Bearing Capacity Characteristics of Sand Columns Stabilized with Recycled concrete and Glass Material in Soft Soils

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ABSTRACT

The objective of this study is to investigate the performance of reinforced compacted soil by the utilization of sand columns composed of recycled brick and cement. These columns are further stabilized with sodium silicate in order to enhance their structural integrity relative to the surrounding soil. The experimental program has been partitioned into three distinct phases with the objective of fabricating columns. The initial step involves the selection of the standard mixing proportions for each material and sodium silicate, considering three different weight percentages of liquid sodium silicate (10%, 15%, and 20%). The second approach involves enhancing the structural integrity of the brick and cement materials through the incorporation of sand at varying weight proportions (10%, 20%, 40%, and 60%). Samples were subjected to a laboratory test to determine their unconfined compressive strength (UCS). The experimental findings revealed that the cohesiveness of sand was significantly increased when 20% of cement and 20% of sodium silicate were added to the cement-sand combination. In the context of the bricks-sand mixture, it was observed that the optimal composition consisted of a 20% proportion of bricks and a 20% proportion of sodium silicate. The final phase of the study involved the utilization of a laboratory model to assess the efficacy of each mixture when applied to sand columns. During this phase of the laboratory experiments, the model test was conducted on three separate occasions. Initially, the earth was strengthened through the implementation of a solitary column. Furthermore, on the subsequent occasion, the structure was further strengthened with the addition of two additional columns. In the third instance, there were four columns present. The findings indicated that the enhancement ratio of the soil, which was reinforced with sand-cement columns and stabilized using sodium silicate, exhibited a 163% increase for a single column, a 256% increase for two columns, and a 358% increase for four columns. The sand-bricks column experiment yielded the following results: 46% for a single column, 144% for two columns, and 261% for four columns.

Keywords: Sand column, sodium silicate, recycle concrete, glass .

Introduction

The sand columns approach is extensively employed in many regions across the globe to enhance the engineering characteristics of soft, saturated cohesive soils. Soft soils can be characterized by their relatively low undrained shear strength, typically less than 40 kilopascals (kPa), and their high compressibility, with a coefficient of compressibility (cc) ranging between 0.19 and 0.44 (Brand and Brenner, 1981). According to a research by Aboshi et al. (1979), sand compacted columns were initially introduced by the Japanese as an alternative method. The primary purpose of including granular columns, composed of either stone or sand, is to enhance the rigidity of the composite soil. This, in turn, leads to an improvement in the soil's load-bearing capacity and facilitates the management of compressibility. In addition, the stone columns serve as drainage systems that expedite the consolidation process. In contrast, sand columns serve as an alternative method to stone columns. Both approaches offer enhancements in terms of load-bearing capacity and compressibility when applied in soft saturated soil. The efficiency of the two techniques is contingent upon numerous aspects, including field condition, type of construction, and availability of materials, among others. Sand columns have experienced a growing utilization over the course of the last forty years as a substitute for the conventional stone columns (Juran and Riccobono, 1991). The bearing capacity and settlement characteristics of soft soil that has been reinforced with sand columns are influenced by various factors. These factors include the area replacement ratio, dimensions, and installation pattern of the sand columns in the field. Additionally, the amount and rate at which loads are applied, as well as the placement conditions of the backfill materials, play a significant role in determining the stiffness of the columns. According to Barksdale and Bachus (1983) and Juran and Guermazi (1988), the efficacy of this approach is most when applied to clayey soils exhibiting undrained shear strength within the range of 15-50 kPa. Nevertheless, the feasibility of this approach diminishes in soils that are more compressible, as they lack the necessary lateral confinement (Ahmed, 2015).

2. Experimental Work

2.1 Materials Used

2.1.1 Soil used

The acquisition of soft clay took place in the southern region of Iraq, namely in the city of Nasiriyah located in the Thi-Qar governorate. The soil sample that was not distributed was extracted from a depth of 5 to 7 meters below the surface of the ground. The soil samples underwent a series of standardized tests to ascertain their physical and chemical qualities. The ASTM standards have been implemented for the purpose of examining the physical qualities of soil, as demonstrated in Table (1). The consolidation test provides valuable insights into the characteristics of clay, which are succinctly represented in Table (2). The cohesiveness (C) of the soft soil, as determined by the unconfined compression test, is measured to be 18.5 kN/m2.

2.2. Physical Tests

2.2.1 Particle Size Distributed

Hydrometer tests were performed on clay samples in accordance with the ASTM D 422 standard. The experiment was conducted to analyze soil samples containing particles smaller than 0.075 mm, as determined by passing through a No.200 sieve. Figure (1) illustrates the distribution of soil composition, with 2% sand, 34% silt, and 64% clay.

2.2.2 Moisture Content

The moisture contents of the soil sample were determined using the oven-drying method as specified in the ASTM D2216 standard.

2.2.3 Attererberg's Limits

The clay samples underwent Atterberg limits testing, namely the determination of the liquid limit (LL) and plastic limit (PL), prior to each physical test in order to verify the uniformity of the clay material being utilized. The liquid limit of the soil was calculated using the Casagrande method, as specified in ASTM D423. Similarly, the plastic limit was obtained according to ASTM D424, as depicted in Figure (2) and Table (1).

2.2.4 Specific Gravity

The determination of the specific gravity of the soft soil was conducted in accordance with the American Society for Testing and Materials (ASTM) standards, as depicted in Figure (3) and Table (1).

2.2 .5 Compaction Test

The experiment was carried out in accordance with the ASTM D698 standard in order to ascertain the optimal moisture content and maximum dry unit weight. The outcomes of the experiment have been graphically represented in Figure (4) and Figure (5).

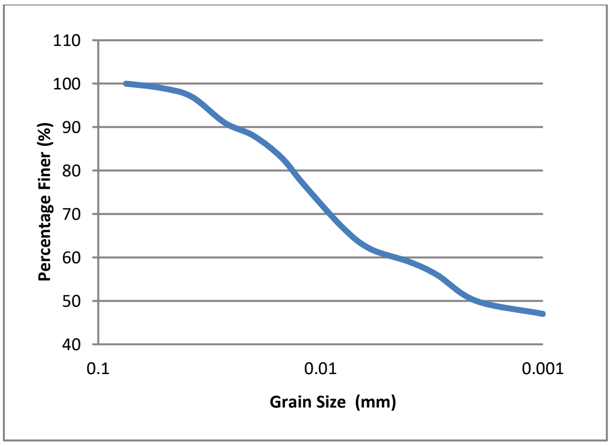


Figure (1): Particle size distribution of soil sample

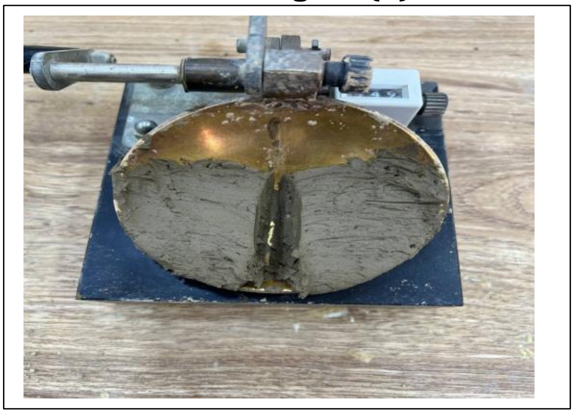


Figure (2): liquid limit test.

Figure (3): Specific Gravity Test.

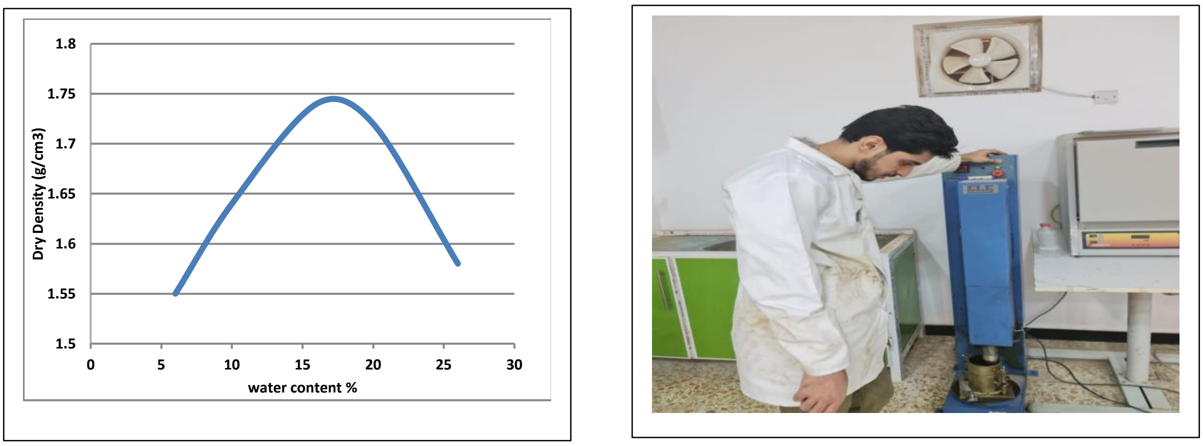


Figure (4): Compaction test results

2.2.6 Consolidation Test

The compressibility of the clay utilized in this study was assessed through the implementation of the standard consolidation test. The standard consolidation test, as outlined in ASTM D 2435, was conducted on a sample of naturally occurring soft soil.The Oedometer ring has a diameter of 50mm and a height of 2mm. The characteristics of soft clay soil in the consolidation test are presented in Table (2).

2.3 Chemical Tests

The chemical characteristics of the soil are displayed in Table (1).

Table (1): Physical and chemical properties of natural soft soil.

Test	Unite	Property	Standard
L.L	%	42	ASTM D 423
Plastic Limit (P.L)	%	19	ASTM D 424
Plasticity Index (P.I)	%	23	----------------
Specific Gravity (Gs)	--	2.74	ASTM D 454
Water Content (W)	%	40.9	ASTM D 2216
Gravel content (G)	%	0	ASTM D 422
Sand content (S)	%	2	
Silt content (M)	%	34	
Clay content (C)	%	64	
Maximum dry unit weight (γd max)	g /cm3	1.74	ASTM D 698
Optimum moisture content (OMC)	%	17	
Organic Matter (O.M)	%	2.8	SORB/ R5) general specifications for roads & bridges in Iraq) Salts Test for Soil
Gypsum content	%	0.37	
SO3 Content	%	0.17	
pH Value		9.1	
Description according to ASTM	--	CL	

Table (2): The remolded clay obtained from consolidation test for the soft soil

Index Property	Value	Standard
Initial Void Ratio (e)	1.13	ASTMD2435
Coefficient of Compressibility (kN/m^2) (av)	7.12*10^{-4}	
Coefficient of Volume Change (mv) (m^2/kN)	3.4*10^{-4}	
Compression Index (Cc)	0.37	
Swelling Index (Cr)	0.047	
Pre-consolidation Pressure (kN/m^2) (pc')	62	

2.4 Sand

The fine aggregate employed in this research was obtained from the Zubair region in Basrah city and comprised of naturally occurring sand. The fine aggregate was subjected to a screening procedure utilizing a sieve size of 4.75mm to segregate particles above a diameter of 4.75mm. Table 3 displays the attributes of the sand that was employed in the study. The study's findings indicate that the grading of the fine aggregate and the sulfate content adhered to the prescribed parameters indicated in Iraqi specification No. 45/1984.

2.5 Water

The experimental work involved the utilization of potable water.

2.1.4 **Recycled Concrete of Grade (20-35) MPa**

The Recycled Concrete employed in this study was obtained by the demolition of concrete cubes that were afterwards transferred to the laboratory for the purpose of conducting tests. The practice of recycling waste offers a viable and sustainable solution to address the issue of waste accumulation in landfills. By reusing items that would otherwise be thrown, recycling minimizes the need for additional resources and costs. The waste material resulting from the process of concrete demolition is obtained and afterwards crushed into a finely ground powder (see Figure 5). Subsequently, the powder undergoes a sieving procedure with a No. 40 sieve. The material's texture is typically described by its fine and white visual qualities, as illustrated in Figure 6.

2.6 Sodium Silicate

Table 4 displays the technical specifications of sodium silicate.

2.7 Waste glass

The discarded glass was manually fragmented in a controlled laboratory environment, and only the particles that were able to pass through sieve #4 were selected for the purposes of this study.

Table (3): Physical and chemical properties of sand.

Index Property	Index Value	Standard
Max. Dry Unit Weight (g/cm^3)	1.74	ASTM D 4253
Min. Dry Unit Weight (g/cm^3)	1.57	ASTM D 4254
D10 (mm)	*0.17*	ASTM D 422
D30 (mm)	*0.32*	
D50 (mm)	*0.4*	
D60 (mm)	*0.42*	
Coefficient of Uniformity (Cu)	*2.45*	
Coefficient of Curvature (Cc)	*1.43*	

Table (4) :Technical properties of sodium silicate (EL Chemical Inc).

Index Property	Index Value
Appearance	Colorless liquid
Melting Point	0 C^o
Boiling Point	100 C^o
Density	1.37 g/ml
pH	11-12.5 (20 C^o)

3. Loading Tests Model

To comprehensively examine the bearing capacity (BC) and settlement of a sand column under the impact of different parameters, it is crucial to precisely replicate the real-world conditions. To achieve this goal, a unique testing apparatus has been developed and designed, with a range of tools and accessories. The current study employs this setup, as depicted in Figure (8).

figure (5): Mechanism of crushing the concrete. **figure (6):** Concrete demolishing waste.

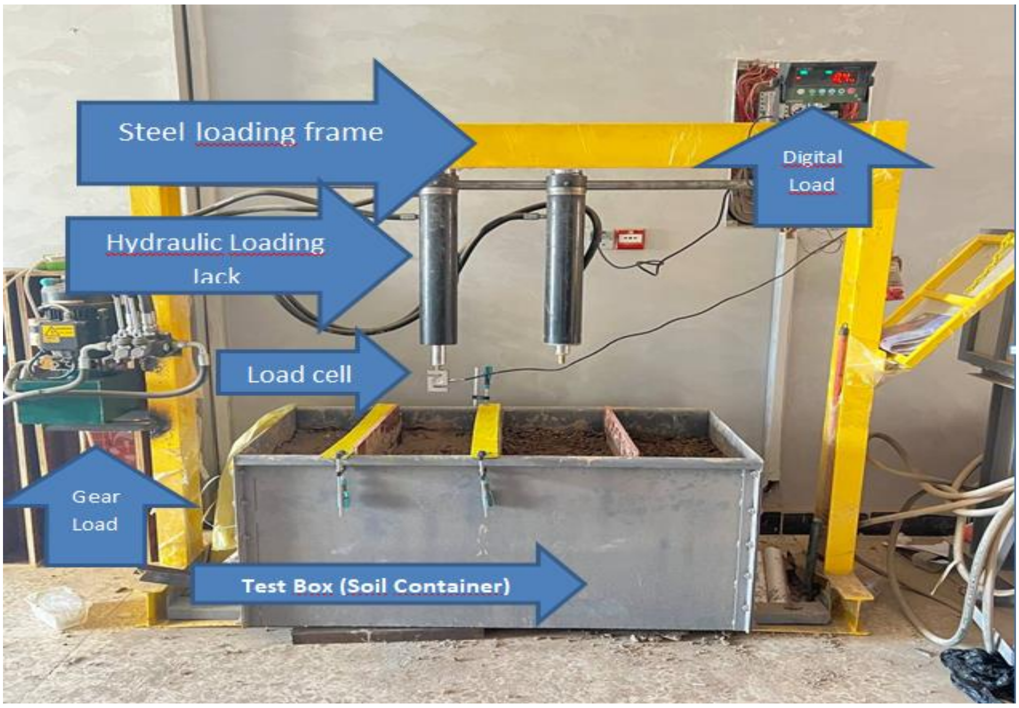


Figure (7): Laboratory test machine manufactured.

4. Construction of Sand Column

After the soil bed preparation was completed, the building of the sand columns instantly began, with an area replacement ratio (AR) of 8%. The following procedures were carried out:

1- A plastic pipe having an outside diameter of 64 mm was driven into the soil bed at the specified depth, as illustrated in Figure 8.

2- To facilitate the process of getting rid of soil from the plastic pipe, a hand auger specifically engineered for this purpose was utilized.

3- Following that, the plastic pipe was carefully extracted. The sand was mixed with different ratios of sodium silicate, with the precise amount selected based on its potential for enhancing the strength of the sand and other materials analyzed in this study (refer to Figure 9).

4-In the present study, the sand, rest material, and sodium silicate amalgamation were carefully fed into the cavity in five layers and slightly compacted using a 20-mm-diameter rod to achieve a unit weight of 1.7 g/cm3 in a compacted state. The cross-sectional representation of the model is shown in Figure 10.

The sand columns exhibit a consistent diameter of 50 mm, with an equidistant spacing of 50 mm between each column, measured from the center of one column to the center of the adjacent column. Rao and Madhira (2010) suggest that an ideal spacing between sand columns should fall within the range of two to three times the diameter of the sand columns. The determination of column length is frequently influenced by the length-to-diameter ratio (L/D), which typically falls within the range of 6 to 10. Mckelvey et al. (2004) propose that there exists no substantial augmentation in the load carrying capability after the L/D ratio surpasses 10. The area replacement ratio (AR) normally ranges from 0.1 to 0.4, with a tendency to exceed 0.2 in most situations. The area replacement ratios can be understood as indicating that a range of 10 to 40 percent of the impoverished soil is substituted with sand columns, with a predominant proportion of applications selecting a replacement quantity of roughly 20% (Nysdot, 2013). The determination of the area replacement ratio is contingent upon the specific ratio in question.

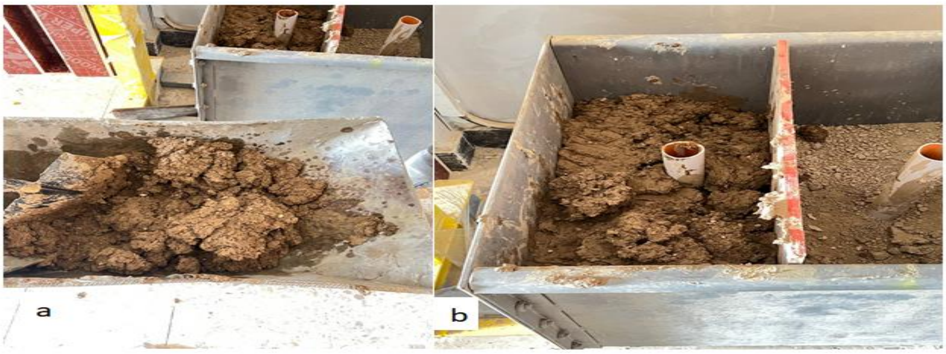


Fig (8): Soil preparation.

Fig. (9): Preparation sand column.

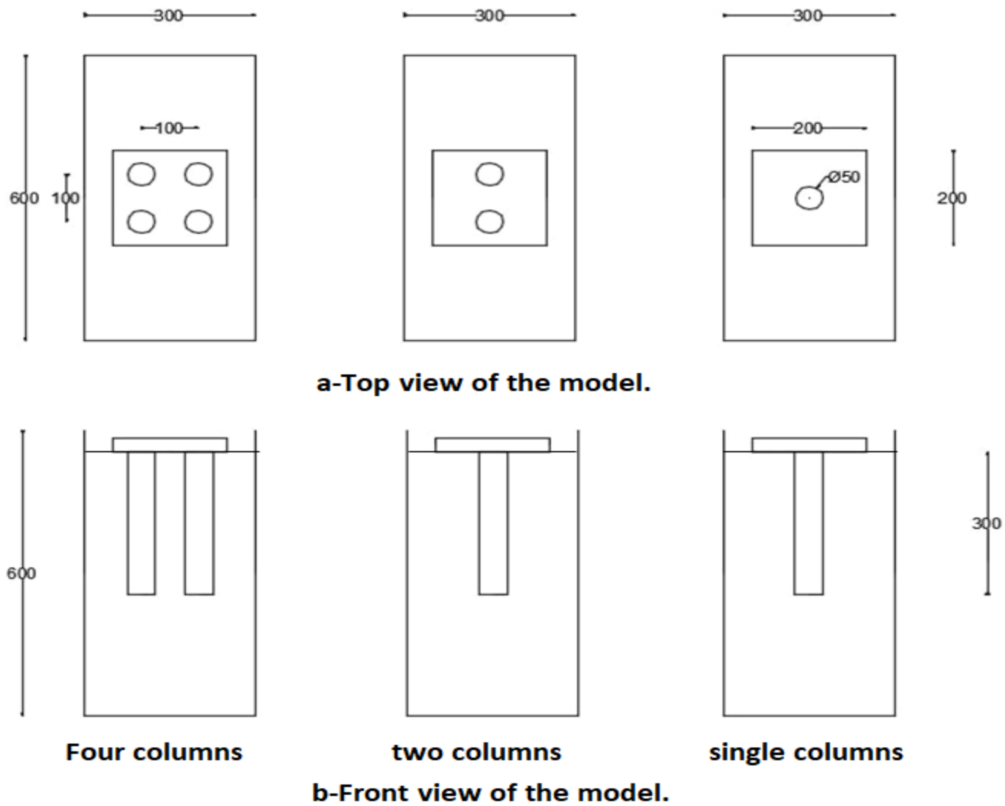


Figure (10): modeling test.

5. Selecting the Appropriate Percentages for cement and bricks

In order to determine the suitable proportions of recycle concrete and glass, in combination with sodium silicate, for the purpose of constructing modeling test columns on compacted clay soil reinforced with sand, two types of columns were considered: those stabilized with sodium silicate and recycle concrete (referred to as S-RC columns), and those composed of sand and glass (referred to as S-G columns). A laboratory experiment was undertaken to ascertain the unconfined compressive strength (UCS) of sand samples containing different ratios of cement and sodium silicate. The specimens underwent a three-day curing phase. The experimental procedure is delineated in the following manner:

1- For recycle concrete

a- 10% of recycle con crete with (10, 15 and 20) % of sodium silicate.

b- 20% of recycle con crete with (10, 15 and 20) % sodium silicate.

c- 40% of recycle con crete with (10, 15 and 20) % sodium silicate.

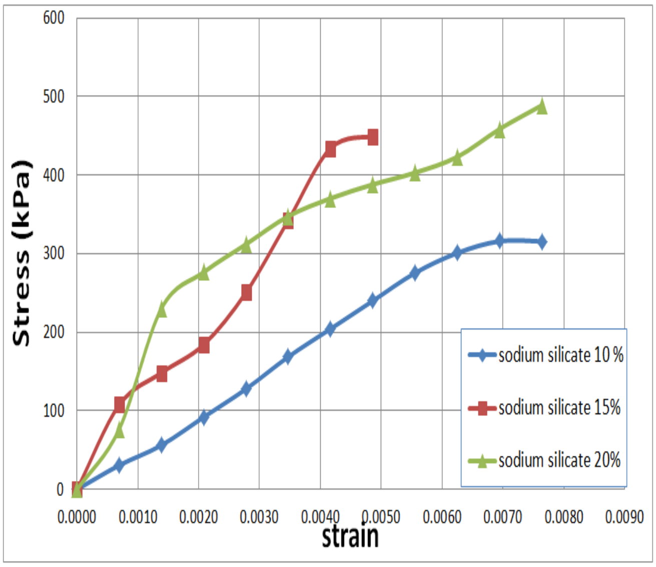
d- 60% of recycle con crete with (10, 15 and 20) % sodium silicate.

The unconfined compressive strength of all samples was determined using the guidelines outlined in the ASTM D-2850 standard. A mold with dimensions of 8.5cm in height and 3.5cm in breadth was employed. The specimens were produced by combining sand with different ratios of sodium silicate. Following this, the resultant mixture was compressed within the mold in a sequential fashion, comprising of three discernible layers. Following this, the specimen underwent a curing procedure before being tested, during which it was encased in a nylon sheet.

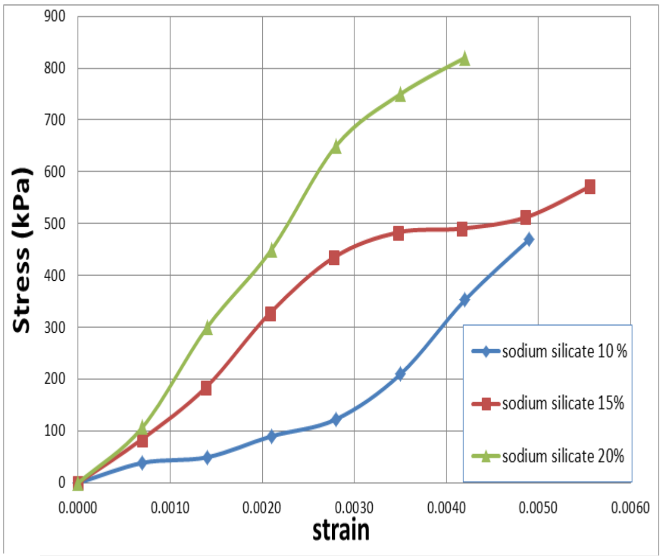
The enhancement of geotechnical properties through the integration of recycled concrete and sodium silicate into sand is depicted in Figures (11a) to (11d) and outlined in Table (5). The unconfined compressive strength of the sand-recycled concrete mixture shown a significant increase, as seen by the samples exhibiting indications of solidification shortly after the initial mixing procedure.

Figure 11a demonstrates a positive correlation between the sodium silicate concentration and the unconfined compressive strength, indicating an increasing tendency. In particular, the compressive strength exhibits an increment from 315 Kpa when the sodium silicate concentration is 10% to 488 Kpa when the sodium silicate concentration is 20%, with the recycled concrete content maintained at a constant level of 10%. Based on the data depicted in Figure 11c, a notable increase in the unconfined compressive strength is evident, as it rises from 469 Kpa to 820 Kpa with the corresponding increase in the proportion of recycled concrete from 10% to 20% in the presence of sodium silicate. Moreover, it can be observed from Figure (11b) that the unconfined compressive strength has a positive correlation with the sodium silicate content, specifically when the recycled concrete percentage is set at 40%. The strength data exhibit an increase from 536 Kpa to 773 Kpa. A decrease in the unconfined compressive strength is observed when the quantity of sodium silicate increases, coinciding with a recycling concrete fraction of 60%. The strength exhibits a notable drop, declining from 449 Kpa to 259 Kpa, as depicted in Figure (11d). The data reported in Table 5 reveals a discernible pattern wherein the unconfined compressive strength of recycled concrete demonstrates a progressive rise with higher proportions of recycled concrete. This observed tendency remains consistent until the proportion of recycled concrete component approaches 60%, after which a decrease in strength becomes apparent. The pressure demonstrated a positive correlation, increasing from 315.75 kilopascals (kPa) when the recycled concrete percentage was 10% to 536 kPa when it reached 40%. Following this, there was a subsequent fall in pressure to 449 kPa as the proportion of recycled concrete reached 60%, while keeping the sodium silicate concentration constant at 10%. At a recycled concrete pressure of 10 kPa, the unconfined compressive strength was measured to be 449 kPa. However, when the proportion of recycled concrete was increased to 20% and the recycled concrete pressure was raised to 40 kPa, the unconfined compressive strength showed a significant rise to 627 kPa. These results were obtained at a sodium silicate concentration of 15%. Nevertheless, a discernible reduction in pressure was observed at reaching a sodium silicate concentration of 20%. The pressure experienced a decrease from 820 kPa at a recycled concrete percentage of 10% to 259 kPa at a recycled concrete content of 60%.

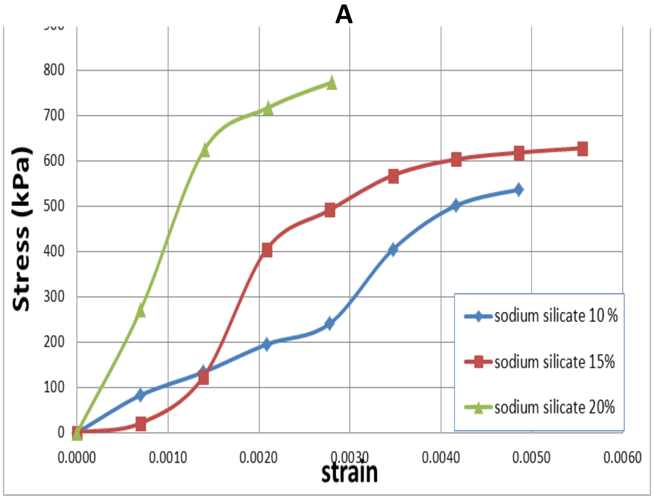
The figure 11b and Table 5 demonstrate a notable rise in the percentage of improvement when the proportion of recycled concrete is set at 20% and the concentration of sodium silicate is likewise 20%. The unconfined compressive strength of the material was determined to be 820 kilopascals (kPa). The aforementioned ratio is utilized in a simulated assessment of compacted clay soil that has undergone reinforcement by the implementation of sand-recycled concrete columns.



A



B



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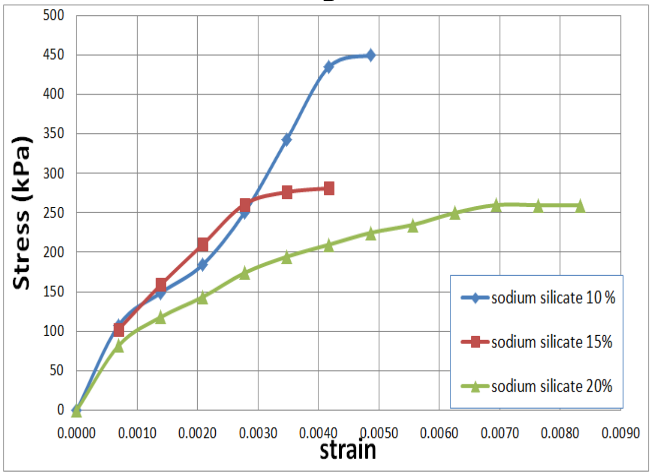


D

Figure (4.12): Effect of sodium silicate on unconfined compressive strength for sand mixing with different percentages of recycle concrete.

(A):Effect of sodium silicate with 10% RC. (B): Effect of sodium silicate with 20% RC.

(C) :Effect of sodium silicate with 40% RC. (D):Effect of sodium silicate with 60 % RC.

Table (5): Effect of sodium silicate on UCS for sand mixing with different percentage of RC.

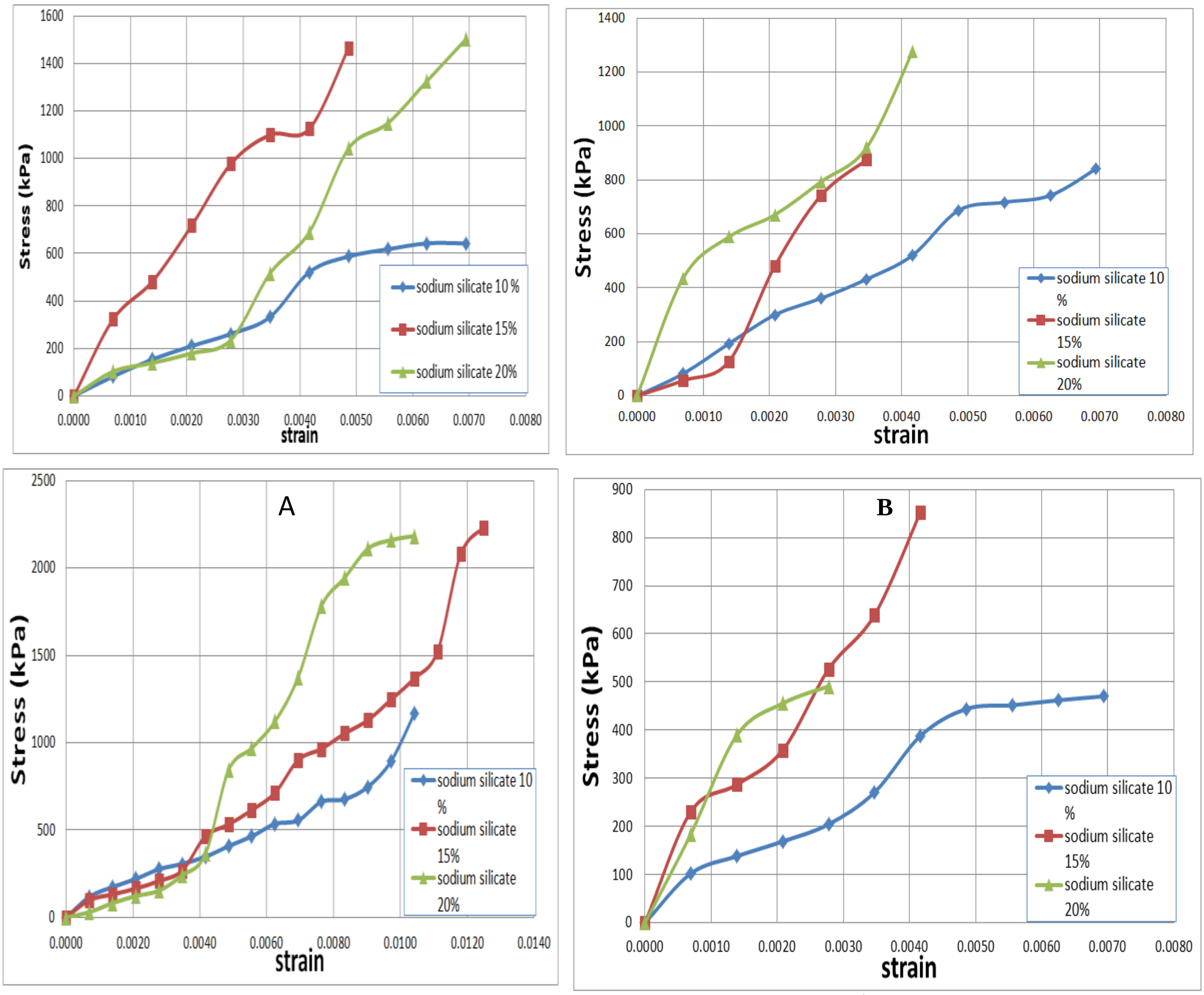
Percentage of recycle concrete %	percentage of sodium silicate %		
	10	15	20
	unconfined compressive strength(UCS) kPa		

10	315	449	488
20	469	517	820
40	536	627	772
60	440	281	259

2- for glass

a- 10% of gl ass with (10, 15 and 20) % sodium silicate.
b- 20% of gl ass with (10, 15 and 20) % sodium silicate.
c- 40% of gl ass with (10, 15 and 20) % sodium silicate.
d- 60% of gl ass with (10, 15 and 20) % sodium silicate.

Based on the data presented in Figure (12a), it can be observed that the unconfined compressive strength exhibits an upward trend in response to an augmented concentration of sodium silicate. Specifically, the strength increases from 642 Kpa when the sodium silicate content is 10% to 1503 Kpa when the sodium silicate content is 20%. According to the data presented in Figure 12b, it can be observed that the unconfined compressive strength exhibited a rise from 842 Kpa at a sodium silicate concentration of 10% to 1277 Kpa at a sodium silicate concentration of 20% when the percentage of glasses was 20%. Furthermore, in Figure (12c), it is observed that when the proportion of glasses reached 40%, the unconfined compressive strength exhibited an upward trend with the rise in sodium silicate concentration. Specifically, the strength increased from 1168 Pa to 2229 Kpa at a sodium silicate concentration of 15%, but then declined to 2183 Kpa at a sodium silicate concentration of 20%. The data presented in figure (12d) illustrates a correlation between the percentage of glasses and the unconfined compressive strength. Specifically, as the percentage of sodium silicate increases, there is an observed increase in the unconfined compressive strength. For instance, at a sodium silicate concentration of 10%, the unconfined compressive strength is measured at 470 kPa. This value increases to 853 kPa when the sodium silicate concentration is raised to 15%. However, when the sodium silicate concentration is further increased to 20%, the unconfined compressive strength decreases to 491 kPa. According to the data presented in Table 6, it is evident that the unconfined compressive strength of glasses exhibits an upward trend as the percentage of glass content increases. Specifically, the percentage of sodium silicate has been found to positively influence the compressive strength until the glass content reaches 60%. However, beyond this threshold, a decline in compressive strength is observed when the sodium silicate content is reduced to 10%. The pressure exhibited a progressive increase, rising from 642 kPa when the glasses constituted 10% of the total, to 842 kPa when they constituted 40%. Subsequently, the pressure decreased to 470 kPa when the glasses constituted 60% of the total. When the concentration of glasses increased from 10% to 20%, the unconfined compressive strength reduced from 1465 to 874. Subsequently, at a concentration of 40% glasses and a sodium silicate concentration of 15%, the unconfined compressive strength increased to 2229. However, there was a decrease in pressure when the concentration of sodium silicate was at 20%. Specifically, the pressure dropped from 1503 kPa for glasses with a 10% concentration to 491 kPa for glasses with a 60% concentration.The most significant improvement percentage was observed in figure 12c and Table 6, specifically when the proportion of glasses reached 40% and the concentration of sodium silicate was set at 15%. The unconfined compressive strength of the material was measured to be 2229 kilopascals (kPa). The aforementioned percentage is employed in a model test conducted on compacted clay soil that has been reinforced with sand-glass columns.



C D

Figure (12): Effect of sodium silicate on unconfined compressive strength for sand mixing with different percentages of glass.
(A):Effect of sodium silicate with 10% glass. (B): Effect of sodium silicate with 20% glass.
(C) :Effect of sodium silicate with 40% glass. (D):Effect of sodium silicate with 60 % glass.

Table (6): Effect of sodium silicate on UCS for sand mixing with different percentage of glass.

Percentage of glasses %	percentage of sodium silicate %		
	10	15	20
	unconfined compressive strength kpa		
10	642	1465	1503
20	842	874	1277.6
40	1168	2229	2183
60	470	853	491

6. Comparison between types of sand columns

The model test was performed on reinforced soil in a sand-recycled concrete column (stabilized with 20% sodium silicate and 20% recycled concrete) and sand-glass column (stabilized with 15% sodium silicate and 40% glass). The diameter of the sand column is selected to be 50 mm, and the spacing between piles (center to center) is 100 mm. The model test was conducted in triplicate for each substance. In the initial instance, the soil was strengthened through the implementation of a solitary sand column. Furthermore, the reinforcement was reiterated by the addition of two sand columns for the second instance. Figure 10 illustrates the presence of four columns during the third instance. Figures (13) to (15) illustrate the relationship between the bearing improvement ratio (q/cu)t/(q/cu)unt and the settling ratio S/Bfooting in the context of this study. The data presented in this study is specifically focused on sand columns that have undergone stabilization by the use of sodium silicate. These columns were created utilizing either glass or recycled concrete components. Based on the data depicted in Figure (13), which pertains to the individual examination of the sand column. The findings suggest that the recycled concrete material shown enhanced performance when used as the treated sand column, as indicated by its bearing ratio (q/cu) of 2.4, which exceeded that of glass. In addition, it was determined that the bearing improvement ratio for recycled concrete is 1.93. Based on the data depicted in Figure (14), it is apparent that recycled concrete exhibited greater performance compared to glass as a material. The bearing ratios for the two variables were 2.97 and 2.54, in that order. Based on the data depicted in Figure (15), it is apparent that there were significant discrepancies in the results obtained from bricks and recycled concrete, as evidenced by a bearing ratio of 5.10 for the concrete material. The refractive index of the glass substance was determined to be 3.42.

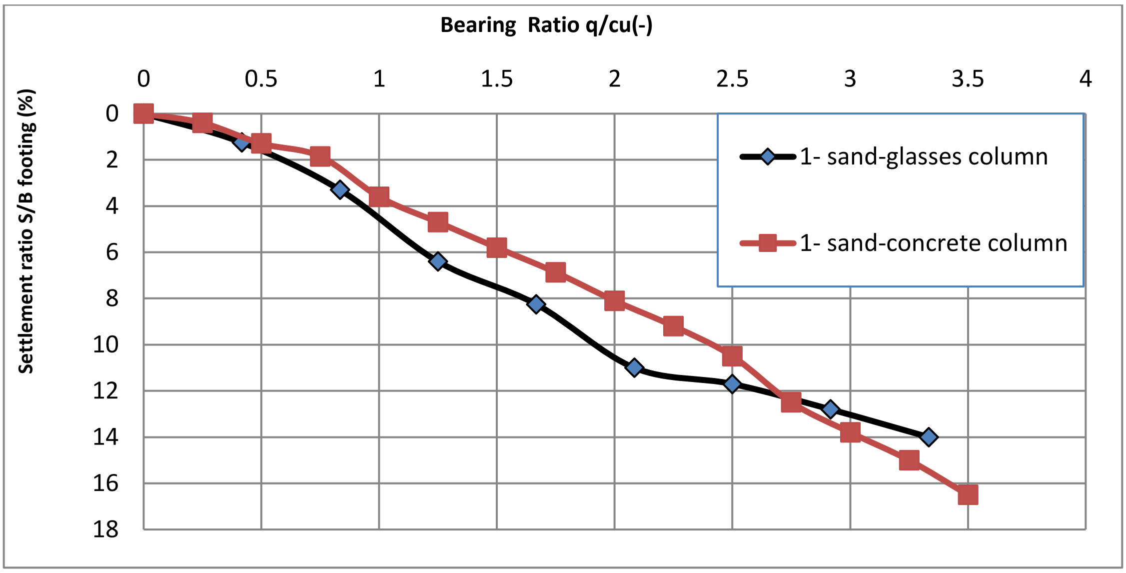


Figure (13): Bearing pressure versus settlement under foundation subjected to static loading for different types of single sand column

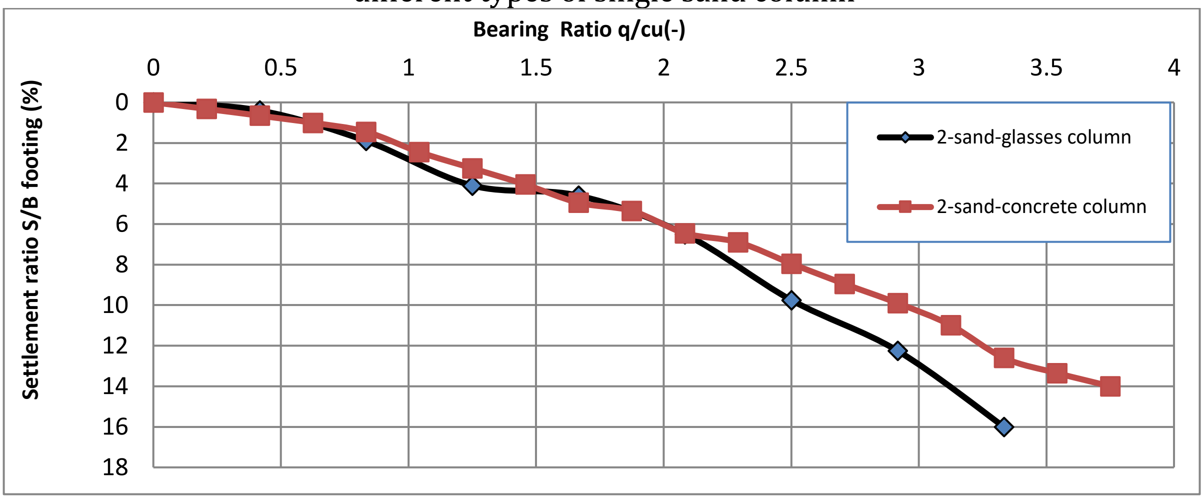


Figure (14): Bearing pressure versus settlement under foundation subjected to static loading for different types of two sand column.

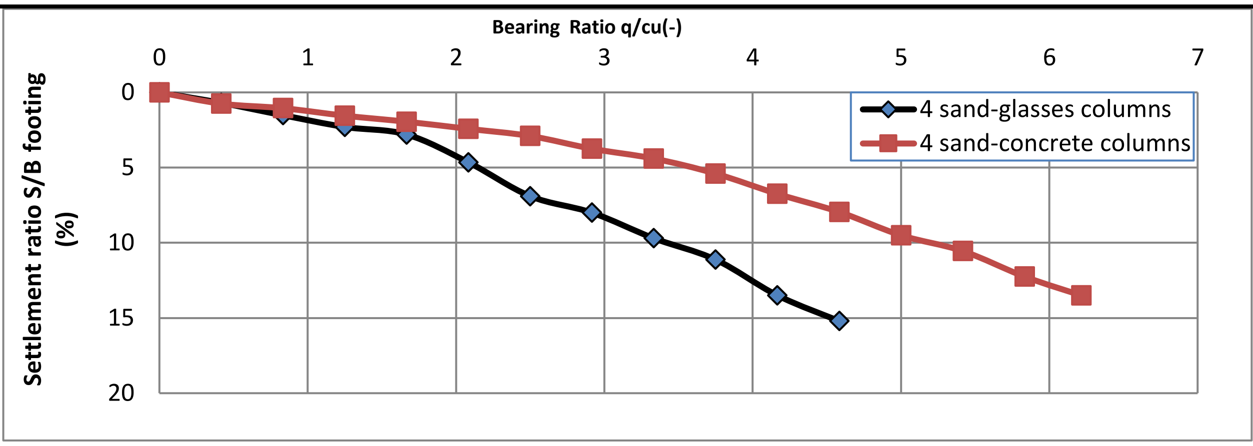


Figure (15): Bearing pressure versus settlement under foundation subjected to static loading for different types of four sand column.

7. Degree of Bearing Improvement Ratio and Settlement Ratio

1- for Sand-Recycled Concrete column

The curve depicted in Figure (16) showcases the correlation between the bearing improvement ratio (q/cu)t/(q/cu)unt and the settling ratio S/Bfooting. The graph representing the single sand-recycled concrete column demonstrates a positive trajectory, reaching its peak value at a settling ratio of 9% (S/B footing). The ratio of the bearing improvement, represented as (q/cu)t/(q/cu)unt, has been calculated to be 1.74. The ratio of the bearing capacity at failure to the ultimate bearing capacity, denoted as (q/cu)t/(q/cu)unt, is equal to 1.72 for the sand column. The two columns made of sand-recycled concrete demonstrate a progressively rising curve, reaching its peak value when the settling ratio (S/B footing) hits 2%. The ratio between the bearing improvement at time t and the bearing improvement at time unt is 2.15. The calculation of the bearing improvement ratio at failure for the sand column yields a value of 2.13, which is represented as (q/cu)t/(q/cu)unt. The four columns made of sand-recycled concrete demonstrate an upwardly sloping curve, reaching its peak value at a settlement ratio of 10% for the S/B footing. At the moment of failure, the ratio of the bearing improvement (q/cu)t to the bearing improvement (q/cu)unt is seen to be 3.74. Table 7 provides a complete summary of the outcomes that were collected. The study's results demonstrate that the soil's enhancement ratio was significantly improved when sand-recycled concrete columns were strengthened with a 20% concentration of sodium silicate. Specifically, a single column achieved a 73% increase, while the use of four columns resulted in a substantial 274% improvement.

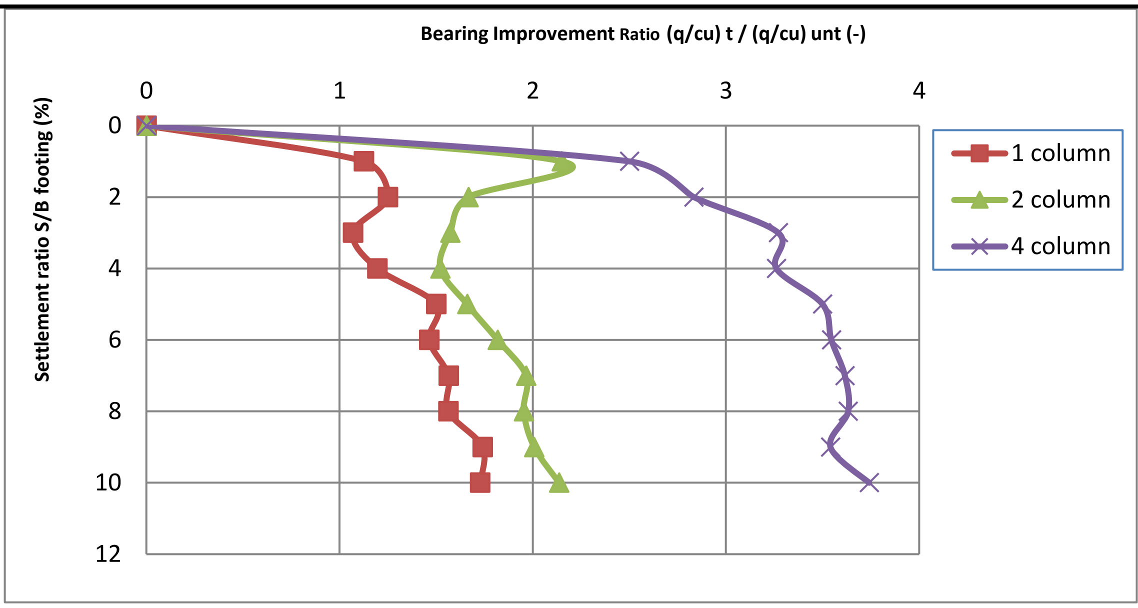


Figure (16): Bearing improvement ratio versus settlement ratio of soil treated with sand-recycle concrete column treated with 20 % sodium silicate.

Table (7): Summary of S-RC column stabilized with treated with 10% sodium silicate.

Iteam	Carrying Capacity Kpa	Improvement Ratio%
Unreinforced soil	56.99	----
Single sand-recycle concrete column	98.4	73
two sand-recycle concrete column	121.77	114
four sand-recycle concrete column	213.2	274

2- for Sand-Glass column

The link between the bearing improvement ratio (q/cu)t/(q/cu)unt and the settling ratio S/Bfooting is depicted in Figure (17). The sand-glass column demonstrates an upwardly sloping curve, reaching its peak value when the settlement ratio (S/B) is 10% relative to the width of the footing, at the moment of failure. The ratio between the bearing improvement at time t and the bearing improvement at time unt is 1.39. The sand-glass columns demonstrate an upward trajectory that culminates at a settlement ratio (S/B footing) of 10% before to experiencing failure. The ratio between the bearing improvement at time t, denoted as (q/cu)t, and the bearing improvement at time unt, denoted as (q/cu)unt, is 1.83.

The sand-glass columns demonstrate a progressive increase, culminating at their peak when the settlement ratio (S/B footing) attains a value of 10%. At the moment of failure, the ratio of the bearing improvement (q/cu)t to the bearing improvement (q/cu)unt is observed to be 2.46.

Table (8) provides a complete overview of the findings. The study's results demonstrate that the soil's enhancement ratio had a 39% rise when reinforced with sand-glass columns stabilized with a 15% concentration of sodium silicate. Moreover, the enhancement ratio demonstrated a substantial 145% increase when four columns were utilized.

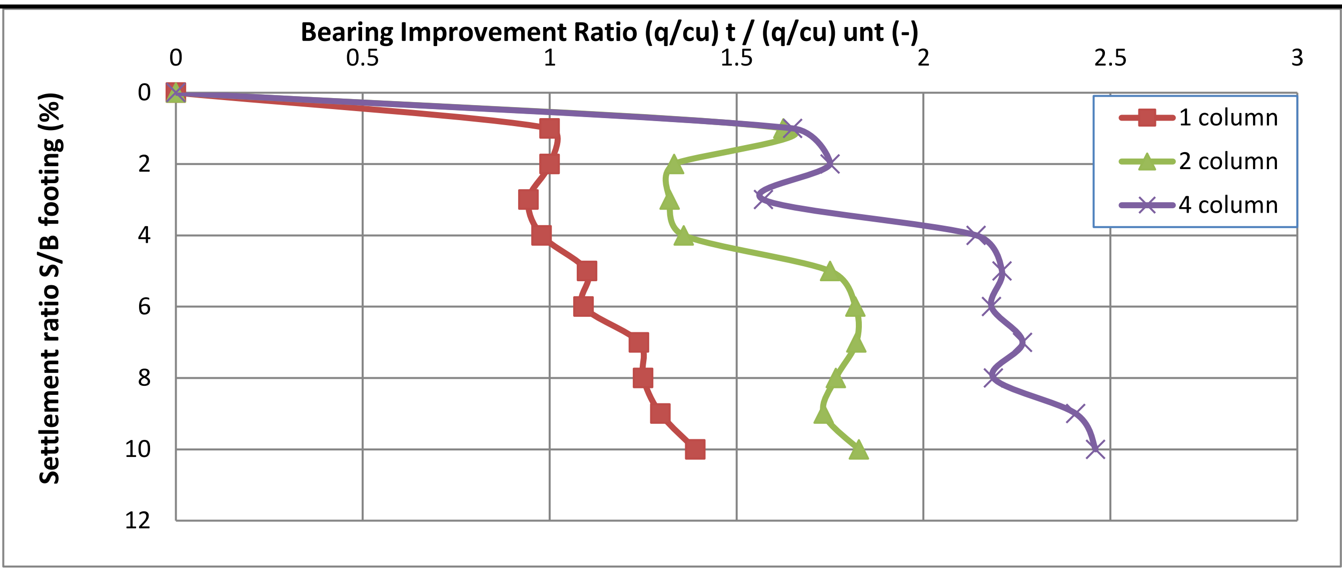


Figure (15): Bearing improvement ratio versus settlement ratio of soil treated with sand-glasses column treated with 20 % sodium silicate.

Table (8): Summary of sand-glasses column stabilized with treated with 10% sodium silicate.

Iteam	Carrying Capacity Kpa	Improvement Ratio%
Unreinforced soil	56.99	----
Single sand-glasses column	79	39
two sand-glasses column	104	82
four sand-glasses column	140	145

Conclusions

Based on the discussions conducted in the preceding chapter and further observations made during the experimental investigation, the following conclusions can be drawn:

1. The duration of the hardening processes for sand treated with recycled concrete and glass, in combination with sodium silicate, exhibited varying rates of completion, with the former being characterized by a very rapid reaction time of approximately 10-12 hours, while the latter had a somewhat shorter duration of 7-9 hours.

2. The cohesiveness of sand treated with cement is greater than that of sand treated with recycled concrete, glass, and bricks, respectively. The investigation yielded the optimal cohesiveness percentages of the sand samples after undergoing the prescribed treatment for each respective material were.

a- 20% of recycled concr ete with 20% sodium silicate by weight.

b- 40% of glasse s with 15% of sodium silicate by weight.

3. The findings indicated that the enhancement ratio for the soil reinforced with sand columns subjected to various materials was:

a-The sand-recycled concrete columns, which were stabilized with a 20% concentration of sodium silicate, achieved a maximum compressive strength of 73% for individual columns, 114% for pairs of columns, and 274% for groups of four columns.

b-The sand-glass columns, which were stabilized using a 15% concentration of sodium silicate, achieved a single column efficiency of 39%. When arranged in pairs, the efficiency increased to 82%, and further increased to 145% when arranged in groups of four columns.

4- The effectiveness of both individual and collective sand columns exhibited a decline as the number of columns increased while maintaining a constant spacing. This observation can be succinctly described as follows:

a-The mixture used in the construction of the columns consisted of sand and recycled concrete. The efficiency of the two-column group was determined to be 62% at the point of failure, whereas the efficiency of the four-column group made with sand and cement was found to be 55%.

b- The experimental setup consisted of a sand-glass column mixture, wherein the efficiency of a two-column configuration was observed to be 67% at the point of failure. In contrast, the efficiency of a four-column configuration was found to be 44%.

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