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The Effect of Stone Column (Nailing and Geogrid) on Stability of Expansive Clay

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Abstract**—**By enhancing the application of grounds for establishment and due to the lack of appropriate sites, engineers attempt to seek out a new method to reduce the weakness of soils. In aspect of economic situation, various ways have been used to decrease the weak grounds. Because of the rapid development of infrastructural facilities, spreading the construction operation is an obligation. Furthermore, in various sites with the really bad soil situation, engineers have considered obvious problems. One of the most essential ways for developing the weak soils is stone column. Obviously, the method was introduced in France in 1830 to improve a native soil initially. Stone columns have an expanding range of usage in different rough foundation sites all over the world to increase the bearing capacity, to reduce the whole and differential settlements, to enhance the rate of consolidation, to stabilize slopes stability of embankments and to increase the liquefaction resistance as well. A recent procedure called installing vertical nails along the round stone columns in order to make better the performance of considered columns is offered. Moreover, thanks to the enhancing the nail diameter, number and embedment nail depth, the positive points of vertical circumferential nails increases. Based on the result of this study, load caring capacity will be develop with enhancing the length and the power of reinforcements in vertical encasement stone column (CESC). In this study, the main purpose is comparing two methods of stone columns (installed a nail surrounding the stone columns and using geogrid on clay) for enhancing the bearing capacity, decreasing the whole and various settlements.

Keywords**—**Bearing Capacity, Clay, Geogrid, Nailing, Settlements, Stone Column.

I. INTRODUCTION

THE application of reinforcement materials in the soil is considered as a method for strengthening the soil engineering characteristics. The soil can be determined as quadruple main type mixtures: sand, gravel, and silt. The soil has some characteristics such as tensile strength and is highly reliant environmental conditions [1]. The reinforcement of the soil is particularly a way for developing the mechanical properties of the soil like shear, hydraulic conductivity, density and shear. For soil reinforcement used of stone columns, soil nailing, micro piles and reinforced soil [2]. Geosynthetics have changed various characteristics of the geotechnical engineering steps and some of the applications have been replaced constructing materials totally traditional. The application of geosynthetic in many cases, it can saliently develop performance, enhance safety, and decrease costs compared to a conventional design [3]. The main aim for use of a geosynthetic is to develop hydraulic, mechanical and physical features of soils. The geosynthesis that are applied in establishment are geoform, geotextile, geomembrane, geogrid, geonet, geocomposites and geocell. Geosynthetics have been applied in various regions of civil engineering entailing roadways, retaining structures, embankments, landfills, railroads, dams, etc. [4].

II. REINFORCED STONE COLUMN BY USING GEOGRID

Reference [5] performed a series of laboratory analysis to study the influence of geogrid on the load bearing capacity and bulging decrease on granular column. A total of 14 plate load tests were conducted for untreated clay bed, unreinforced granular columns and the geogrid reinforced column with various numbers of geogrid layers and spacing. The experimental establishment can be observed in Fig. 1. The clayey silt was chosen as the soil bed while the crushed stone aggregated with special size from 2.36 to 4.75 mm was applied as the backfill materials for the granular column. The reinforcing material applied in the granular column was a biaxical geogrid. The clay bed with a height and diameter of 300 mm was gotten ready by compaction method. A sand layer of 50 mm thick was laid at the bottom of the tank. The 60 mm diameter stone column was installed by compact the crushed stone aggregated in layered to assumed density with the help of casing. The needed geogrid layers were transformed at the upper section of the granular column in assumed spacing. Two series of load tests were conducted. Initially, the load tests were leaded by the column alone a 60 mm diameter carrying plate which had a similar size with the column diameter. Moreover, the load tests were used by loading the entire area (both column and soil) by applying a 120 mm diameter bearing plate. The load was applied in increments of 45 N until 275 N. The establishment was estimated with a dial test and the diameter of the bulge was estimated at different depths from the top of the granular column. Due to this analysis, it can be considered that the geogrid has significantly developed the load carrying capacity of the granular column and decrease the bulging diameter and bulging length of the granular column. The development factors enhanced with the growth of numbers of geogrid and reduction of geogrid spacing. The stress to induce an establishment of 3mm increased 80% comparing to the unreinforced granular column. For 5 numbers of geogrid with a spacing of 10mm, the bulge was ignorable at 1.04 times of the column diameter while, the bulge length was 1.33 times of the column diameter. But, the effect of mesh size and power of the geogrid was not studied [5].

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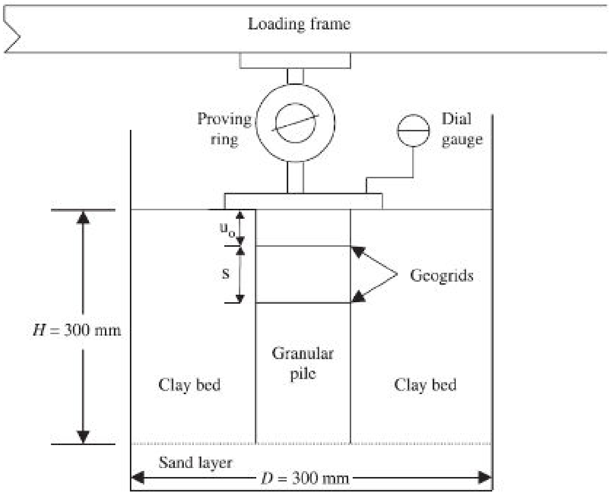

Fig. 1 Experimental setup by [5]

Reference [6] conducted a series of small scale model tests on the geogrid encased column to study the geogrid encasement length on the strain decrease and the bulging prevention. The laboratory gauge was used in enlarged diameter with 143 mm internal diameter which was planned on the basis of the unit cell idealization concept. The soft clay bed with the undrained shear strength of 5kPa was gotten ready by consolidating the kaolin slurry with the moisture content about 115%, from 480 mm to 310 mm in the diameter by using a pressure of 50 kPa. A weak graded sand (Grade 8/16, supplied by Unimim Australia Ltd.) with the special size of 1.6 mm was applied to show the stone as the backfill material of the stone column. The commercially fiberglass and aluminum ‘window mesh’ are used as an encasement material for small scale geogrid. The mesh was established into a cylindrical sleeve of 50.5 mm with 10 mm overlap which was tied with resin and cured for three days. The mesh sleeve was placed in the mold of 51 mm diameter for sand column before the sand was being filled in. After that, the san column was frozen before installed in the clay bed. Then, the specimen was installed after the sand column was perfectly thawed which the specimen had to be left minimum for three hours at room temperature. The specimens were loaded at the whole region and the column region. From this detail study, it was considered that the encasement of the stone column applying geogrid can significantly enhance the stiffness and decrease the strain of the stone column. For a fully encased stone column in a column group, the strain can be decreased up to 80% while for the alone column which was loaded at the column region, the load carrying capacity enhance with the increase of encasement length; but the strain at failure was remained quite consistent. For the fully encased stone column, bulging was shown along the entire length of the non-encased column in the column groups and limited to a length of approximately column diameters. But, in this investigation, the stone column was gotten ready by application of frozen method which cannot show the actual limitation process of stone column at site as the limiting pressure of the soil was low at site thus the quality of the stone column might be lower [6].

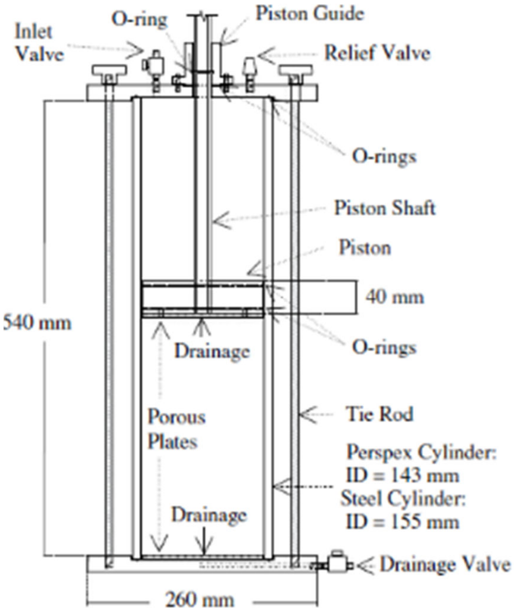

Fig. 2 Sketch of enlarged consolidation cell by [6]

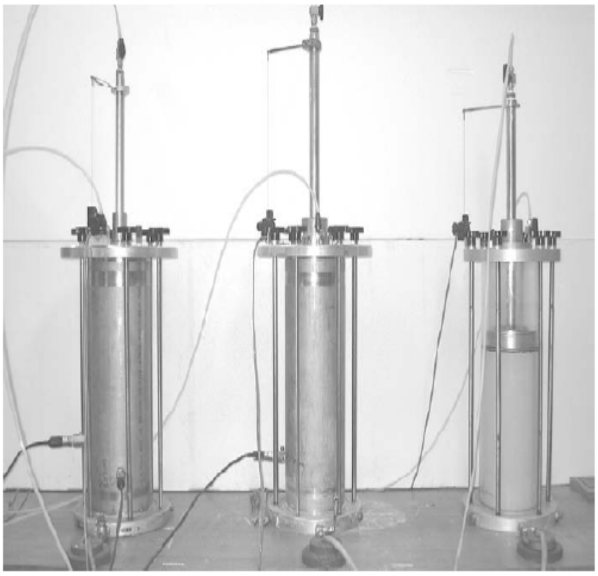

Fig. 3 Photograph of enlarged consolidation cells in operation by [6]

Reference [7] designed a series of laboratory gauge to study the influence of geogrid-reinforced sand bed on stone column. Just one single stone column test was designed in a square tank of 525 mm size and 400 mm high. The tests were conducted on the unreinforced and georgic reinforced sand bed. The clay bed with bulk unit weight of 19.8 kN/m3 was prepared by compaction way. The diameter of the stone column was 50 mm and the backfill material is the crushed stone materials with the special size range from 2 mm to 6mm.

The 50 mm diameter stone column was established by transformable method with the guide of steel casing. While the sand bed materials were sand elements which can pass through 4.75 mm. The biaxial geogrid was applied as the reinforcement layer. A 50 mm sand layer was placed before the georgic was place on the stone column. After, the sand bed was laid on the geotextile to a required high. The basis of this test can be observed in Fig. 4. The specimen was loaded by used pressure on a 10 mm diameter extruded after it had gotten enough power in order to study the bulging diameter and depth of the stone column. From this study, it was found that the load carrying capacity of the soft clay was influentially enhanced by involving the geogrid in the sand bed above the stone column on the soft clay. The increment was up to 233% of the untreated soft clay for the settlement of 20% from footing height. The maximum thickness of unreinforced sand bed was 1.7 time of the maximum thickness for geogrid reinforced sand bed while the maximum measurement of geogrid reinforced region was three times of the footing diameter. Besides, with the entailment of geogrid reinforced sand bed on the stone column, the bulge diameter was influentially decreased and the bulge depth was enhanced. But, this test can only show the trait for the stone column with particular properties. This investigation should be limited by conducting experiment on different materials and soil conditions to get better results [7].

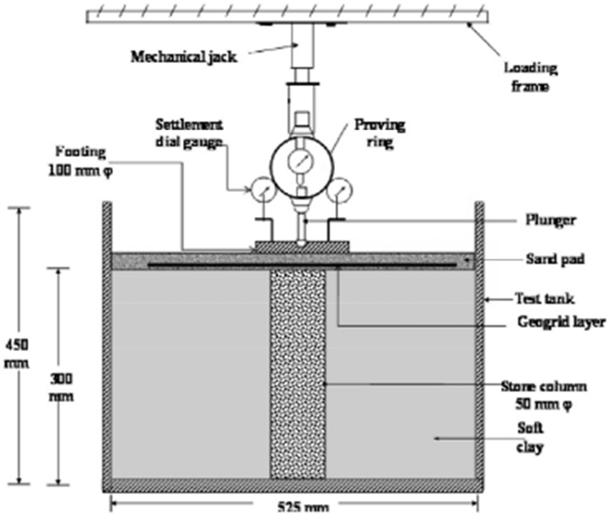

Fig. 4 Schematic diagram of the test setup by [7]

Reference [8] investigated a series of experimental analysis on the geogrid followed stone columns to research the influence of geogrid on the load carrying capacity of the soft marine clay. Stone column encased with various type of geogrid and slenderness ratios were analyzed and the action was compared with the traditional stone column. The high plasticity marine clay from coastal region of Chennai city was applied as the clay bed while the granite chips with special size range from 5 to 10 mm was used as the backfill material for the stone column. The geogrids which included of the Netlon Nova curtain with the net of 1 mm x 1 mm aperture, square mesh net of 4mmx4mm aperture size and CE 121 were applied as the encasement materials of the stone column. From this study, it was found the geogrid encasement has enhanced the load carrying capacity for both floating and end bearing stone column. The final bearing capacity of geogrid encased stone column operated clay bed and stone column treated clay bed and stone column treated clay bed was three times and two times of the untreated clay bed. The stiffness of the encasement enhanced the load carrying capacity of stone column. The encased stone column decreased the establishment of the clay bed. But, the performance of reinforced stone column must be refined by different region ratio, moisture environment of clay and l/d ratio of columns [8].

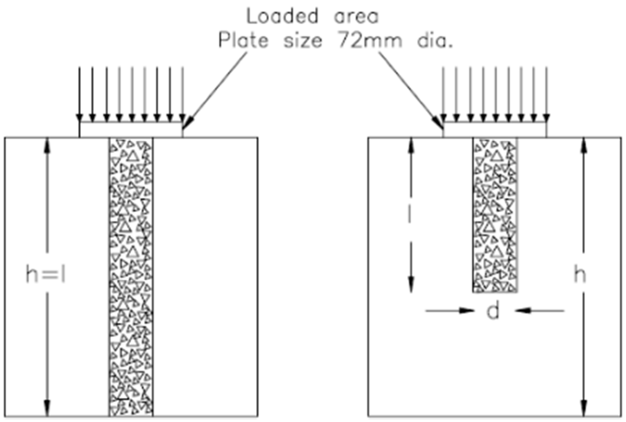

Fig. 5 Loading of the composite bed by [8]

Reference [9] did Field Load Test of Geogrid Encased Stone Columns (GEC field Load Tests were done out on the 2-2 track of the railroad site of Pusan New Port. At this site, the upper layer of sand and the clay layer are combined in some sections of the region and a low compressibility clayey soil layer of less than about 4.8 m thickness accounts for most of the upper section of the region. The field load test was carried out to test the increase in the bearing capacity of the stone column and to evaluate horizontal deformation of stone column and reinforcing the influence prohibited by the geogrid encasing. The geogrid applied for GESC establishment was consisted of polyster and involved a square grid with a compression of 10 t/m. The geogrid net was planned to be 0.8 m in diameter and 1.6 m and 2.4 m long, which are 2D and 3D of the diameter of the stone column, so it could encase the stone column. They drilled the designed established point applying an auger, installed a casing and excavated the remaining soil in the casing, as in Fig. 7. After, they put inside a stone 25 mm in diameter in the casing and shaped a stone column at the place where the geogrid was to be established, repeating compaction and insertion of the stone with a rammer. Then, they inserted the geogrid net into the stone column and bulit the stone column at the place where the geogrid was to be established the stone column to the ground surface, repeating compaction and insertion of the stone. They used a hopper to insert the stone into the geogrid net. The investigators applied a hopper to insert the stone into the geogrid net. Therefore, the stone could be replaced within the geogrid net. The last constructed stone column was 5.5 m in depth, and the geogrid encased reinforcement was used to the stone column at 1.6 m and 2.4 m height, which were 2D and 3D of the diameter of the stone column considering to the upper part. In the load tests, the stone columns constructed in the major were applied as the reaction force anchor, and load was used as the reaction force anchor, and load was applied using a hydraulic jack of 300 ton capacity. From the conclusion of the major load test, it was found that the establishment of a stone column dramatically enhanced above a load of 40 tones, which is the same as having been caused by the failure of the stone column as a result of the bulging failure at the upper part of the column.

Fig. 6 Construction GESC at the site

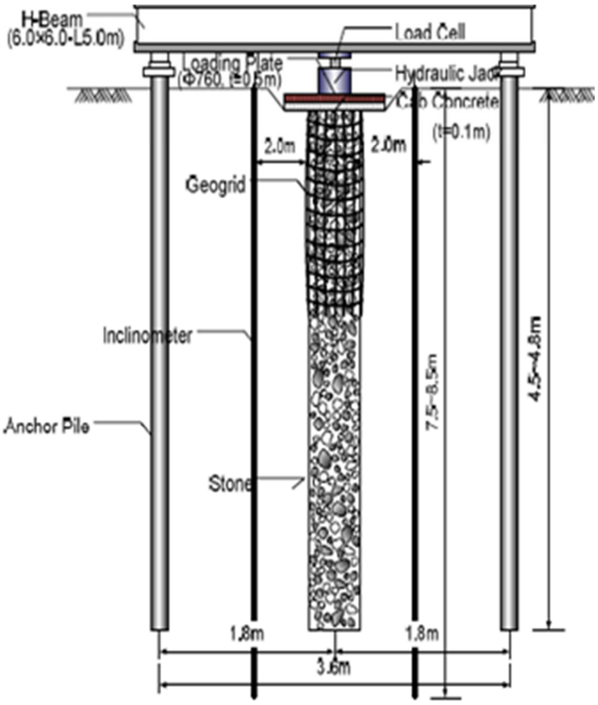

Fig. 7 Load test and measurement equipment

The load carrying capacity of the geogrid encasing prohibited the sharp failure of the stone column by constricting the bulging failure of the stone and thus developed the load carrying capacity for the Load similarities for establishment corresponding to 10% of the diameter (D) of the stone column observed that the load carrying capacities of the stone column, 2D reinforcement and 3D reinforcement were 44 tones, 39 tons and 42 tons, and that the establishment at the lower section of the stone column reduced approximately 3D reinforcement, 2D reinforcement and the stone column [9].

III. REINFORCED STONE COLUMN BY INSTALLING NAIL

Reference [11] designed a method of reinforcing the stone columns with vertical nails installed along the circumference of the stone column for developing the action of these columns. Tests were operated with two kinds of loading (1) the whole region in the unit cell tank loaded, to measure the stiffness of developed ground and (2) just the stone column loaded, to evaluate the constricting axial capacity. A common test arrangement is shown in Fig. 8. All the experiments were conducted on floating stone columns in soft soil in unit cell tanks so L/D ratio (length of the column/diameter of the column) is a minimum of 6, which is needed to improve the complit constricted axial stress on the column [10]. The whole height of the clay bed replaced in the tank is Eightfold the diameter of the column. Vertical stress was used both over the whole tank region and over the stone column. The load was used all over the proving ring at a stable displacement rate. A 30 mm thick sand layer was replaced at the top to serve as a blanket for the case where the whole region is loaded. The load was used through a 12 mm thick mild steel plate.

Aggregates of 2 to 10 mm special size have been applied to shape the stone column. The highest and the lowest dry section weights of the aggregates are considered as each procedure proposed by the Bureau of Indian standards (IS 2720, section 14-1983) and are discovered to be 16.5 and 14.1 N/m3. The sand applied is clean river sand of size less than 4.75 mm. Soil was completed in the tank in layers with evaluated quantity by weight. Every layer was aimed to unify compaction with a tamper to obtain 50 mm height and unit weight of 12.8 kN/m3. Thin open-ended seamless steel pipes of 90, 75 & 60 mm outer diameters and wall thickness 2 mm were applied to establish the stone columns. After the soft soil bed were ready for a depth of twice the diameter of the column, the steel pipe was shaped at the centre of the soft soil bed and establishment of soft soil bed and stone column were carried out at the same time. In conclusion, the results are as mentioned below.

The load carrying capacity (for 10mm settlement) of treated ground with unreinforced and reinforced stone columns with 2D, 3D ,4D and 5D depth of embedment nails are enhanced by 54, 66, 98, 104 and 109% in contrary to that of untreated ground. Stone column reinforced with vertical circumferential nails over a depth thrice the diameter (3D) shows much higher stiffness and final load capacity than unreinforced stone column for all the diameters studies Bulge diameter and bulge length are reduced substantially for a stone column reinforced with vertical circumferential nails compared to that of unreinforced stone columns [11].

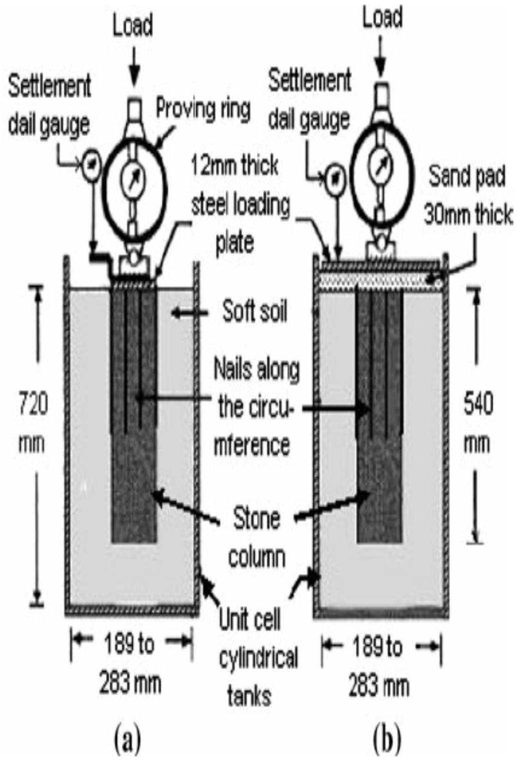

Fig. 8 Test arrangement -90 mm diameter stone column a Load applied only on column area b Load applied on entire area

Reference [12] investigated and published an article called “Performance of stone columns with circumferential nails”. Experiments were done on the stone columns with diameters of 90, 75 and 60 mm, surrounded by soft clay in cylindrical tanks 780 mm high and with diameters differing from 158 to 283 mm to show the needed unit cell region of soft clay around each column assuming an equilateral triangular model of installation of columns. The number of nails (n) was differed from 6 to 10. Tests were done with three various applicable area ratios (Ar): 10, 15 and 23% which correspond to spacing of 3D, 2.5 D and 2D respectively, where D is the diameter of the stone column. The other factor mentioned was the diameter of the nails (d), which was differed by using steel bars with diameters of 2 and 4mm. All the experiments were don on floating stone columns in soft soil in unit cell tanks so the ratio of the length of the column to its diameter (L/D) was the lowers of 6, w10 mm to hich is needed to improve the complete constriction axial stress on the column [10]. A common test arrangement is observed in Fig. 1. Aggregates differing from 2 to 10 mm special size were applied to form the stone column. The sand used to shape the sand pad in tests with the whole region loading was clean river sand with particle size less than 4.75 mm. Circular steel bars of diameter 2 and 4 mm and of the needed length were applied as nails along the circumference of the stone columns. The yield power of the steel bars was 540 Mpa. The performance of stone columns installed in soft soils can be saliently increased by reinforcing individual stone columns with circumferential nails. The development enhances with the number of nails and diameter of nails. The depth of embedment of nails up to 3D depth may be enormous to significantly increase the action of the stone columns. Due to this fact, the limitation is required only in the area where bulge occurs. Significant decrease in settlement (more than 20%) was shown when the stone columns were reinforced with nails [12].

IV. COMPARISON OF DISCUSSED METHODS

Initiating with bearing capacity, this feature is developing by applying geogrid in the stone columns, like the load carrying capacity are enhanced by installing nail around the theses columns. Regarding the bulging of stone column, as can be observed, the existence of geogrid in the stone column has significant effect on the decrease of bulging diameter. Furthermore, the height of bulging is being affected by applying this type of geosynthesis. The length of bulging will enhance. Similarly, reinforcing these columns with vertical circumferential nails has a direct impact on the decrease of the diameter and height of bulging (reinforcing by the 3 times of column diameter). The settlement of stone column is declined by applying geogrid and installing nail around the stone columns. On the basis of these experiments done in installing nail, this way is appropriate for smaller area ratio. Therefore, this method benefited from the usage of stone column which are placed at wider spacing and due to this fact, it will optimum the expenditure. But, the geogrid is not capable of the provision of this feature.

V. CONCLUSION AND RECOMMENDATION

Both methods (geogrid and installing nail) are applying to develop the three considered characteristics of stone column. But, one critical point that has a major influence on decision making of engineers and employers is economic status. Due to this fact, this characteristic of installing nail causes it better than using geogrid. To sum up, using the installing nail method is offered as beneficial factor.

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