Improving the Bearing Capacity of Soft Clay Using Encased Recycled Concrete Aggregate RCA Columns

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Abstract
Stone columns are one of the effective ground improvement techniques to increase the bearing capacity of the soil and reduce settlement. In this study, stone columns made of recycled concrete aggregates and fully geogrid reinforced were used soft clay soils have been reinforced in several different ways.The results indicated that the use of stone columns made of recycled concrete aggregate and fully reinforced with geogrid significantly improved the bearing capacity of the soil.Compared to natural soils, the use of single and double stone columns reinforced with geogrid improved the bearing capacity of the soil by 9% and 22%, respectively

1. INTRODUCTION

Around the world, soft clayey soils are common, and in Iraq's central and southern regions, particularly in locations near wetlands, these soils are also to be found. One of the main solutions is to enhance the geotechnical features of soft soils since the population is increasing and cities are rapidly expanding, making it vital to use such soil as a building material or foundation for various projects. There are several methods available for improving soft soil. Stone columns are utilized to strengthen the soft clay soil, which is subjected to various forms of loads and has an undrained shear strength (cu) of 10 Kap. Increased shear strength of soft soil accelerated soil consolidation and decreased soil liquefaction potential can all be achieved with the usage of stone columns. The stone columns are known as floating stone columns because they do not reach the stable layer of soil when there is a thick, soft layer that is deeper than 25 meters. (Datye, 1982; Abdullah et al., 2020) [1][2].

(Fattah et al., 2017) length to the stone column's diameter Numerous earlier studies claimed that several variables, including the column's stiffness, length, diameter, and replacement ratio for the area, all had an impact on the strength of stone columns [3]. (Mohammed Al-Wailey2012) Regarding the effect of the area replacement ratio on the load-bearing capacity of the soil treated with stone columns, a laboratory study was presented to show the relationship between the load improvement and the percentage of the replaced area by taking different diameters (20-30-40-50-60 mm), which corresponds to the area replacement ratio (0.042). - 0.099 - 0.333 - 0.563 (inside a laboratory test container that has different shear strengths 11 Kpa, 16 Kpa, 22 Kpa. The results show that the tolerance improvement ratios are 1.16, 1.29, and 1.64. 2.29, in soils with a shear strength of 11 Kpa and treated with stone columns at a replacement ratio of 0.042 - 0.099 - 0.333 - 0.563) respectively, as well as the growth of stopping additional loads when the final settlement reached 40 mm, it was also observed that the percentage of increased Slightly bearing with increasing load and reaching the top by the end of the test and also found the highest percentage of improvement of soil resistance at shear strength 16 Kpa [4]. Many researchers have given other similar views [5]-[10]. As for the stress concentration ratio (SCR), a laboratory study was conducted to show the effect of the parameters that affect SCR. It was noted that the transitional reduction peak was between 4-6 for a group of parameters and materials, and the peak stress concentration ratio ranged between 4-5.5 when the internal friction angle of the stone column differs from 38 the 42 as well as greatly influenced by the thickness of the blanket material forming the column and the strength of the surrounding soil[11].This is in principle compatible with both (Barksdale and Bachus, 1983, Han and Ye 1991, Aslani and J. Nazariafshar2021) [12][13]. To combat the weakness, because of a defect in the soil surrounding the stone column, some researchers, and some studies, resorted to encapsulating the column with geogrid or any other high-tension material.Where it was observed that the packing increases the bearing capacity and the hardness of the stone column, and that the behavior of the coated stone column is much better than the unwrapped column [14]-[16].About the effect of stone column encapsulation on settlements, it was noted by researchers that precipitation decreases by up to 50% and that the encapsulation of the upper part at 2.5 D (D) the diameter of the pillar has proven its effectiveness in this field [17]-[18].encasement imparts additional confinement to the stone column and brings in several advantages increased stiffness of the column, preventing the loss of stones into the surrounding soft clay, preserving the drainage and frictional properties of the stone aggregates., as described by (Raithel et al. _2002_, Alexiew et al._2005_, Brokemper et al. _2006_, Murugesan and Rajagopal_2006a, b, 2007a_, Kempfert, and Gebreselassie _2006_, and di Prisco et al. _2006) [19]-[23]. The distribution of several patterns of stone columns influences the bearing capacity and porosity pressure. This was observed from the laboratory experiment, where a soil with very weak shear resistance of 5.5 Kap was taken and patterns (single, bi-plan, triangular, quadrilateral, square) were taken. The length of the column reached by the stone is 180 mm in diameter and 30 mm in diameter. The material of the stone column has a friction angle of 48.5 degrees. He noted that despite the percentage of replacement in the area is very small, he noticed an increase in the loading capacity of 79, 97, 132, 148, and 145%, respectively. He also noted that the use of the square pattern is more effective. of the square distribution even though they have the same area substitution ratio[24].In this study, the stone columns covered with a comprehensive cover with a length of 1.5 meters and a diameter of 15 cm were discussed. The examination was conducted in a field manner, and several patterns were taken (single, double, triangular, quadruple, pentagonal, hexagonal, eight-column, and nine-column).

2. MATERIALS USED:

2.1 -Soil Sile.

The Soft Clay utilized in this pilot research was categorized by the Uniform Soil Classification System (USCS) as (CL). Figure 1 depicts the distribution of clay particle sizes. The physical characteristics 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/m³)	19.5

C (kpa)	20
Θ	4º
E(mpa)	15
Poisons ratio	0.45
Symbol according to Unified Soil Classification System	CL

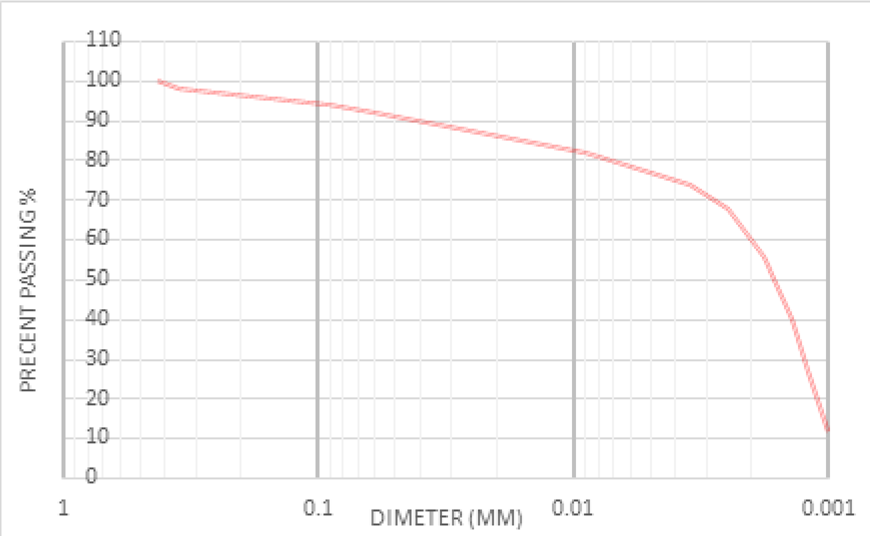

Figure 1:depicts the distribution of clay particle sizes

2.2-Recycled concrete aggregate

Figure 1:Grain size distribution of Soft clay soil

T[illegible]ced from the consulting lab of DhiQar University. They were smashed up with a hammer and passed through a 25 mm filter to ensure a constant gradient (1-2.5 cm). Recycled concrete aggregates, Figure 2. (RCA). The physical characteristics of recycled concrete aggregates are presented in Table (2).

Table 2:The characteristics of Recycled concrete aggregate:

Property	Values
Specific gravity	2.35
Total water absorption	2.40%
Moisture content	0.45%
Bulk density (Loose)	1355 kg/m³
Bulk density(compacted)	1590 kg/m³
Fineness modulus	6.23
Elongation Index	15.5%
Flakiness	5.8%
C(kpa)	0
Poisons ratio	0.35
Θ	45º

Figure 2:Recycled Concrete Aggregates (RCA)

2.3- Geogrids

In this investigation, a net made of high-density polyethylene (HDPE) was employed. The Ministry of Science and Technology provided the (Netlon CE121) for this article. The mechanical and physical characteristics of Netlon CE121 are presented in Table (3) and Figure (3)

Table 3:physical characteristics of the Netlon CE121

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

Figure 3:Netlon CE121

3. SETUP OF THE STONE COLUMN

The steel bar marked and pinpointed each stone column's precise placement. The stone column was drilled to a depth of 150 cm and a diameter of 15 cm using an auger machine, which sent its blades descending into the stone column. Geogrid reinforcement was also cut into circular layers with a diameter of 8–9 cm to be put within the column. The owner surface of the reinforcement column and the circler layers were then placed with the strain gauge. After chorally installing the geogrid reinforced down, recycled concrete aggregates (RCA) were poured inside the encased hollos in a form of six layers, and a vibrating machine was used to compact such RCA material. The process of attaching and installing the strain gauge on the column made of geogrid followed. Nylon was used to cover the ground surface as well as the mechanism for inserting recycled concrete aggregates (RCA) within the geotextile cavity utilizing a vibrating machine strain gauge.

4- SET THE RECYCLED CONCRETE AGGREGATES (RCA) COLUMN AS NEEDED

Case 1.

In this model, soft clay soil was taken in its natural form without any improvement, and a numerical examination was conducted on it in addition to the examination of precipitation and the amount of load bearing in its natural form

Case 2.

In this case, the effect of reinforcement was investigated using Recycled Concrete Aggregates (RCA) Figure 4 shows the patterns of this case where geogrid casing with diameter and length of 15 cm and 150 cm was used to cover the Recycled Concrete Aggregate (RCA) patterns.

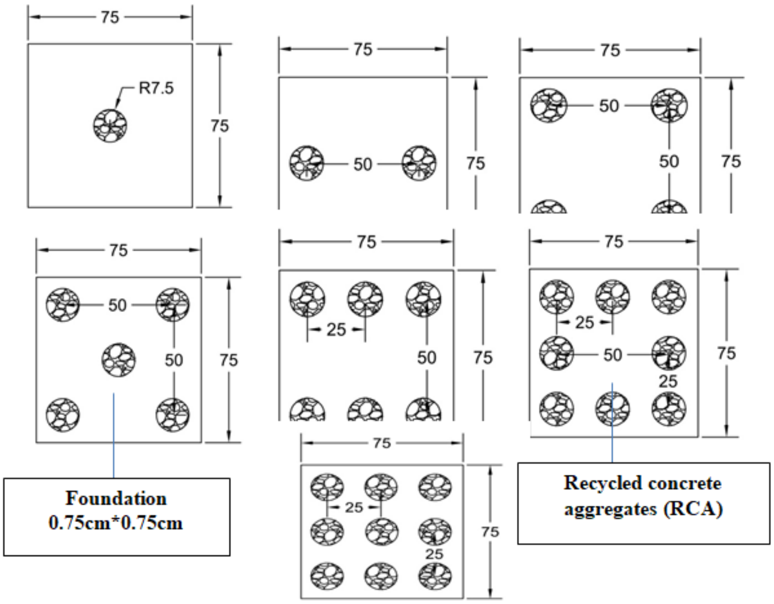

Figure 4: Patterns of stone columns with layers of geogrid with comprehensive encapsulation

5. TEST PROCEDURES

Twelve-millimeter rebar was used to strengthen the piles, and five bars were added to each pile. With the use of an oxygen torch, it was vertically welded until it reached a height of 43.5 cm. After that, an antioxidant was used to stain it. The complete steel structure was put on the pillars while regulating the horizontality and straightness after a steel foundation with a thickness of 12 mm was welded into the concrete pillars. He placed two of his LVDT landing sensors on either side of a test plate that was supported by a side stand. All sensors, sensors, and measurement tools were attached to data recorders after the tests were conducted using a plate load test. Using a geotechnical data collecting system, the outputs from load cells, displacement transducers, and strain gauges were measured and recorded. To monitor the status of trials in real-time, data is automatically uploaded in real-time to a PC. Compatible with pressure transducers, linear LDT transducers, LVDT tuning transducers, strain gauge load cells, and potentiometric displacement transducers. A steel foundation with dimensions of 75*75 cm and a thickness of 25 mm was employed, and dirt was deposited in a layer of 10 cm under the base of the area in up to 64 distinct channels. The field methods for the examination process are shown in Figure 5.

Figure 5: The process of checking and connecting devices

6- RESULTS

6.1- Soil test normal (soft clay)

Figure (6). It shows the relationship between pressure and settlement of untreated soft clay soil with stone columns, where the value of the ultimate bearing capacity was extracted from the double tangent method. It was found that the BCR value is about 90 kpa, corresponding to a settlement of 29.5 mm

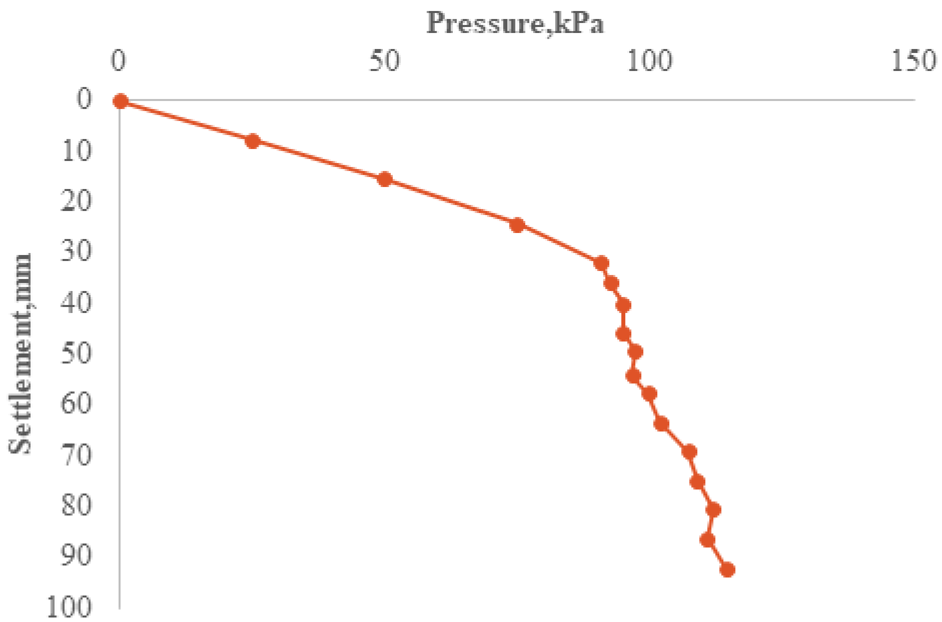

Figure 6: Therelationship between pressure and settlement for untreated soft clay soils

6.2-Reinforced Recycled Concrete Aggregates (RCA) Columns

In this investigation, seven different types of stone columns consisting of recycled concrete aggregate (RCA) reinforced in annular form with geogrid were installed.

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 absorptive capacity reached 98 kPa compared to untreated soil, which amounted to 85 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.

In this test, two stone columns were installed which were wrapped by geotextile nets to improve the bearing capacity of soft clay soil. From the results, we notice a clear increase in the final load-bearing capacity of the soil treated with two stone columns coated with geogrid, where the final carrying capacity reached 110 kpa, offset by a decrease in leveling of 29 mm. The encapsulation increases the radial pressure at all stages of loading. In addition, it provides an increase in lateral excavation, and from the previously mentioned relationship, the improvement ratio is about 1.29.

n 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 to that, the improvement rate was found to be 1.47

n this research, five stone columns were installed inside the weak and soft clay soil to improve its properties. We notice from the graph a clear increase in the final load capacity, as well as a clear decrease in the leveling rate, in addition to the effect of the number of columns embedded under the foundation in increasing the bearing capacity. There is a clear effect of the packing, as the clay and its hardening do not provide sufficient confining pressure, as the packing overcame this deficiency as well. the encapsulation increases the tensile strength of the stone columns, in addition to that, not the limitation and hardness was the reason for that improvement, but the initial strain of the geogrid that occurs during fixation also contributes to improving the rigidity of the stone column and the reduction of settlement when compared to the total absorptive capacity of the untreated soil, which reached 85 kpa. The improvement in the coated columns amounted to 160 kpa, i.e., double the value, corresponding to an improvement in the leveling rate, which reached 29.9 mm. From the relationship to find the improvement rate, it amounted to 1.88.

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 190 kpa, corresponding to a decrease in leveling at a rate of 25 mm. The improvement ratio was found to be 2.2.

Eight stone columns were installed to study soil behavior during improvement with reinforced stone columns. We notice a very clear improvement because the column provides great soil hardness and improves its properties and the hardness of the material constituting the stone columns. We note from the graph an increase in the capacity of the improved soil with it carrying capacity, up to 220 kPa, which is accepted by a significant decrease in stability due to the material forming the column from a high friction angle, and settlement. It reached 16.5 mm, and the percentage of improvement increased by increasing the number of columns to reach 2.58.

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 4.5 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 245 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 packageincreases, so does the maximum carrying capacity

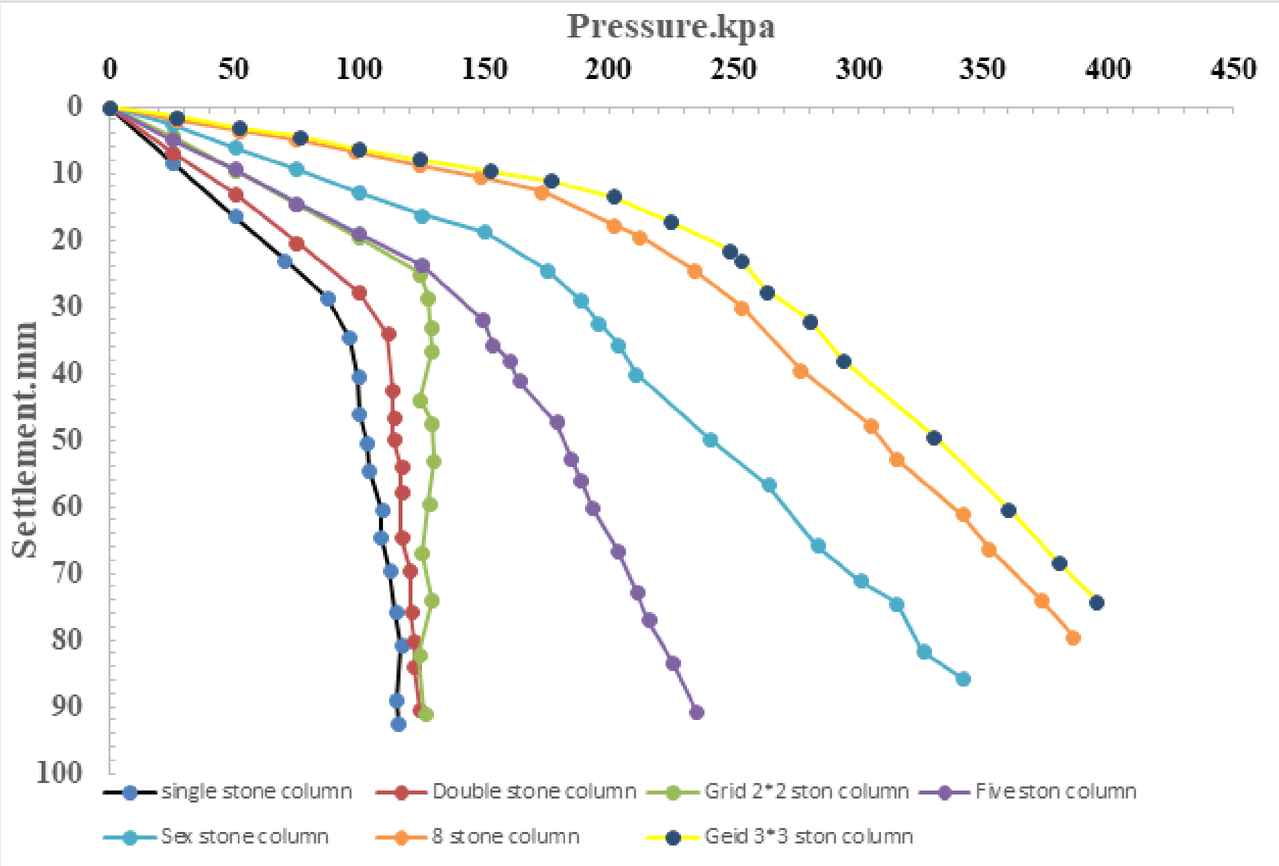

Figure 7: Relationship between applied stress and stability of masonry columns of recycled concrete aggregates reinforced with geo-cladding materials (RCA).

The percentage improvement achieved by the stone columns is represented by the relationship. Table 4. shows the endurance capacity ratio (BCR) values. Figure 8 shows the relationship between the percentage of improvement and the number of columns covered by the geogrid for which the soil has been strengthened.

$$\textbf{BCR}=\frac{\textbf{bearing capacity of reinforced soil}}{\textbf{bearing capacity of unreinforced soil}}$$

Table 4:The bearing capacity ratio (BCR) values

Number of stone columns	Bearing capacity ration BCR %
1	1.15
2	1.29
4	1.47
5	1.88
6	2.2
8	2.58
9	2.88

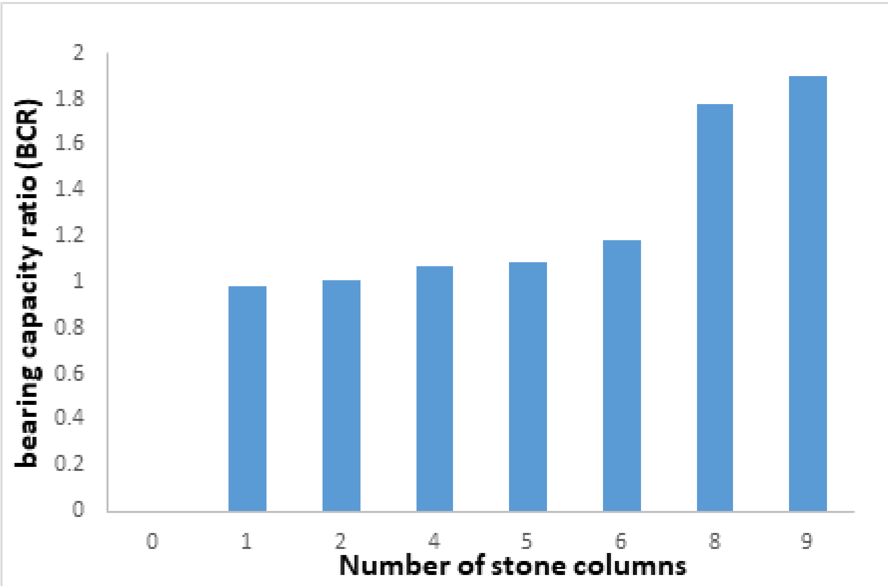

Figure 3:The relationship between the percentage of improvement with the number of columns with which the soil was reinforced

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- Unlike traditional stone columns, the pressure settlement response of geosynthetic-encased stone columns often exhibits linear behavior without showing any catastrophic breakdown. Depending on the stiffness of the geosynthetic utilized for encasement, the geosynthetic encasement enhances 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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