BEARING CAPACITY OF ENCASED RECYCLED CONCRETE AGGREGATE (RCA) COLUMNS IN SOFT SOIL BASED ON EXPERIMENTAL AND NUMERICAL ANALYSIS

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Reception: 16/02/2023 **Acceptance**: 25/04/2023 **Publication**: 10/06/2023

Suggested citation:

Ahmed H. and Alaa H. J. Al-Rkaby. (2023). **Bearing Capacity of Encased Recycled Concrete Aggregate (RCA) Columns in Soft Soil Based on Experimental and Numerical Analysis**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 107-123.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

ABSTRACT

One of the finest techniques to highlight the terrain is to employ stone columns. decreasing soil stability while raising the soil's carrying capacity. In this study, recycled concrete aggregate-reinforced masonry columns were applied as the support structure. There are various techniques to fortify soft clay soils. According to the findings, soil BC significantly improved when stone columns made from recycled concrete aggregates and thoroughly reinforced with a geogrid net were used. The soil BC of the single, five, and nine columns was enhanced using stone and double columns supported by a geogrid in comparison to natural soils. The corresponding improvement rates were 5.5%, 23.3%, and 61.1%.

KEYWORDS

Bearing Capacity, Stone Column, Improving, Geogrid

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https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

1. INTRODUCTION

From the perspective of geotechnical engineering, the unique properties of soft soil deposits are undoubtedly the most intriguing soil to work with. Soft soils are quite common around the planet, and some of them are found in significant cities. Excessive settlement and weak shear strength are the two primary issues that arise while executing civil engineering works in soft soil deposits. Stone columns are used to strengthen the ground because they have been proven to be an extremely successful approach for raising the shear strength and bearing capacity of ground soils as well as lowering total and differential settlements [1]. Related studies on theoretical, experimental, and field observations on the behavior of stone columns have been done by many researchers (Ambily and Gandhi 2007; Malarvizhi and Ilamparuthi 2007; Andreou et al. 2008; Lo et al. 2010; Awf A.Al-Kaisi, Hiba H. Ali 2013; Namir K.S. Al-Saoudi, et. al 2014). By altering variables like the distance between the columns, the shear strength of soft clay, and the loading situation, they presented a thorough experimental investigation of the behavior of a single column and a group of seven columns. To analyze and illustrate the behavior of a stone column with various parameters, a finite element analysis (FEA) using the PLAXIS software program was also carried out [2]. In the laboratory, Malarvizhi and Ilamparuthi (2007) investigated the load versus settlement response of a stone column and the impact of a reinforced stone column, specifically a geogrid-encased stone column. On a soft clay substrate stabilized with a single stone column and a reinforced stone column with varying slenderness ratios and utilizing various types of encasing material, load tests were conducted. They discovered that the stabilized bed with smaller diameter columns settles more readily than the stabilized bed with larger diameter columns and that the increased load capacity of the encased stone columns was caused by the hoop stress created in the geogrid [3]. According to Andreou et al (2008). research, the drainage conditions, the composition of the stone column, and the soil loading rate all have a significant role in how a soft foundation soil reinforced by granular columns responds to vertical loads. The study also showed that the reinforced soil loses strength as confining pressure rises [4]. Kirsch (2006) analyzed the changes in situ stress systems in soft clay formation due to the Installation of two sets of twenty-five stone columns. the difference in pore water pressure, effective horizontal stress, and soil Stiffness was analyzed to determine the post-fixation state stress in the soil. An increase in pore water pressure has been recorded in different locations immediately after installation [5]. An axisymmetric finite element analysis was used by Guetif, Bouassida, and Debats (2007) to predict the installation effects connected with stone columns (FEA). They created a stone column out of an elastic, low-stiffness "dummy material" by applying a cylindrical expansion to it. The initial radius of the "dummy substance" was increased from 250 mm, which corresponds to the normal poker radius, to a final column radius of 550 mm. The scientists carried out numerical analyses to determine how this approach affected the stiffness development of the surrounding soil and the expanding column's effect zone.[6]. (2012) Mohammad Al-Wailey A laboratory study was presented to examine the relationship between the load improvement and the percentage of the replaced area by using different diameters

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(20-30-40-50-60 mm), which corresponds to the area replacement ratio. This study was done regarding the effect of the area replacement ratio on the load-bearing capacity of the soil treated with stone columns (0.042). 11 Kpa, 16 Kpa, and 22 Kpa (inside a test container used in laboratories with varying shear strengths of 0.099, 0.333, and 0.563). The findings reveal that the tolerance improvement ratios are 1.16, 1.29, and 1.64. 2.29, respectively, in soils treated with stone columns at a replacement ratio of 0.042 - 0.099 - 0.333 - 0.563 and has a shear strength of 11 Kpa. It was also noted that the proportion of increased stopping additional loads grew when the final settlement approached 40 mm, in addition to the rise of stopping additional loads. By the conclusion of the test, the soil resistance had improved by the largest percentage at shear strength of 16 Kpa and was only slightly bearing with increasing load.[7]. A laboratory investigation was done to demonstrate the impact of the factors that affect the stress concentration ratio (SCR). The peak stress concentration ratio when the internal friction angle of the stone column was between 4 and 5.5 was noted to be between 4-6 for a group of parameters and materials. This differs from 38 the 42 and is also significantly influenced by the thickness of the blanket material forming the column and the strength of the surrounding soil [8]. The vertical strength of the stone columns is influenced by the degree of confinement provided by the earth's surface. For the Stone column treatment to be effective, the soil may be too loose and not provide enough lateral support. The unaligned shear strength of the surrounding soil is often used as a criterion, with a minimum in the range of 5e15 kPa, to decide if a treatment is viable.[9]. In this field study, the behavior of reinforced and unreinforced stone columns with different patterns was studied, and the results were confirmed by using the finite element program Plaxis 3D.

2. MATERIALS USED

2.1. SOIL SILE.

The Soft Clay employed in this pilot research was classified as follows by the Universal Soil Classification System (USCS): (CL). The physical features of soft clay soil are shown in Table 1.

Table 1. The physical characteristics of soft clay soil

Property	Values
Type soil	Soft clay
L.L%	45
P.L%	23
Maximum dry unit weight (KN/m^3)	19.5
C (kpa)	20
Θ	4°
E (mpa)	15
Poisons ratio	0.45
Symbol according to Unified Soil Classification System	CL

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2.2. RECYCLED CONCRETE AGGREGATE

To conduct the laboratory testing for this component, precast concrete cubes were procured from the consulting lab of Thi Qar University. They were smashed up with a hammer and put through a 25 mm filter to create a constant gradient (1-2.5 cm). recycled concrete's recycled aggregates, Figure 1. (RCA). The table provides a list of the physical characteristics of recycled concrete aggregates (2). (RCA).

Figure 1. Recycled Concrete Aggregates (RCA)

Table 2. The characteristics of (RCA)

Property	Values
Specific gravity	2.35
Total water absorption	2.40%
Moisture content	0.45%
Bulk density (Loose)	1,355 kg/m^3
Bulk density (compacted)	1,590 kg/m^3
Fineness modulus	6.23
Elongation Index	15.5%
Flakiness	5.8%
C (kpa)	0
Poisons ratio	0.35
Θ	45º

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2.3. GEOGRIDS

In the experiment, a high-density polyethylene (HDPE) net was utilized. For this publication, the Ministry of Science and Technology made the (Netlon CE121) accessible. The mechanical and physical characteristics of the Netlon CE121 are shown in Table (3) and Figure 2.

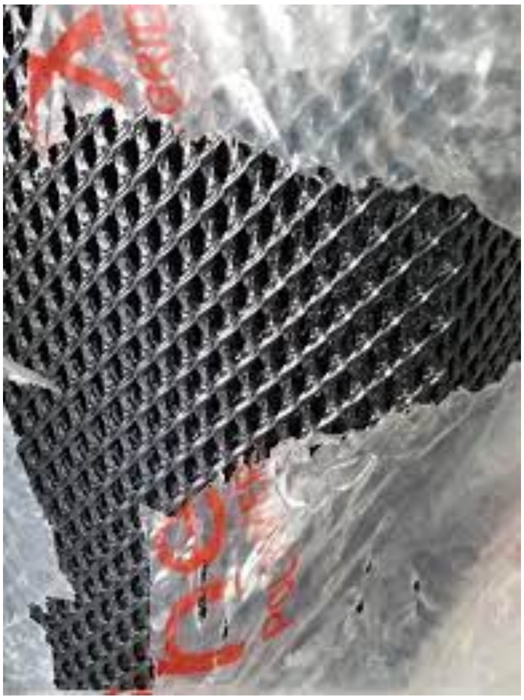

Figure 2. Netlon CE121

Table 3. Physical characteristics of the Netlon CE121

Property	Values
Material	High-density polyethylene
Type	CE121
Mesh aperture (mm*mm)	6*8
Weight per unit area (N/m^2)	7.15
Machiner direction	9.8
Transversal direction	6.15
Machine direction	68
Transversal direction	60

3. SETUP OF THE STONE COLUMN

The steel bar was used to accurately outline and designate the location of each stone column. The stone column was drilled using an auger machine to a 150 cm depth and 15 cm diameter. The auger machine rammed the stone column with its blades. Geogrid reinforcement was also divided into layers with a diameter of 8–9 cm

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so that it could be put into the column. Afterward, the strain gauge was mounted on the circler layers and owner surface of the reinforcing column. Installed chorally is the geogrid that has been reinforced down. Inside the enclosed hollos, recycled concrete aggregates (RCA) were poured into six layers and crushed with a vibrating machine. The strain gauge was then put on the geogrid column and linked to it. Nylon was utilized to cover the ground and recycled concrete aggregates (RCA) were added into the geotextile cavity using a vibrating machine strain gauge.

4. SET THE RECYCLED CONCRETE AGGREGATES (RCA) COLUMN

Case 1.

In this model, soft clay soil was obtained in its natural state without any improvement, and in addition to examining precipitation and the amount of load bearing in its natural state, a numerical examination was done on it.

Case 2.

In this instance, a recycled concrete aggregates (RCA) column was utilized to simulate soft clay. The column's length in this instance was 150 cm, and its average diameter was 15 cm. according to figure 3

Case 3.

Like Case 2, in this instance, the effect of the reinforcement was examined using encased recycled concrete aggregates (RCA). Figure 3 depicts the patterns of this case, in which a casing of geogrid with a respectable diameter and length of 15 cm and 150 cm was used to cover the patterns of RCA.

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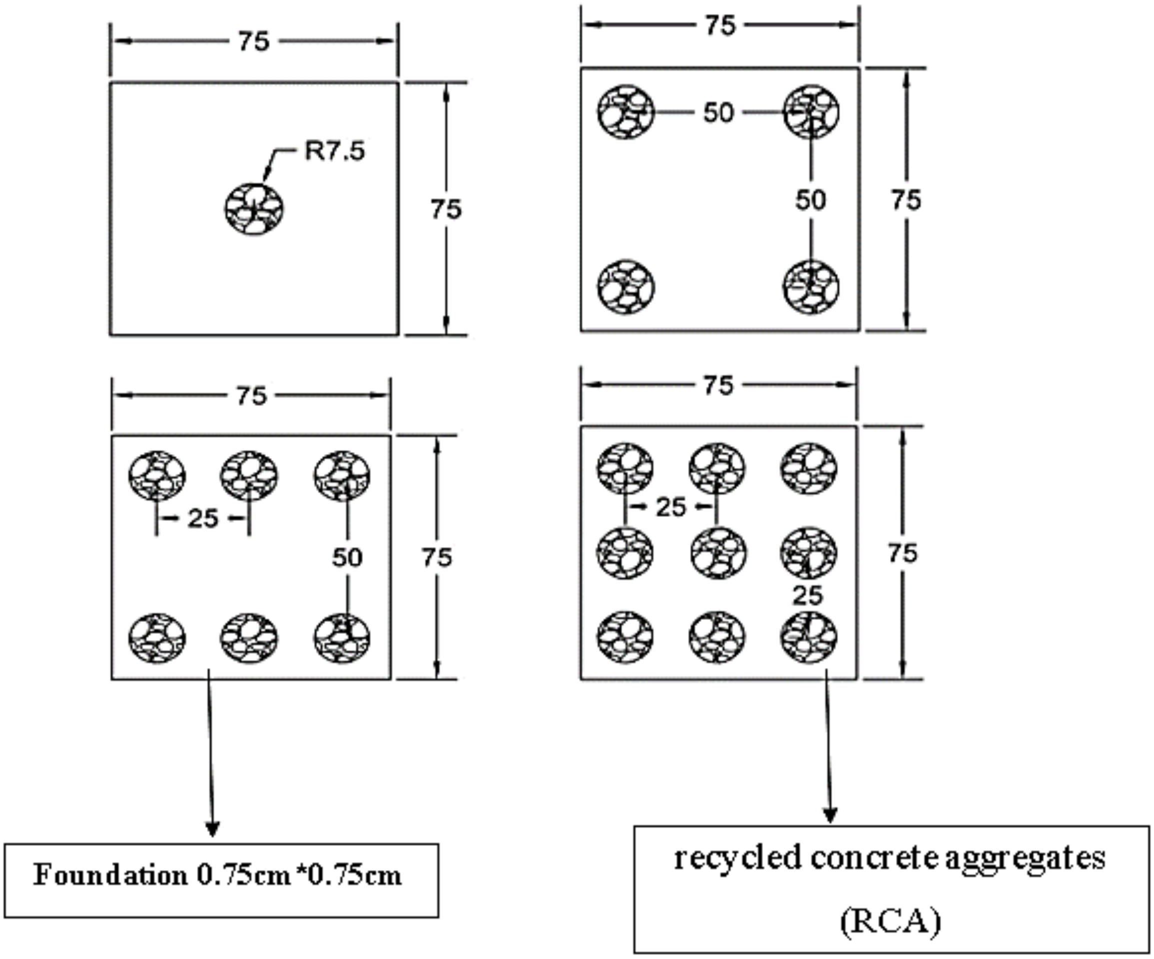

Figure 3. The seven patterns of the stone column

5. TEST PROCEDURES

Five rebars, each measuring 12 millimeters, were placed in each pile to reinforce them. It was vertically welded using an oxygen torch until it measured 43.5 cm in height. Then it was stained with an antioxidant. A steel foundation with a thickness of 12 mm was welded into the concrete pillars, and the entire steel structure was then placed on top of them while controlling the horizontality and straightness. On either side of a test plate that was supported by a side stand, he set up two of his LVDT landing sensors. When the tests were carried out using a plate load test, all sensors, sensors, and measurement instruments were connected to data recorders. The outputs from load cells, displacement transducers, and strain gauges were measured and recorded using a geotechnical data collection system. Data is instantly transferred in real-time to a computer so that trials may be tracked in real-time. Compatible with strain gauge load cells, potentiometric displacement transducers, linear LDT transducers, LVDT tuning transducers, and pressure transducers. A steel foundation with dimensions of 75*75 cm and a thickness of 25 mm was used, and up to 64 different channels were used to dump dirt in a layer 10 cm deep under the area's base. Figure 4 depicts the field procedures for the examination procedure.

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Figure 4. The process of checking and connecting devices

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6. RESULTS

6.1. FIELD MODEL RESULTS

6.1.1. SOIL TEST NORMAL (SOFT CLAY)

Figure 5 The ultimate carrying capacity value, which shows the connection between pressure and settling of untreated soft clay soil with stone columns, was calculated using the double tangent approach. The BC value was discovered to be around 90 kpa, translating to a settlement of 29.5 mm.

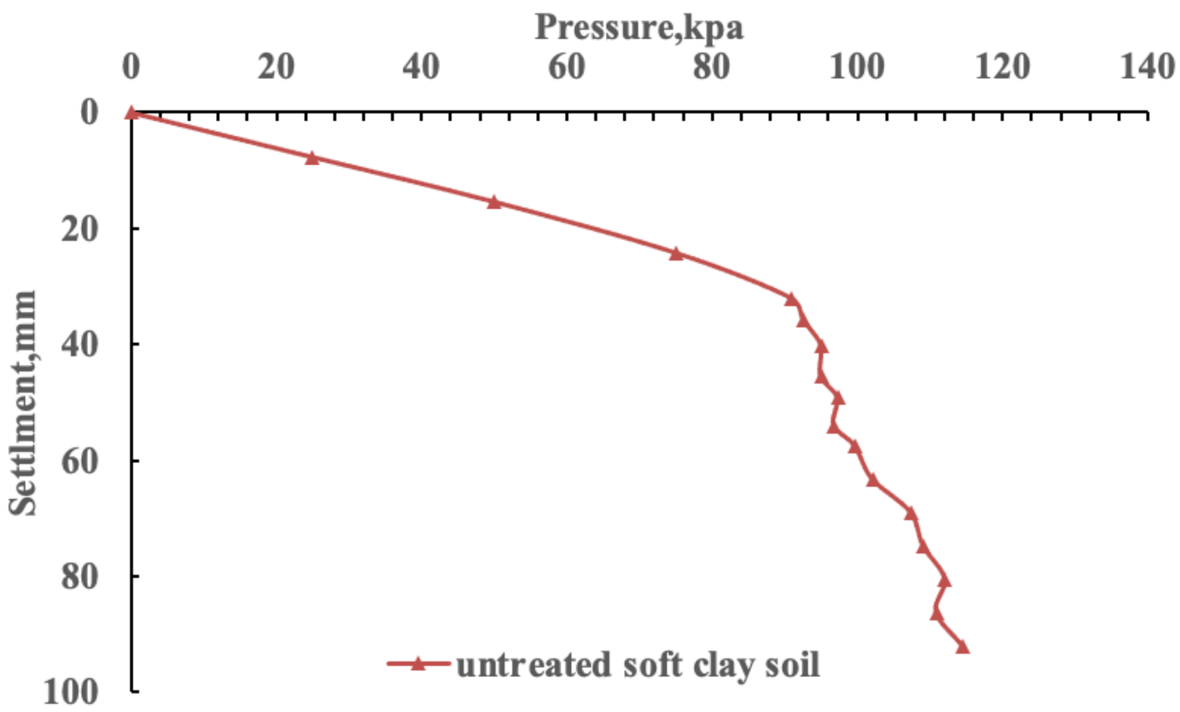

Figure 5. The relationship between pressure and settlement for untreated soft clay soils

6.1.2. UNREINFORCED RECYCLED CONCRETE AGGREGATES (RCA) COLUMNS

In this investigation, the results of stone columns made of recycled concrete aggregates (RCA) without geotextile coating are presented. This field study was conducted on a single stone column without packaging that was installed inside a bed of soft clay, and it was examined after 24 hours of the preparation process. From Figure 6. which shows the relationship between the pressure applied and settlement, we notice an increase in the total carrying capacity due to the greater efficiency of the soil treated with a stone column One, an increase in the applied load is observed. This behavior is due to the correct use of the stone shaft to improve weak soils as well as

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the replacement area ratio and the increase in friction thanks to the stone used for the high friction angle and the double tangent method to extract the final bearing capacity. The soil treated with one stone column reached (95 kPa), with a decrease in the stability value of about (29 mm (. Where the percentage of soil improvement with one stone column was (1.14). Compared to natural soil, we note that the improvement rate was 5.5%.

In this pattern, stone columns were installed in the form of a 2 * 2 grid in a square shape, with center-to-center dimensions of 50 cm. The pressure-bearing was calculated using the double tangent method, where we notice a noticeable increase in the increase in pressure tolerance and the maximum bearing value reached 111 kpa, corresponding to a settlement of 37 mm and a noticeable increase for untreated soil. The explanation for this is due to the increase in the number of columns under the square foundation and an increase in the stress distribution area on the columns and reduce the camel on the weak soil, where the percentage of improvement was found to be 1.37. Compared to natural soil, we note that the improvement rate was 23.3%.

In this field investigation, six stone pillars were installed within the weak and soft clay soil. Through the results, we note an excellent resistance to the pressure applied to the enhanced soil, and this is due to the availability of the soil from lateral confinement and the high lateral pressure of the columns installed inside the soil. In addition, the group of stone columns is exposed to the vertical pressure of the load as a foundation, and therefore it that can enhance confinement against swelling from the double shadow method to extract the absorptive capacity of the stone-enhanced soil and the columns reached 123 kPa, and we notice a decrease in the settlement rate, which reached 32 mm. From that resistance, we notice an increase in the rate of improvement, which reached 1.78, which is a good rate. Compared to natural soil, we note that the improvement rate was 36.6%. In this examination, 9 stone columns were installed inside the soft clay bed. The increase in the carrying capacity was 220 kPa, compared to a decrease in settlement of 28 mm and an increase in the improvement ratio of 2.58. Compared to natural soil, we note that the improvement rate was 77.7%.

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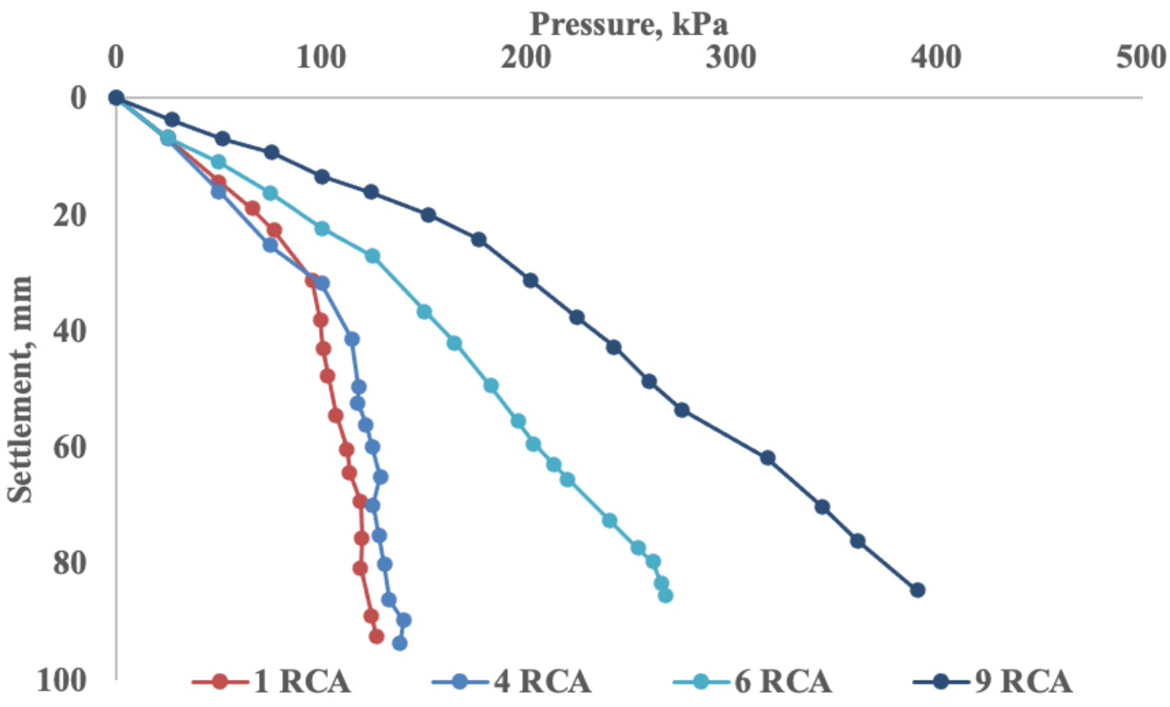

Figure 6. The relationship between applied stress and settlement of stone columns of unreinforced recycled concrete aggregates (RCA).

6.1.3- Reinforced Recycled Concrete Aggregates (RCA) Columns

In this investigation, a stone column covered with geogrids packed with recycled concrete aggregates (RCA) was installed to study the effect of the reinforced column on soft clay soil behavior. (Figure 7) represents the relationship between applied pressure and settlement of the reinforced stone columns, we note an increase in the absorptive capacity of the soil, which was improved by one stone column covered with a layer of geogrid, where the ab-sportive capacity reached 97 kPa compared to untreated soil, which amounted to 90 kPa because the packaging provides sufficient lateral confinement to resist The loads applied as well as the casing has a major role in increasing the stiffness that results. Increasing the carrying capacity and decreasing the leveling, as the improvement rate reached 1.15. Compared to natural soil, we note that the improvement rate was 7.77%.

In this style, laminated stone columns are installed in the form of a 2*2 square grid, with center-to-center dimensions of 50cm. We notice from the results that the casing works to improve the transfer of the load to the depths of the deep soil. The casing also works to prevent contamination of the stones that make up the column, and this will lead to a better performance of the stone pillar in the long run because the frictional properties of the recycled aggregate remain unchanged. Moreover, the casing reduces significantly due to the confinement provided by the geogrid cover, therefore, improving the performance of the stone column by reducing stability and preventing failure in the stone column. All these reasons are sufficient to increase the absorptive capacity of the soil improved by the coated stone columns, as it reached 125 kpa, corresponding to a drop in settlement, which reached 27.5 mm, where we notice a noticeable improvement When compared with the untreated soil, in addition

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to that, the improvement rate was found to be 1.47 Compared to natural soil, we note that the improvement rate was 38.8%. In this field research, several stone columns were installed inside the weak and soft clay soil. We notice a very clear improvement in the carrying capacity of the applied loads when compared to the untreated soil. The reason is due to the strengthening of the vertical position and the drainage layer of the stone column by acting as a good filter file to prevent the mixing of fines with the stone material produced by the packaging, as it resists the tensile strength of a collar in the casing and develops confining pressure to prevent the occurrence of Lateral bulging as well, whenever the pressure in the casing increases, the stiffness of the stone column increases, and thus this increases the final absorption capacity and a clear decrease in leveling, as the absorption capacity after improvement reached 166kpa, corresponding to a decrease in leveling at a rate of 25 mm. The improvement ratio was found to be 2.2. Compared to natural soil, we note that the improvement rate was 84.4%. This is also what we can see from the schematic diagram of the stone pillars fixed in the form of a 3 * 3 grid. Figure 7 shows the relationship between the pressure applied between the untreated soil and the soil which was supported by a grid of 3 * 3 stone pillars covered with a geogrid. The increase in carrying capacity was 235 kPa, corresponding to a decrease in settlement of 15.5 mm, and an increase in the rate of improvement of 2.88. This improvement is the reason for the cladding, as it reduces lateral swelling as well as provides perfect confinement to the stone columns. As the maximum tensile capacity of the package increases, so does the maximum carrying capacity- Compared to natural soil, we note that the improvement rate was 161.1%.

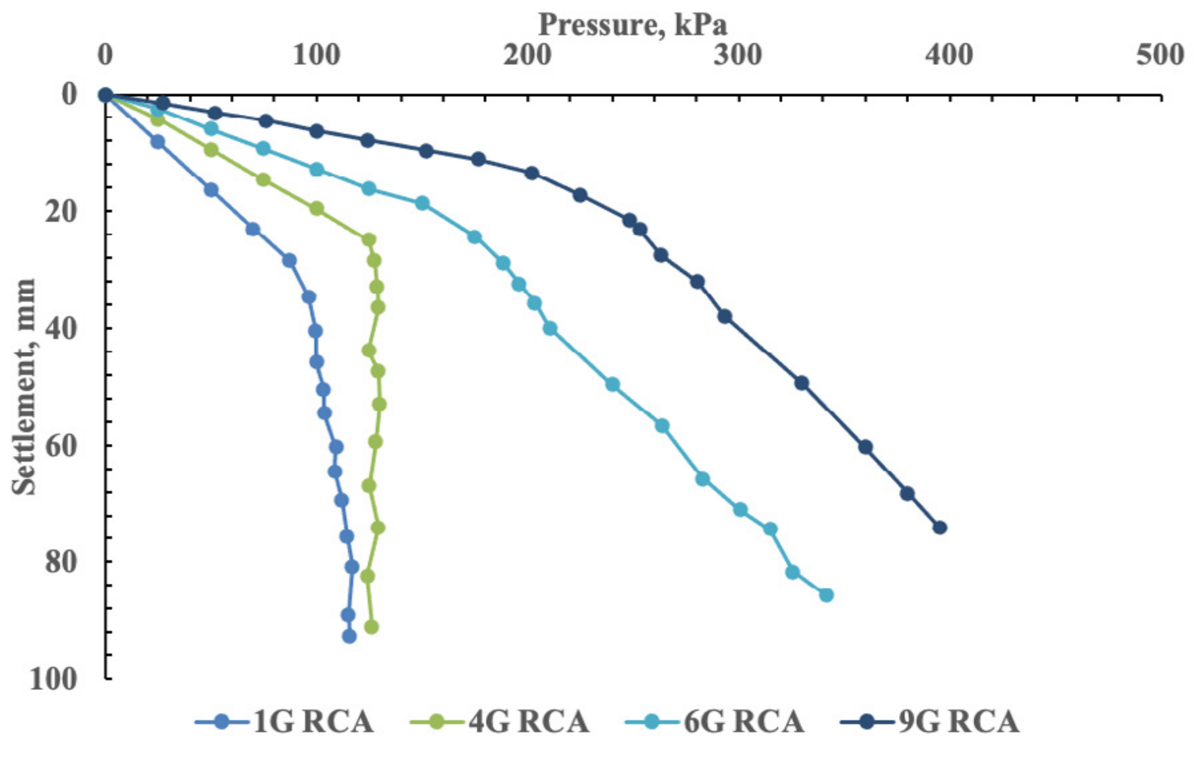

Figure 7. Relationship between applied stress and stability of masonry columns of recycled concrete aggregates reinforced with geo-cladding materials (RCA).

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6.2. RESULTS NUMERICAL MODEL

6.2.1. SOIL TEST NORMAL (SOFT CLAY)

The initial bearing capacity of the soil recorded in several unimproved soils was analyzed with a solid base resting on the soil to be analyzed. The load leveling relationship is a direct method to obtain the final bearing capacity. Figure 8 shows the relationship curve between load and settlement that was analyzed using PLAXIS 3D It was found that the value of the maximum bearing capacity of the unimproved soil from the leveling curves of the double tangent method is 90kPa.

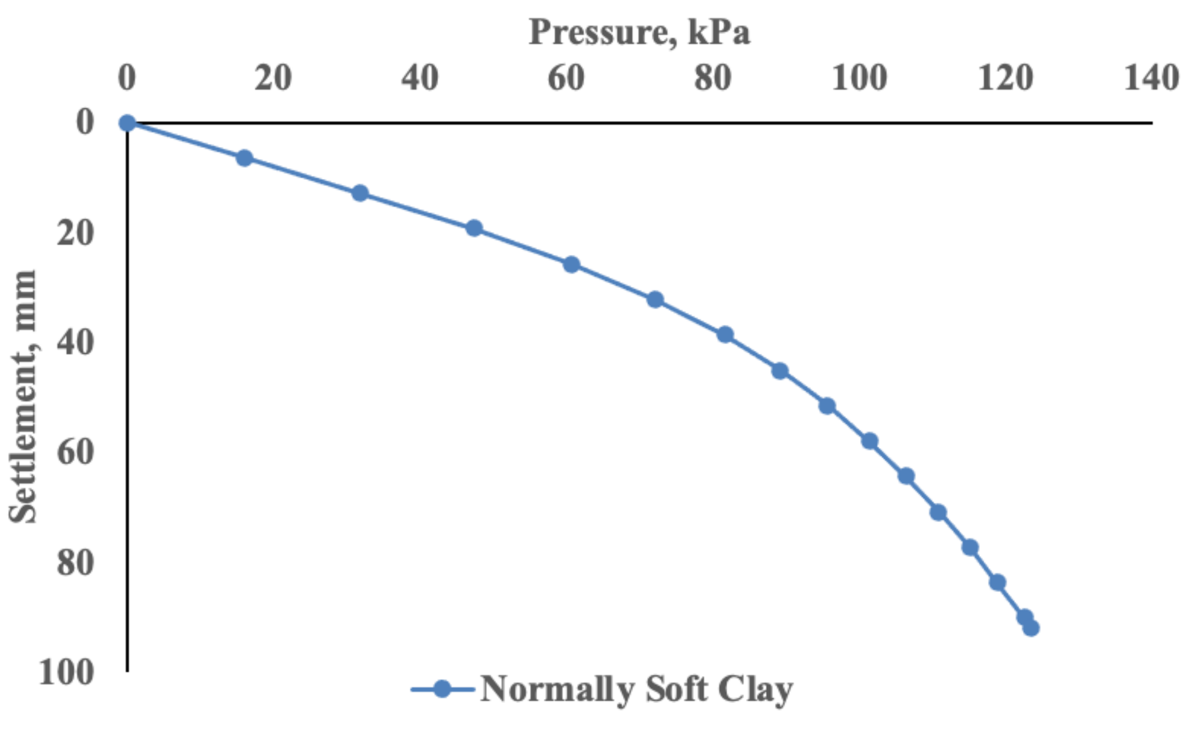

Figure 8. Curve load and settlement that was analyzed using PLAXIS 3D

6.2.2. UNREINFORCED RECYCLED CONCRETE AGGREGATES (RCA) COLUMNS

Figure 9 shows the pressure leveling curves for stone columns consisting only of stones after representing them within the finite element program Plaxis and installing them inside the soft clay bed, where we note the final bearing capacity of the single column amounted to 93 kPa, which is slightly higher than the natural soil, due to the increase in the area replacement ratio. From the diagram, we notice that there is a slight difference between the installation of the two columns and the four columns, as the final bearing capacity reached 105 kPa. The improvement jumps with an increase with the installation of six columns, where we notice an excellent improvement of the pressure applied to the improved soil. The reason for this is due to the increased concentration of stress on the annular collar of the stone columns and thus increasing

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the consolidation process, as the final load capacity reached 160 kPa. With the increase of the stone columns inside the supposed foundation, we notice an increase in the bearing capacity also with a noticeable increase. Therefore, when installing nine stone columns inside the soft clay, the total capacity of the load reached 205 kPa. It is very important in improving the performance of the stone columns, as it amounted to more than 25% of the total soil percentage, as well as increasing the condensation area around the stone column. Also, the presence of columns reduces the liquefaction force.

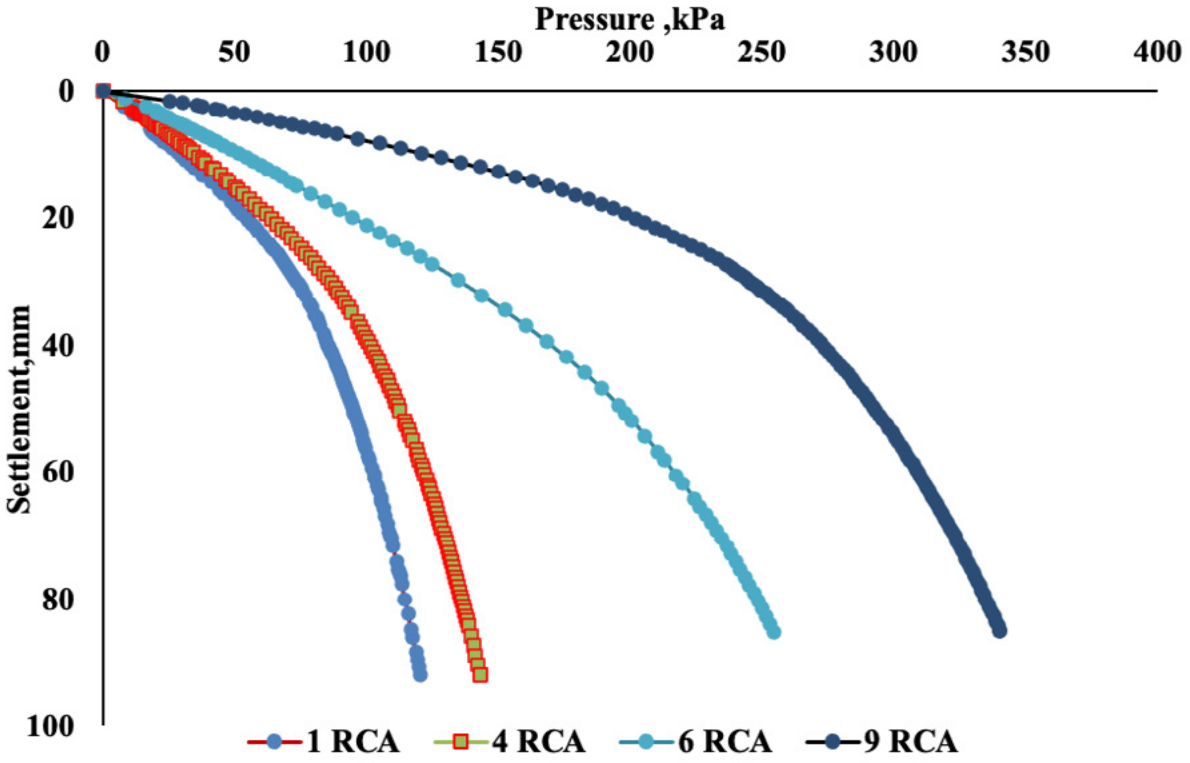

Figure 9. Settlement and load curves for stone columns included in the 3D Plaxis analysis.

6.2.3. REINFORCED RECYCLED CONCRETE AGGREGATES (RCA) COLUMNS

The addition of geographic networks leads to a change in the mechanical properties of the stone columns in this section. The results of the analysis were presented from the finite element method using the Plaxis 3D program. The design was made by placing the geogrid in a complete annular shape on the stone column. Figure 10 shows the relationship between applied stress and settlement of stone columns reinforced with geogrid, which were analyzed by the Plaxis 3D program. When reinforcing a single stone column, we notice a significant increase in the bearing capacity, and the reason is due to the presence of geogrid, which increases the lateral confinement force to provide a better loading capacity. The increase in the carrying capacity continues successively when increasing the number of columns with geogrid reinforcement, as it reached a succession of (single, fourth, pentagonal, and hexagonal columns, and a 9 column). as the final bearing capacity, respectively, reached (110, 150, ,240 and 255). The reason for these increases is due to the availability of geotextiles of high lateral confinement, as it prevents the occurrence of early failure of the stone columns. The synthetic geosphere also greatly increases the bearing and increases in turn by confining the pressure on the column, in turn, increases the stiffness of the column, and this in turn improves the bearing capacity and the flexibility factor and the non-flexibility of the geogrid has a role in This process and with the formation of pre-stress in the casing with the development of the initial tensile strength in the casing, which increases the bearing capacity. Also, the concentration of stress on the columns reduces the lateral pressure. The geogrid acts as a good filter to prevent soil particles from mixing with the column materials. This leads to better performance over time. The percentage of improvement, when compared with natural soil for stone columns, was 6.66%,38.8%,94.4%, and 183.3%.

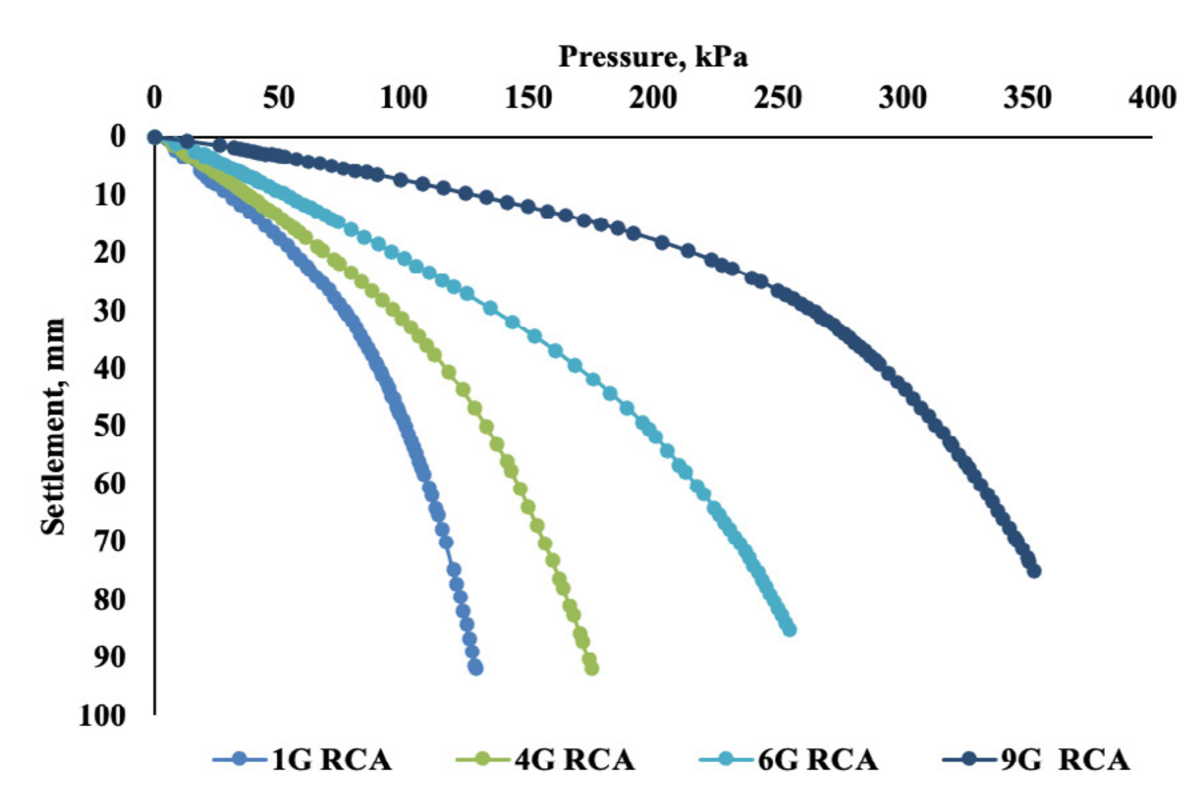

Figure 10. The relationship between pressure and settlement of stone columns reinforced with geogrid.

7. CONCLUSIONS

1. It is affordable to employ recycled concrete aggregates (RCA).

2. Using stone columns composed of recycled concrete aggregates (RCA) improved weak soils effectively.

3. In contrast to conventional stone columns, geosynthetic-encased stone columns frequently display linear behavior in response to pressure settlement without displaying any catastrophic breakage. The stiffness of the geosynthetic

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material used for encasing determines how much the geosynthetic encasement improves the load capacity.

4. The rigidity of the geosynthetic utilized for the encasement also affects how well the stone column performs.

5. Using geotextile and geogrid as the stone column, encasing the granular blanket reinforcement increases its efficacy. increases the reinforced soil and stone column's rigidity. Due to the soil particles being caught in the stiff, tensile geogrid apertures, considerable frictional strengths are generated at the geogrid-soil interface. Additionally, geotextile increases bearing capacity by preventing the stone column's components from sinking into loose soil.

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