained shear strength of the surrounding soil. Based on the results, a new prediction method is developed and compared reasonably well with the existing analytical solution and the field measurements.*

Keywords: Stone Column

I. INTRODUCTION

The existing soil on a given site may not be suitable for supporting the desired facilities such as buildings, bridges, dams and so on because safe bearing capacity of a soil may not be adequate to support the given load. To improve these soil types to allow building and other heavy construction, it is necessary to create stiff reinforcing elements in the soil mass. A number of these techniques have been developed in the last fifty years. The mechanics of ground improvement depends largely on the type of soil. A method for increase of strength is the incorporation into a weak foundation soil of cylindrical inclusions (columns) made up of a material having higher strength characteristics, will obviously result in an increase of its bearing capacity. Considering for instance a soft clay with a relatively low shear strength, two kinds of column reinforcement techniques might be envisaged: the 'stone column' technique which consists in introducing within the soft clay a vibro compacted stone or ballast material, the friction angle of which may exceed 40 and the 'lime column' technique obtained from mixing the weak soil mass with a given percentage of lime or lime–cement, thus producing a considerable increase of the soil initial shear strength (up to 20 times), together with a relatively small friction angle[1].The stone column technique, also known as vibro replacement or vibro-displacement, is a ground improvement process where vertical columns of compacted aggregate are formed through the soils to be improved. These columns result in considerable vertical load carrying capacity and improved shear resistance in the soil mass

Installing a system of stone columns is a common ground improvement technique used in soft clay. The wished-in-place concept is usually applied to predict the load-settlement behavior of the treated ground. In this approach, the effect of the installation process on the properties of the surrounding soil is neglected. High radial displacements of the soil particles associated with the installation process of the stone columns, to achieve their target diameter, significantly alter the surrounding soil properties and affect the overall performance of the improved soil. This work aims to numerically study the influence of the stone column construction process on the improvement of soft ground by utilizing the finite element method. Different radial excitations have been considered in the analyses to mimic the construction procedure. Aspects of the two- and three-dimensional numerical analyses are combined in this study to overcome the local numerical instabilities.

1.1 General Idea

Stone column ground improvement involves adding vertical columns of stone into the ground to a depth of at least 4m below the ground surface. A layer of compacted gravel can then be put over the top of the columns, ready for the construction of new house foundations. The stone column method is quick to construct and can be done at any time of the year.

1.1.1 Stone Column Construction

Stone columns are constructed by experienced contractors using specialist equipment. The construction uses an excavator with a vibrating probe to feed stone into the ground, forming a vertical column of stone. Some stone column rigs feed stone into the ground through the vibrating probe, exiting at the bottom, and other rigs require the stone to be fed in from the ground surface down the vertical hole in the ground. Both types use a vibrating probe that densifies the surrounding soils to help feed the stone into the ground.

1.1.2 Ground Improvement by Stone Column

Stone columns help to limit the amount and consequences of future liquefaction by:
Densifying the soil through vibration and introducing stone into the soil
Reinforcing the soil creating a stiff composite soil mass.
By achieving this, the non-liquefying soil crust is thickened and stiffened to reduce the likelihood of undulations, tilt and uneven ground surface subsidence from liquefaction of the underlying soil layers, therefore reducing damage to the house foundations.
In addition, stone columns may sometimes provide the soil with an increased drainage path to help reduce excess pore water pressure that can lead to liquefaction, so the columns can reduce the consequences of liquefaction when this occurs.

1.1.3 Stone Columns

The stone column method is quick to construct and can be constructed at any time of the year Stone columns Typical triangular grid installation pattern Non-Liquefiable Crust Liquefiable Soil Rammed Aggregate Piers (RAP) 54 Specialist stone column equipment and stockpile of stone (gravel) An advantage of stone columns is that no dewatering or excavation is required for the construction and they typically have a short construction period.

1.1.4 Soils Suitable for Stone Columns

Stone columns are best suited to sandy soils. A greater concentration of stone columns are required in siltier soils. Because of the large equipment required and the requirement for an area to store the stone (gravel), this method may not be practical for smaller properties or those with limited access

1.2 Scope

In spite of technological advances in column construction, accurate prediction in bearing capacity of the single stone column still remain a challenge. Thus, to enhance the understanding of the performance of the single stone column, this paper aims to investigate the bearing capacity of the single stone column in homogenous soil layer using numerical approach. Three-dimensional (3D) finite element modelling was carried out with associated flow rules adopted for the stone column material to take into account the dilatancy behaviour of compacted stone columns. The influence of compaction effort in terms of the different friction angle of stone column material was investigated for very soft to soft clay condition represented by different undrained shear strength. The results of this numerical study were compared against the analytical approach and the field recorded measurement**.**

II. LITERATURE REVIEW

Priebe H J (1976) He proposed a method to estimate the settlement of foundation resting on the infinite grid of stone columns based on unit cell concept. In this concept, the soil around a stone column for area represented by a single column, depending on column spacing, is considered for the analysis. As all the columns are simultaneously loaded, it is assumed that lateral deformations in soil at the boundary of unit cell are zero. The settlement improvement factor is derived as a function of area ratio and angle of internal friction of column material. The calculation of the improvement factor was done by considering the stone columns material is incompressible and column is based on a rigid layer (end-bearing). He considered the effect of compressibility of the column material and the overburden. He developed design charts to calculate the settlement of the improved ground to unimproved ground under identical surcharges. They considered linear elastic behaviour for stone column.

Poorooshasb H B and Meyerhof GG (1996) They proposed the performance ratio, which is defined as the ratio of the settlement of the improved ground to unimproved ground under identical surcharges. They considered linear elastic behavior for stone column. Bment of single and strip footing reinforced by a limit number of stone columns.

Balaam N P (1999) He proposed a finite-element approach for soft clay treated with granular piles and reported the effect of stiffness of granular pile on load deformation behavior

Ambily A P and Grandhi SR (2007) They conducted experimental and numerical analysis on singles and groups of stone columns. They presented improvement factor without considering stress due to installation of stone column.

Han J and Ye S L(2001) They developed a simplified and closed form solution for estimating the rate of consolidation of the stone column reinforced foundations accounting for the stone column soil modular ratio.

Guetif (2007) The installation of stone column in soft clay simulated by adopting a composite cell model. He reported that the improvement of the Young modulus of soft clay, due to the consolidation caused by the installation of the vibro compacted column, should be considered in the design procedure.

III. METHODOLOGY

3.1 Identifying Sample

Various test were conducted inorder to identify the collected sample falls in the category of the soft clay. Samples were collected from two different areas.

1. Velleyani Paddy Field
2. Mangalapuram clay factory

The test was done and confirmed with the first soil sample.

3.2 Experimental Study

The laboratory experiments were conducted inorder to identify the properties of the taken sampleand the clay collected from vellayani paddy field was found to be soft clay. The experiments conducted were liquid limit, plastic limit,specific gravity and unconfined compression test. The Liquid Limit, Plastic Limit and Specific Gravity of the test were 72, 36% and 2.7 respectively. From the Unconfined Compression Test the cohesion, frictional angle and dilatancy angle was computed. The cohesion of the sample was computed as 0.10 and the frictional ngle as 28 degrees. The dilatancy angle was computed 0 degrees.

3.3 Numerical Model and Analysis

Three-dimensional numerical analysis was carried out using commercial geotechnical software PLAXIS 3D. Stone column diameter, *d* of 1.0 m was installed in the soft clay. The column length is determined to be 5.0 m. Figure 1 shows the numerical model for the study. The horizontal and vertical boundary were set to be far enough to have caused no influence on the numerical results. A rigid footing of the same diameter as the stone column was placed on the column head. In this study, both stone column and soft soil were modelled as Mohr Coulomb (MC) soil model. Material properties are shown in Tables 1,2 and 3for a series of tests. Total Dimensions of Soil Area was estimated as 10x10x5.5 m, the footing diameter as 1.0 m ,the diameter of the pipe is 1.0 m and the length of the stone column as 5.0 m. The length of thefooting was estimated as 0.5

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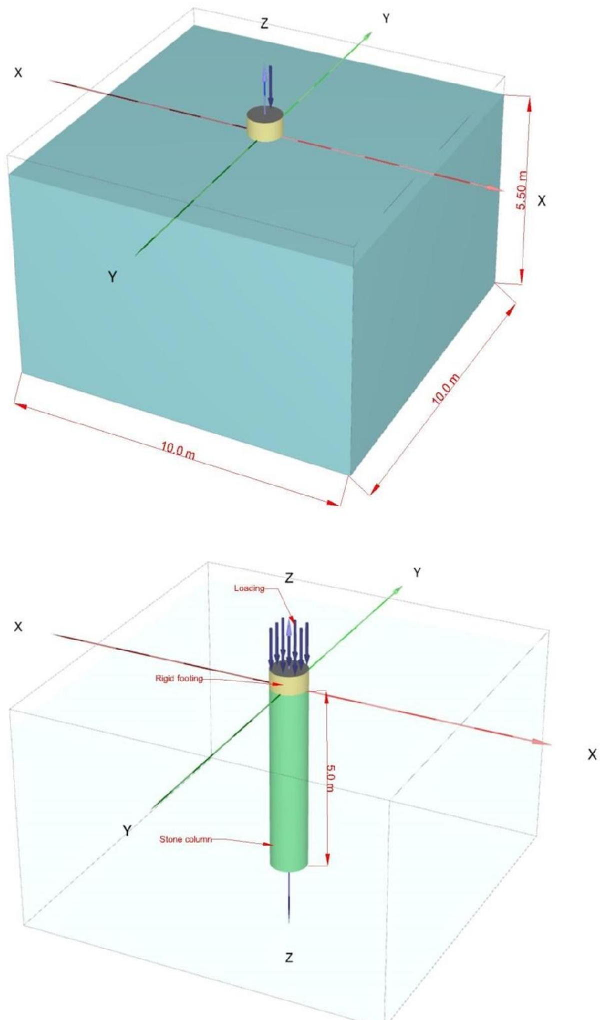

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Fig 1: Dimensions of the soil ,stone column and footing model.

The material propertis of soft soil, stone column and rigid footing was eastimated in table 1, 2 and 3 respectively

Soft Clay

Table 1: Material properties of soft clay

Material model	Mohr Columb
Type of Material behaviour	Undrained
Soil unit weight above phreatic level γ_{unsat}	16 kN/m^3
Soil unit weight below phreatic level γ_{sat}	16 kN/m^3
Permeability in horizontal direction k_x	1.0
Permeability in vertical direction k_y	1.0
Young's modulus Eref	16 kN/m^3
Poisson's ratio v	0.30
Cohesion c_{ref}	40.0kN/m^2
Friction Angle φ	28 degrees
Dilatancy Angle ψ	0

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Stone Column

Table 2: Material properties of stone column

Material model	Mohr Columb
Type of Material behaviour	Undrained
Soil unit weight above phreatic level γ_{unsat}	18 kN/m^3
Soil unit weight below phreatic level γ_{sat}	18 kN/m^3
Permeability in horizontal direction k_x	1.0
Permeability in vertical direction k_y	1.0
Young's modulus E	60.0E3 kN/m^2
Poisson's ratio v	0.30
Cohesion c_{ref}	40.0kN/m^2
Friction Angle φ	40 degrees
Dilatancy Angle ψ	0

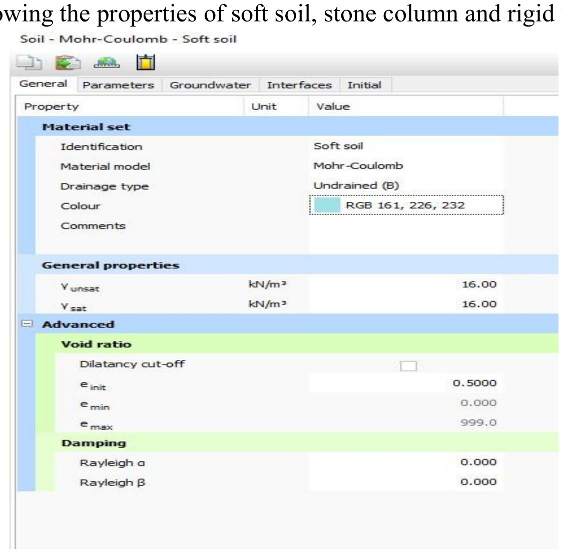
Rigid Footing

Table 3: Material properties of rigid footing

Material Type	Linear Elastic
Drainage type	Non porous
Youngs modulus	30.00E6
Poissons ratio	0.30

The material property tab was given in fig 2,3 and 4 respectively. Initial stresses were generated by K_o procedure with the proposed value of lateral earth pressure, K = 1.0 for both the column and the soil reflecting wish-in-place approach was adopted in the model. The staged construction with the prescribed displacement approach was adopted to obtain the load that has caused the footing to deform 0.2 m vertically. Thus, the ultimate bearing capacity in this study is determined to be the pressure that has caused 20% strain relative to the column diameter.

The load transfer mechanism is changed from the bulging in the upper column to a combination mode where bulging and punching failure take place at the same time as shown in the case with the higher friction angle of column . All other parameters remain the same as in the base case. Higher friction angle allows more loads to be transferred down to a deeper depth. Thus, the bearing capacity of the column is derived from both the radial expansion and the end resistance. It can be further deduced that the column length of 4 to 5 times the column diameter may not be the optimum length if the friction angle of the column is high even though the surrounding soil is very soft. The material tab showing the properties of soft soil, stone column and rigid footing is shown in figure 4 ,5 and 6.



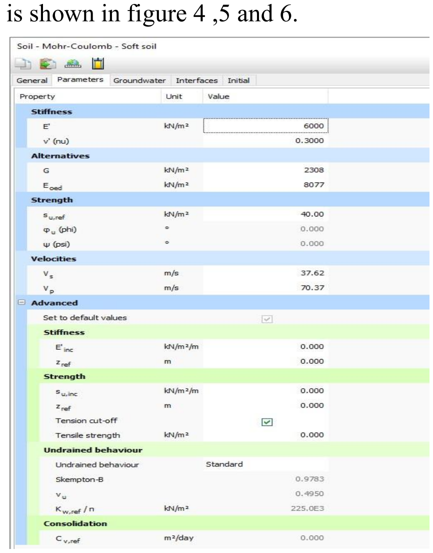


Fig 2: Material property tab of soft soil

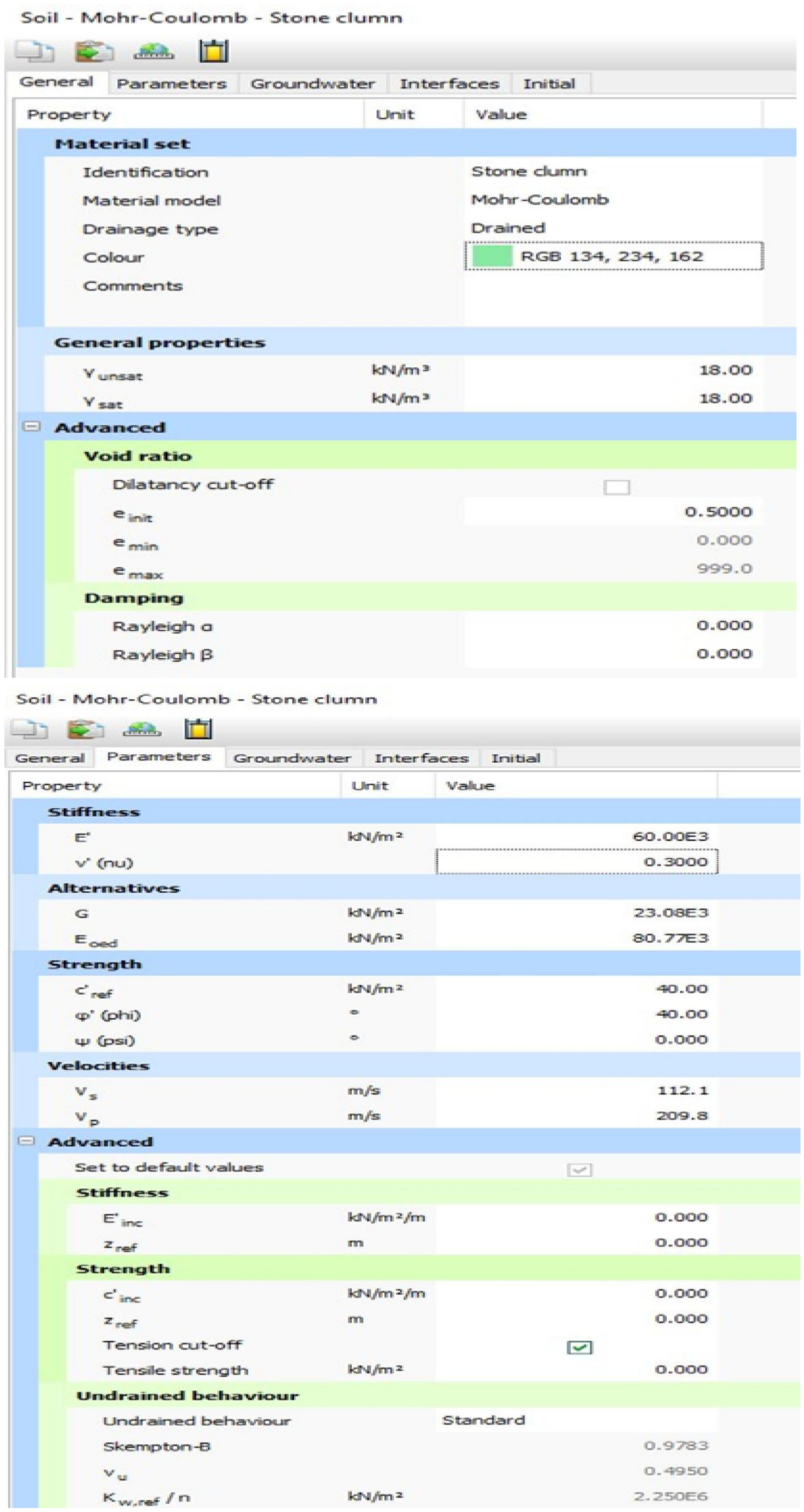


Fig 3: Material property tab of stone column

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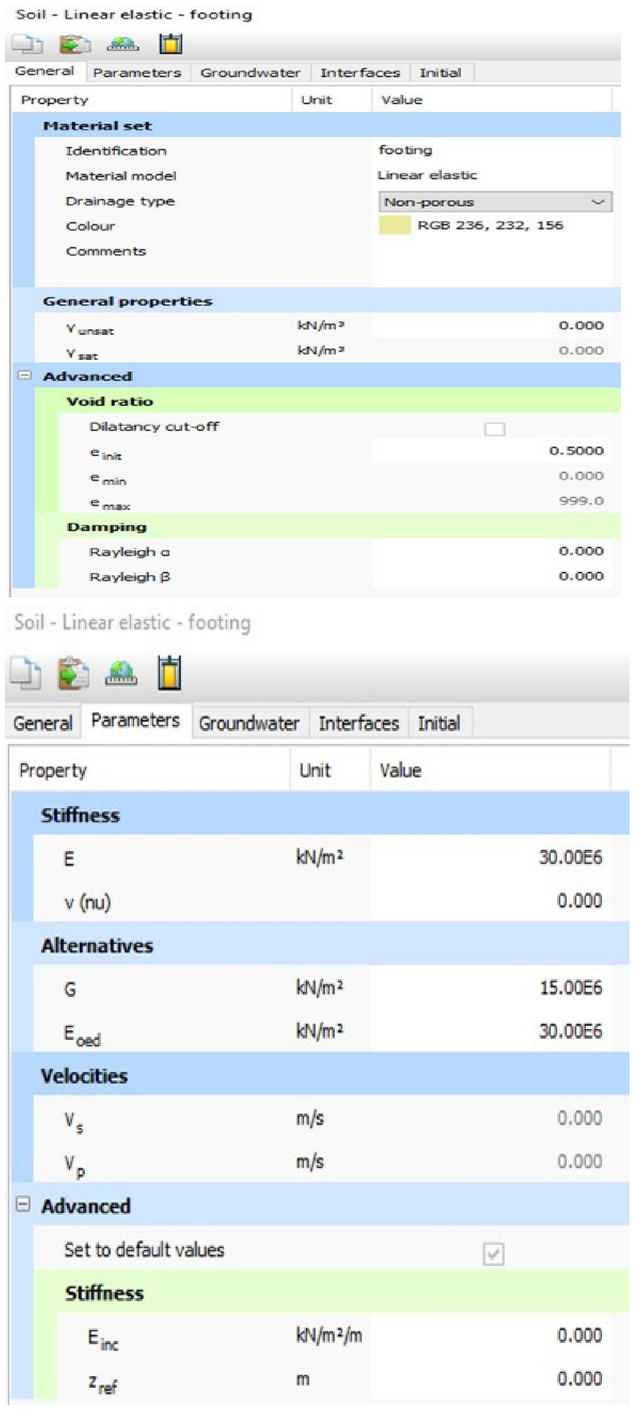

Fig 4: Material property tab of rigid footing

3.3.1 Finite Element Meshing

Numerical modeling was performed using the PLAXIS V8 program. PLAXIS is used for the analysis of deformation and stability in geotechnical engineering. The improved soil is modeled with 15 nodes triangular finite elements. In the numerical analysis, medium mesh was used. In the reinforced area, medium mesh was refined, because stresses and displacements are higher in this area.

In this investigation, it was assumed that the raft is rigid, and both the stone column and soft clay undergo the same amount of settlement. There are no interface elements placed between the soil and the footing, so any slippage between footing and soil occurs within the soil. The interface elements were used at the interface between the stone column and soft clay. This can be explained by the fact that the deformation of the column is mainly by general failure and which produces significant shear between clay and stone column . In this paper, it is supposed that stone columns are extended to a hard layer. In most practical cases, a soil layer is placed at the top soft clay reinforced with stone columns, so a sand layer of 20 cm thickness was placed at the top of model. The analysis was carried out on stone column with the diameter of 1 m and depth of 10 m. Because of symmetry, only half of the geometry is modeled. Four different types of geometry are modeled to investigate the effect of stone column installation, stress ratio, bearing capacity in both heterogeneous and homogeneous soil.

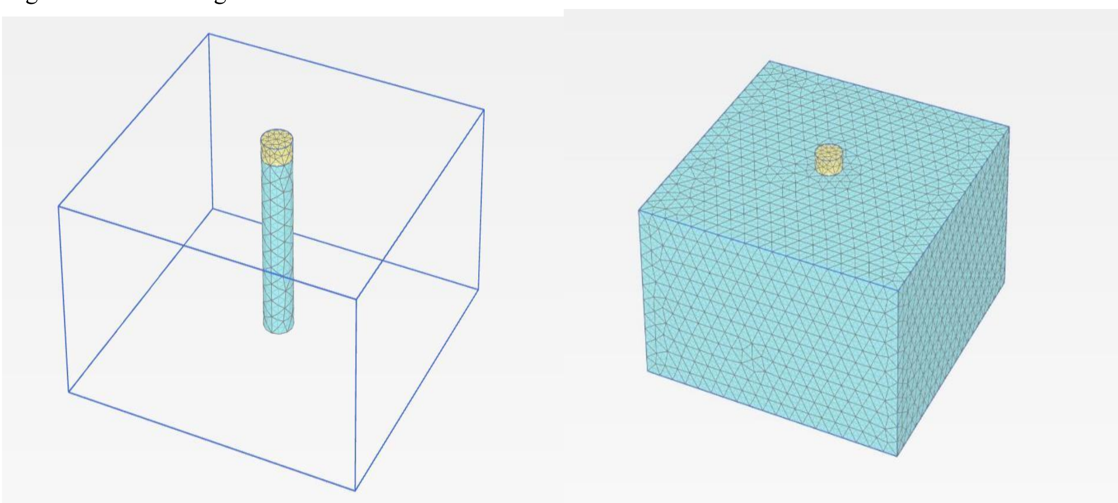

Fig 5: meshed geometry

Here the element distribution is fine. Now the element size of 5E-3m is adopted. The loading and boundary condition chosen here is normally fixed for the case of Xmin and Xmax. Now the Ymin and Ymax is also Normally fixed whereas Zmax is free fixed and Zmin Fully fixed.. Here a prescribed load of 1108KN/m3 and prescribed displacement of 0.0 .

Element Distribution = fine
Element size = 5E-3m
Loading and Boundary conditions
Xmin = normally fixed
Xmax= Normally fixed
Ymin= Normally fixed
Ymax= Normally fixed
Zmax= Free Fixed
Zmin= Fully Fixed
Prescribed Displacement=0.2 kN/m^2

IV. RESULTS

4.1 Analysis

In the analysis, the case with C_u of 5 kN/m^2, E_c/E_s of 10 and $\varphi_c' = 35°$ is taken as the base case. Figure 6 shows the failure mechanism in the base case. Bulging is observed, and the maximum lateral displacement occurred at about one column diameter below the ground surface. The bulging is noticed up to the depth of 3.5*d*. The toe penetration of the column is insignificant. column as well as the surrounding soil. Radial expansion of upper column has resulted in the plastic zone up to 1*d*. Beyond that, the soil is still in the elastic state. It can be postulated that the ultimate bearing capacity of the column is solely derived through the maximum radial reaction or the confinement.

The load transfer mechanism is changed from the bulging in the upper column to a combination mode where bulging and punching failure take place at the same time as shown in the case with the higher friction angle of column . All other parameters remain the same as in the base case. Higher friction angle allows more loads to be transferred down to a deeper depth. Thus, the bearing capacity of the column is derived from both the radial expansion and the end resistance. It can be further deduced that the column length of 4 to 5 times the column diameter may not be the optimum length if the friction angle of the column is high even though the surrounding soil is very soft.

Figure 7 shows that there is not much difference in the failure mechanism when the undrained shear strength of the surrounding soil is increased to C_u = 40 kN/m^2 while the other parameters remain the same as in the base case. However, when the C_u is 40 kN/m^2 and the φ_c' is altered to a higher value i.e. 50°, then the radial expansion is more prominent than the case with lower C_u and lower φ_c'. There is more yielding around the column, but less toe penetration and less yielding below the toe. Another finding in this study is that the modular ratio does not play an important role in governing the failure mechanism and thus the results due to the changes in the modular ratio are not shown here.

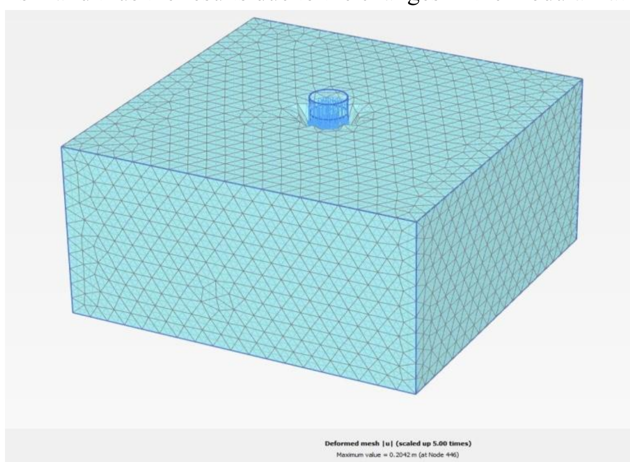

Fig 6: Deformed mesh showing base failure

The similar displacement response is found in all other cases with E_c/E_s of 20, 30 and 40. The results indicate the significant influence of the column's friction angle and the undrained shear strength of the surrounding soil where higher ultimate bearing capacity, q_{ult} is obtained when the values of these parameters are increased. From the results of Fig. 7 and in view of negligible influence of the modular ratio, the relationship of the ultimate bearing capacity, the undrained shear strength of the surrounding soil and the friction angle of the column

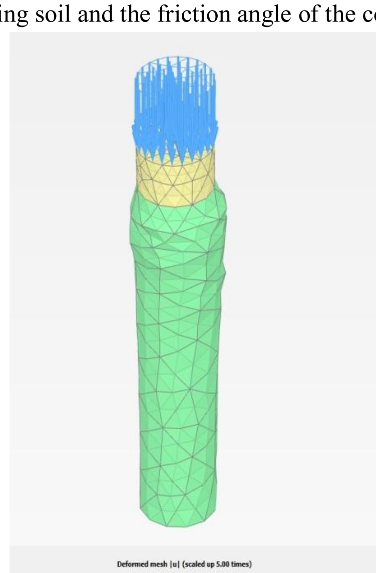

Fig 7: Bulging

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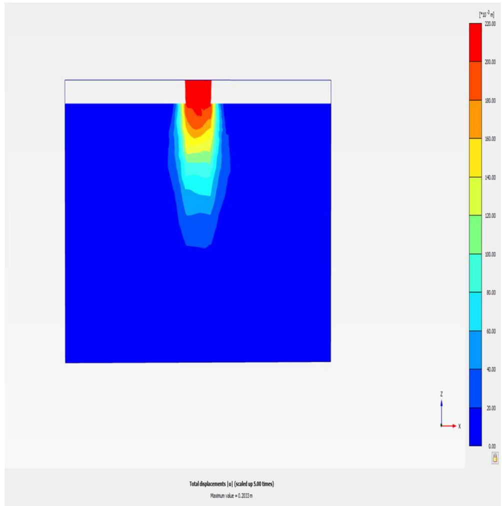

Fig 8: Vertical Deformation

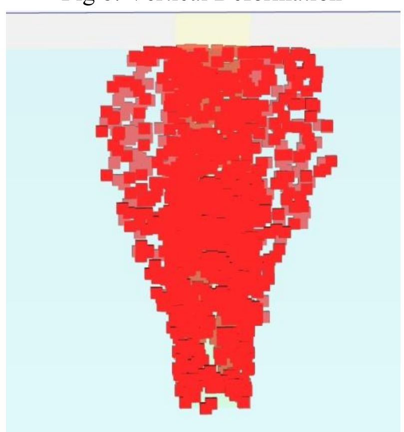

Fig 9: Plastic points

Stone column diameter, d of 1.0 m was installed in the soft clay. The column length is determined to be 5.0 m. The horizontal and vertical boundary were set to be far enough to have caused no influence on the numerical results. A rigid footing of the same diameter as the stone column was placed on the column head. In this study, both stone column and soft soil were modelled as Mohr Coulomb (MC) soil model. Table 4 for a series of tests. The undrained strength of the soft soil, C_u varied from 5 to 40 kPa and the effective friction angle for the column material, φ_c' varied from 35° to 50°. Associated flow rules were adopted for column material where the dilation angle, is taken to be $\varphi_c' - 30°$. The Young's modulus of the surrounding soil, E_s is determined to be 150 times the undrained shear strength. The modular ratio, $m = E_c/E_s$ is taken as 10–40 which is within the typical range; where E_c is the Young's modulus of column material.

Table 4: Stiffness of surrounding soil and stone column

Cu	Es	10Es	20Es	30Es	40Es
5	750	7500	15000	22500	30000
10	1500	15000	30000	45000	60000
15	2250	22500	45000	675000	90000
20	3000	30000	60000	90000	120000
25	3750	37500	75000	1125000	150000
30	4500	45000	90000	135000	180000
35	5250	52500	105000	1575000	210000
40	6000	60000	120000	180000	240000

Initial stresses were generated by K_o procedure with the proposed value of lateral earth pressure, K = 1.0 for both the column and the soil reflecting wish-in-place approach was adopted in the model. The staged construction with the prescribed displacement approach was adopted to obtain the load that has caused the footing to deform 0.2 m vertically. Thus, the ultimate bearing capacity in this study is determined to be the pressure that has caused 20% strain relative to the column diameter. In the analysis, the case with C_u of 5 kN/m^2, E_c/E_s of 10 and φ_c' = 35° is taken as the base case. Figure 2 shows the failure mechanism in the base case. Bulging is observed, and the maximum lateral displacement occurred at about one column diameter below the ground surface. Similar observation on a field load test was also being made. The bulging is noticed up to the depth of 3.5d. The toe penetration of the column is insignificant. Figure 2c shows the yielding occurred in the column as well as the surrounding soil. Radial expansion of upper column has resulted in the plastic zone up to 1d. Beyond that, the soil is still in the elastic state. It can be postulated that the ultimate bearing capacity of the column is solely derived through the maximum radial reaction or the confinement.

The load transfer mechanism is changed from the bulging in the upper column to a combination mode where bulging and punching failure take place at the same time as shown in the case with the higher friction angle of column i.e.φ_c' = 50° (Fig. 11). All other parameters remain the same as in the base case. Higher friction angle allows more loads to be transferred down to a deeper depth. Thus, the bearing capacity of the column is derived from both the radial expansion and the end resistance. It can be further deduced that the column length of 4 to 5 times the column diameter may not be the optimum length if the friction angle of the column is high even though the surrounding soil is very soft.

Figure 14 shows that there is not much difference in the failure mechanism when the undrained shear strength of the surrounding soil is increased to C_u = 40 kN/m^2 while the other parameters remain the same as in the base case. However, when the C_u is 40 kN/m^2 and the φ_c' is altered to a higher value i.e. 50°, then the radial expansion is more prominent than the case with lower C_u and lower φ_c' as shown in Fig. 13, compared to Fig. 11. There is more yielding around the column, but less toe penetration and less yielding below the toe. Another finding in this study is that the modular ratio does not play an important role in governing the failure mechanism and thus the results due to the changes in the modular ratio are not shown here.

4.1.a Column with Cu=5kN/m, Ec/Es=10 and Frictional angle= 35 degrees

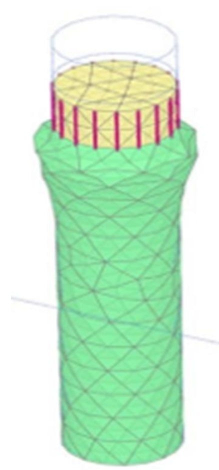

Fig10 a: bulging

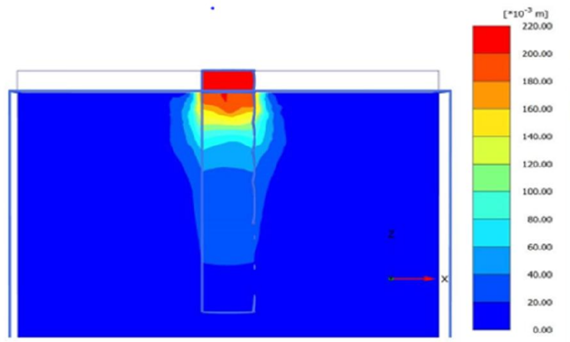

Fig 10b: Displacement shading in stone column

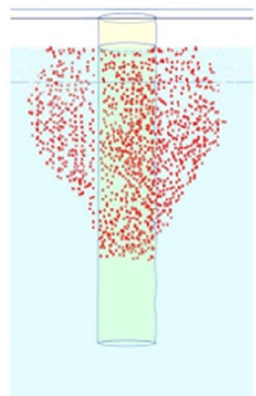

Fig 10 c: plastic points

4.1.b Column with Cu=5kN/m, Ec/Es=10 and Frictional angle= 50 degrees

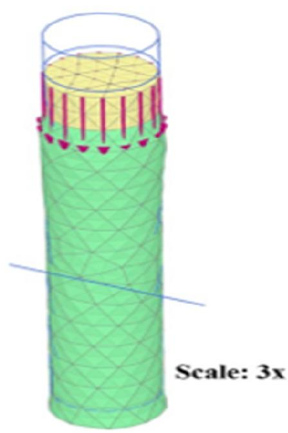

Fig 11a : BULGING

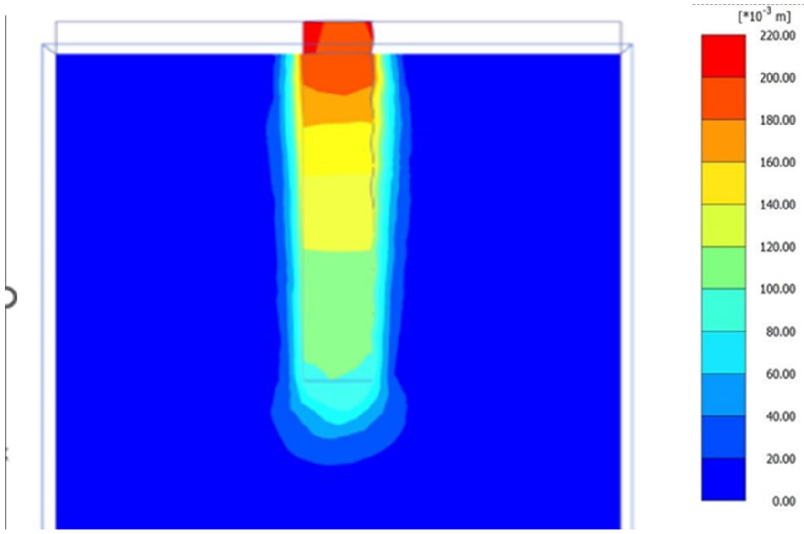

Fig 11b: displacement shading in stone column

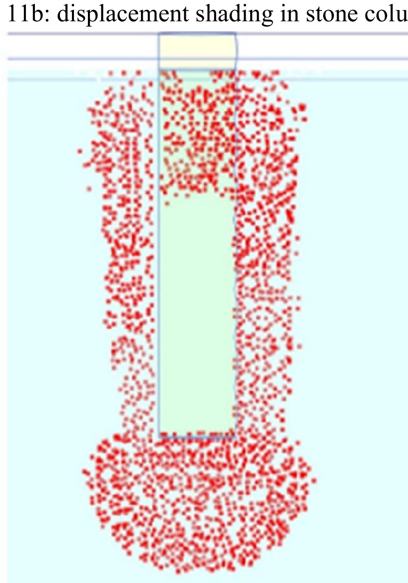

Fig 11c: Plastic points

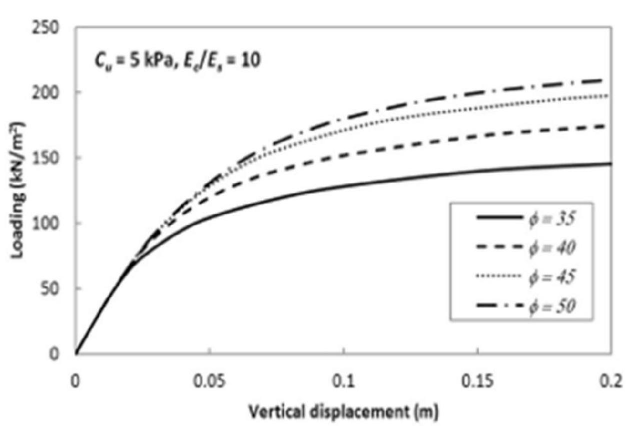

Fig 12 : Load Displacement Curve

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4.1.c Column with Cu=40kN/m, Ec/Es=10 and Frictional angle= 35 degrees

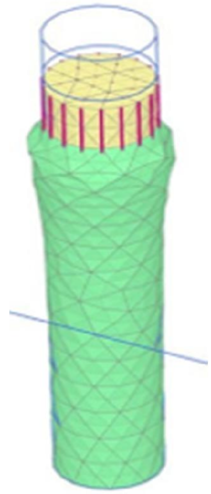

Fig 13a: Bulging

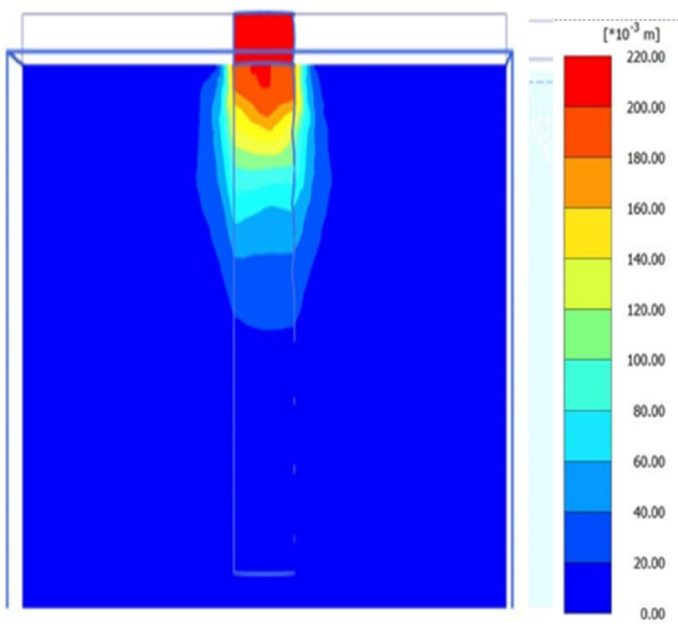

Fig 13b: displacement shading in stone column

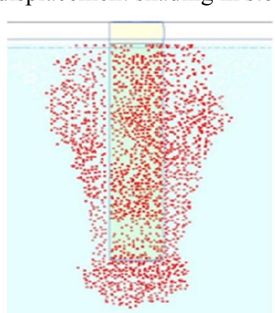

Fig 13c: plastic points

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4.1 d Column with Cu=40kN/m, Ec/Es=10 and Frictional angle= 50 degrees

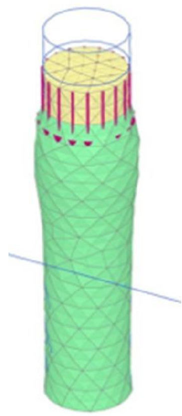

Fig 14a: bulging

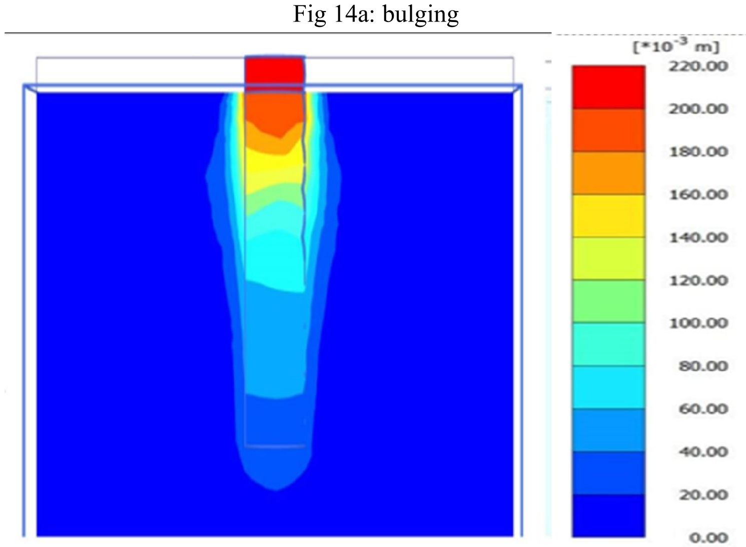

Fig 14b: displacement shading in stone column

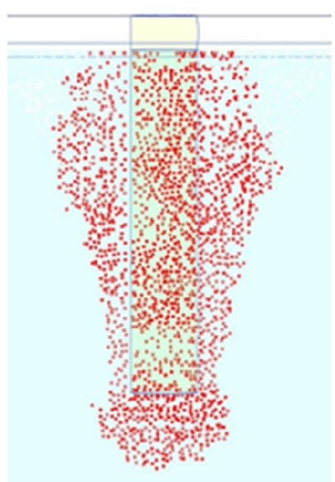

Fig 14c: plastic points

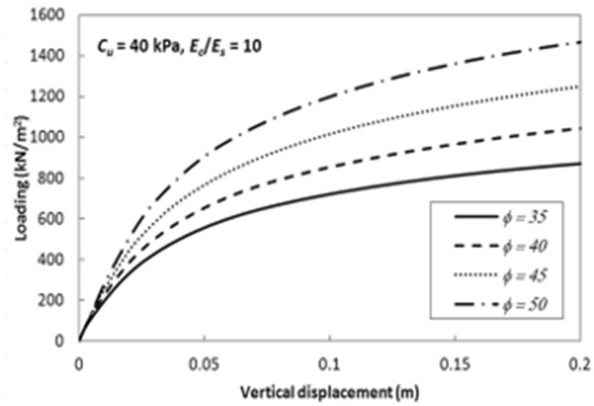

Fig 15: Load displacement curve

VI. CONCLUSION

1. Bulging or combination of bulging and punching can happen to the single stone column having the same length. The failure modes are influenced by the value of column's friction angle and not much by the shear strength of the surrounding soil and the modular ratio.
2. The ultimate bearing capacity of the single stone column is influenced by the column's friction angle and the undrained shear strength of the surrounding soil. The effect of modular ratio is small and can be ignored.
3. Strain hardening behavior is noticed with no distinct peak strength.

REFERENCES

[1]. Ahmed Naseem, Patil K A; Geo Reinforced Stone Column Technique For Soft Soil Improvement; International Journel Of Engineering Science And Research Technology April 2018

[2]. A J Choobbasti, A Zahmatkesh; R Noorzad (2011); Performance Of Stone Columns In Soft Clay Numerical Evaluation; Geotechnical And Geological Engineering Sep (2011)

[3]. H F Shehata,T M Sorour And A L Fayed(2018) ; Effect Of Stone Column Installation On Soft Clay Behaviour ; International Journel Of Geotechnical Engineering .

[4]. 4.Samuel Thamaraj, Freeda Christy C, Brema J; Performance Of Different Types Of Stone Columns In Soil Stabilization International Journal Of Engineering Technology Science And Research.

[5]. Zahmatkesh And Choobbast; Settlement Evaluation Soft Clay Reinforced By Stone Coumns IJRAAS .May 2010

[6]. Ng KS, Tan SA (2014) Design and analyses of floating stone columns. Soils Found 54(3):478–48

[7]. Kirsch F (2006) Vibro stone column installation and its effect on ground improvement. In: Numerical modelling of construction processes in geotechnical engineering for urban environment: proceedings of the international conference on numerical simulation of construction processes in geotechnical engineering for urban environment. Bochum, Germany, p 115

[8]. Hughes JMO, Withers NJ (1974) Reinforcing of soft cohesive soils with stone columns. Ground Eng 7(3):42–49

[9]. Barksdale RD, Bachus RC (1983) Design and construction of stone columns. Federal Highway Administration Office of Engineering and Highway Operations

[10]. Brauns J (1978) Initial bearing capacity of stone columns and sand piles. Soil reinforcing and stabilizing techniques in engineering practice, Sydney, pp 1497512

[11]. Greenwood DA (1970) Mechanical improvement of soils below ground surface. In: Proc., ground engineering conf., Institution of civil engineers, London, p 11–22

[12]. Van Impe WF, Madhav MR, Vandercruyssen JP (1997) Considerations in stone column design. In: Ground improvement geosystems: densification and reinforcement: proceedings of the third international conference on ground improvement geosystems, Londopp 190–196

[13]. Wissmann KJ (1999) Bearing capacity of GEOPIER—supported foundation systems. Technical Bulletin, No.2, GEOPIER Foundation Co., Inc., Scottsdale, AZ

[14]. Hughes JMO, Withers NJ, Greenwood DA (1975) A field trial of the reinforcing effect of a stone column in soil. Geotechnique 25(1):31–44

[15]. Gibson RE, Anderson WF (1961) In situ measurement of soil properties with the pressuremeter. Civil Eng Public Works Rev 56:615–618