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Bearing Capacity Characteristics of Sand Columns Stabilized with Recycled Bricks Material In Soft Soils

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Abstract

The current endeavor is to achieve enhanced solidity of sand columns relative to the surrounding soil through the utilization of recycled brick and cement, facilitated by the process of sodium silicate stabilization. The experimental program has been partitioned into three distinct components to facilitate the construction of columns. The initial step entails determining the standard mixing proportion for each substance and sodium silicate across three weight percentages of liquid sodium silicate (10%, 15%, and 20%). To investigate the properties of the second material, a mixture of cement and brick is prepared by incorporating sand at different weight ratios, specifically 10%, 20%, 40%, and 60%. Samples were subjected to a laboratory test to determine their unconfined compressive strength. The experimental findings indicated that the cohesiveness of sand can be increased by incorporating 20% cement and 20% sodium silicate into the cement-sand combination. The optimal composition for the brick-sand mixture was found to be 20% brick and 20% sodium silicate. The final phase of the experiment involved the utilization of a laboratory model to assess the efficacy of each mixture on 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. The second occurrence was further strengthened with the addition of two columns. In the third instance, there were four columns present. The findings of the study indicate that the soil's improvement ratio was seen to be 163% for a single column, 256% for two columns, and 358% for four columns when the soil was reinforced using sand-cement columns stabilized with sodium silicate. The sand-brick column yielded a single column efficiency of 46%, a two-column efficiency of 144%, and a four-column efficiency of 261%.

Keywords: *Sand column, sodium silicate, cement, Brick, bearing improvement.*

1. Introduction

Iraq is one of the nation’s whereby a significant portion, perhaps 30 to 40 percent, of its land area is classified as soft saturated silty clay. The presence of this loose soil is observed along the alluvial plain, commencing from the northern region of Baghdad and extending towards the southern vicinity, ultimately reaching the Arabian Gulf. According to Al-Saoudi et al. (2014), the region is anticipated to see significant growth in its infrastructure, hence making ground improvement a crucial undertaking for the building sector. The utilization of sand columns has gained significant international recognition as a viable, sustainable, and effective method for enhancing the load-bearing capacity and managing settlement in soft soil conditions. In numerous instances, it has been seen as a

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cost-effective alternative to deep foundation systems. Sand columns consist of sand that is put into the soft clay foundation using the displacement method. The ground that has been enhanced through the implementation of sand columns is commonly referred to as composite ground. Upon being subjected to a load, the pile undergoes deformation by exhibiting bulging into the underlying subsurface strata. This deformation mechanism facilitates the distribution of stresses primarily within the upper section of the soil profile, rather than transmitting the stresses to deeper layers. Consequently, this behavior enables the soil to provide support to the pile. Consequently, the composite ground has the potential to enhance its strength and bearing capacity while simultaneously reducing its compressibility (Bergado et al., 1996). Sand columns have experienced a growing utilization over the last forty years as a viable substitute for conventional stone columns. 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 arrangement of the sand columns during installation, the magnitude and rate at which loads are applied, and the conditions under which the backfill materials are placed. The placement conditions of the backfill materials are particularly important as they significantly contribute to the stiffness of the sand columns. According to Najjar et al. (2009), the utilization of sand columns in soft clay soils has shown effective in enhancing several mechanical qualities, such as settlement, bearing capacity, and physical characteristics. This improvement is achieved by mitigating the formation of excessive pore water pressure during loading, Ahmed,(2015).

2. Experimental Work

2.1 Materials Used

Soft clay was obtained from the south of Iraq in Al-Nasiriyah city at Thi-Qar governorate. The undistributed soil sample was taken from depth of (5 - 7) m under the ground surface. Standard tests were conducted in order to determine both physical and chemical properties of the soil samples. The ASTM standards are adopted to investigate the physical soil properties as illustrate in Table (1). The properties of clay in consolidation test are summarized in Table (2).From unconfined compression test the cohesion of the soft soil (Cu) is 18.5kN/m2.

2.2 Physical Tests

2.2.1Particle Size Distributed

Hydrometer test were conducted on clay samples, according to ASTM D 422. The test was performed for soil with particle sizes less than 0.075 mm (Passing from No.200 sieve). Figure (1) shows the percentage of 2 % sand, 34 % silt and 64% clay.

2.2.2 Atterberg’s Limits

Atterberg limits, liquid limit (LL) and plastic limit (Pl) were performed on the clay samples at the beginning of each physical test to ensure the homogeneity of the used clay. The Cassagrande method was used to determine the liquid limit of the soil according to (ASTM D423), while the plastic limit is determined according to (ASTM D 424) as shown in Figure (2) and Table (1).

2.2.3 Specific Gravity

The specific gravity of the soft soil was determined according to (ASTM) as. as shown in Figure (3) and Table (1).

2.2.4 Compaction Test

This test was conducted according to (ASTM D698) to determine the value of optimum moisture content and maximum dry unit weight and the results are plotted in Figure (4).

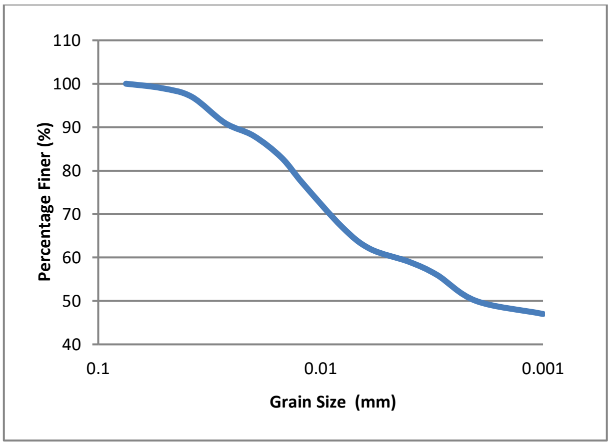


Figure (1): Particle size distribution of soil sample

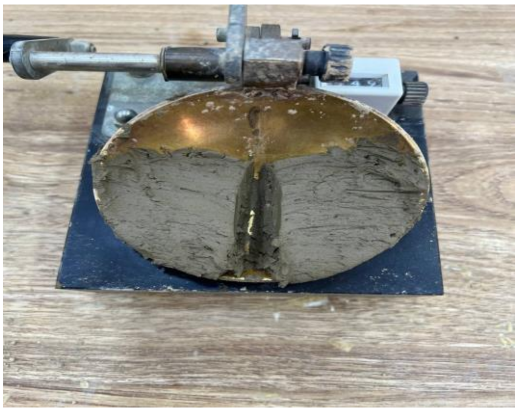


Figure (2): liquid limit test.

Figure (3): Specific Gravity Test.

Figure (4): Compaction test results

2.2.5 Chemical Tests

Chemical properties of the soil are presented in Table (1).

2.2.6 Consolidation Test

Standard consolidation test was performed to determine the compressibility of the clay used in this study. Standard consolidation test was carried out according to (ASTM D 2435) for natural soft soil. The dimensions of Odometer ring are 75mm diameter and 2mm height. The properties of soft clay soil in consolidation test as shown in Table (2).

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	

2.2.7 Sand

The fine aggregate utilized in this study was sourced from the Zubair area in Basrah city and consisted of natural sand. The fine aggregate underwent a sieving process using a screen size of 4.75mm in order to separate the aggregate particles with a diameter larger than 4.75mm. Table 3 presents the characteristics of the utilized sand. The results obtained from the study revealed that both the grading of the fine aggregate and the sulfate content were found to be within the specified limits as outlined in the Iraqi specification No. 45/1984.

2.2.8 Sodium Silicate

Table (4) presents the technical characteristics of sodium silicate.

2.2.9 Cement

The cement that used in the model tests is sulfate resistant cement, which manufactured by Tasluja cement factory The physical and chemical properties was tested in The National Center for Construction Laboratories and Research (NCCLR), Ministry of

Construction and Housing, and the physical and chemical properties are shown in Table (5).

2.2.10 Brick powder

The waste brick powder utilized in the experimental investigation was procured from waste fire clay brick via a crusher situated in the laboratory within the College of Engineering at the University of Thi-Qar, as depicted in Figure 6. The object exhibits a red and yellow coloration, possessing a delicate texture. The specific gravity of water-borne polyurethane (WBP) was measured to be 2.76. When the WBP was blended with natural soil, the specific gravity of the mixtures exhibited an increase in contrast to the natural soil. The chemical compositions depicted in Table (6) and Figure (6). The composition of WBP mostly consists of silica, which accounts for 56.20% of its total composition

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*	
D30 (mm)	*0.32*	
D50 (mm)	*0.4*	ASTM D 422
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)

Table (5): Physical and chemical properties of the cement

Index Property	Index Value
Compressive strength after 3 days (MPa)	17
Compressive strength after 7 days (MPa)	26
Time of initial setting (minute)	93
Time of final setting (hour)	4.85
C_3S	50.02
C_2S	26.23
C_3A	4.4
C_4AF	13.62

Table (6): Chemical composition of Brick powder

Compound	**Percentages (%)**
/SlO_2	57
Al_2O_3	10
K_2O	1.88
Na_2O	0.95
CaO	3.77
FeO	10.3
Fe_2O_3	7.54
MgO	2.65
TlO_2	0.96
Other compostions	5.4

Figure. (6): brick used for this study after crushing

3. Loading Tests Model

In order to investigate the bearing capacity (BC) and settlement of a sand column under the influence of various parameters, it is imperative to accurately simulate the real-life conditions. In order to accomplish this objective, a specialized testing apparatus, equipped with various tools and accessories, has been manufactured and designed. This apparatus is utilized in the present investigation, as seen in Figure 7.

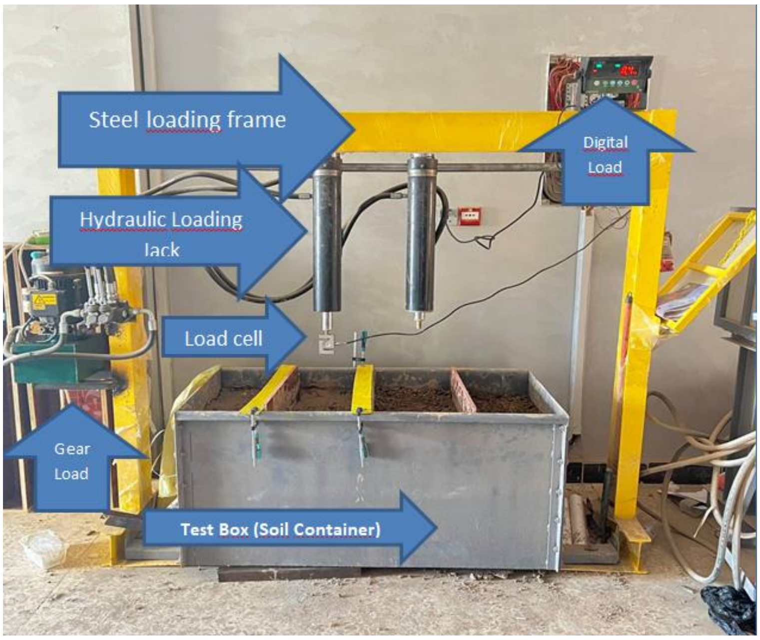


Figure (7): Laboratory test machine manufactured.

4. Construction of Sand Column

Following the completion of soil bed preparation, the construction process of the sand columns commenced promptly, beginning with an area replacement ratio (ar) of 8%. The subsequent procedures were executed:

1. A plastic pipe, measuring 64 mm in outer diameter, was put into the soil bed at the specified depth, as shown in Figure 8.

2. In order to remove the soil from the plastic pipe, a hand auger specifically designed for this task was employed.

3. Subsequently, the plastic pipe was meticulously removed. The sand was blended with varying proportions of sodium silicate, with the specific percentage chosen based on its ability to enhance the strength of the sand when combined with the other materials examined in this study (see Figure 9).

4. In this study, the sand, rest material (used for the purposes of this investigation), and sodium silicate combination were meticulously introduced into the cavity in a sequential manner, consisting of five layers. Subsequently, a 20-mm-diameter rod was employed to slightly compact the mixture, with the objective of attaining a unit weight of 1.7 g/cm3 in a densely consolidated state. The figure (10) depicts the cross section of the model.

The sand columns have a uniform diameter of 50 mm, with a consistent spacing of 50 mm between each column, measured from center to center. According to Rao and Madhira (2010), it is recommended that the optimal distance between sand columns should range from two to three times the diameter of the sand columns. The selection of column length is often determined by the length-to-diameter ratio (L/D), which commonly falls within the range of 6 to 10. According to Mckelvey et al. (2004), it is not recommended to exceed an L/D ratio greater than 10 in order to get a significant improvement in load carrying capacity. The area replacement ratio (AR) often falls between the range of 0.1 to 0.4. However, in the majority of applications, the replacement ratio exceeds 0.2. The area replacement ratios can be interpreted as suggesting that from 10 to 40 percent of the poor soil is substituted with sand columns, with a majority of applications opting for a replacement quantity close to 20% (Nysdot, 2013). The selection of the area replacement ratio is determined based on this particular ratio. In order to accurately investigate the bearing capacity (BC) and settlement of a sand column under various parameters, it is imperative to replicate the real-life situation using simulation. In order to accomplish this objective, a specialized testing apparatus, equipped with various tools and accessories. This apparatus is utilized in the present investigation, as seen in Figure 10.

Figure (8): Soil preparation.

Figure. (9): Preparation sand column.

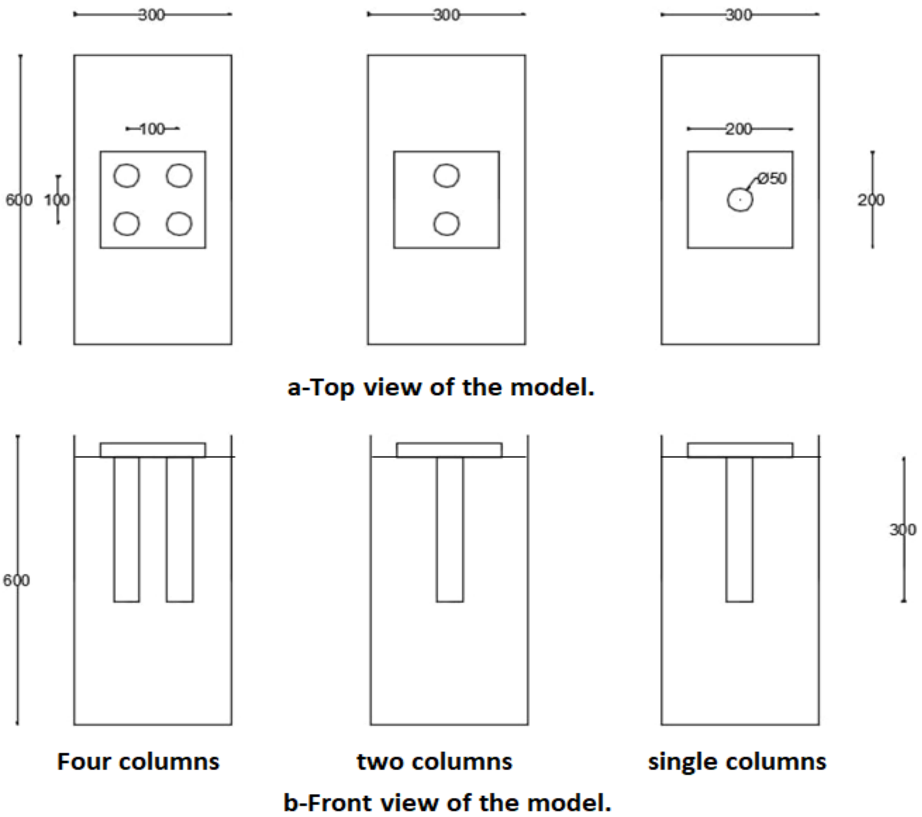


Figure (10): modeling test.

5. Selecting the Appropriate Percentages for cement and brick

In order to determine the optimal proportions of cement and brick, in conjunction with sodium silicate, for the purpose of constructing columns for modeling tests on compacted clay soil reinforced with Sand-Cement columns stabilized with sodium silicate (S-C column with SS) and Sand-brick columns (S-B column). A laboratory experiment was conducted to determine the unconfined compressive strength of sand samples with varying proportions of cement and sodium silicate. The samples were subjected to a curing period of 3 days. The experimental procedure is outlined below:

1- Cement

a) 10% of cement with (10, 15, and 20%) sodium silicate

b) 20% of cement with (10, 15, and 20%) sodium silicate

c) 40% of cement with (10, 15, and 20%) sodium silicate.

d) 60% of cement with (10, 15, and 20%) sodium silicate.

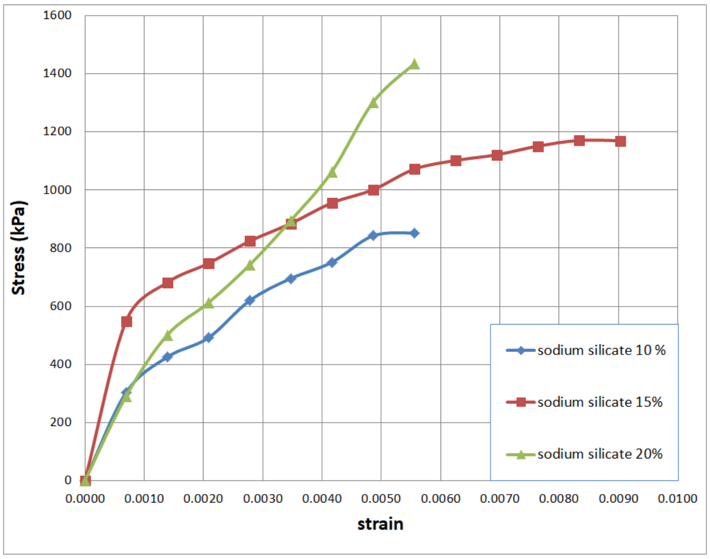
The unconfined compressive strength of all samples was determined in accordance with the ASTM D-2850 standard. A mold measuring 8.5cm in height and 3.5cm in width was utilized. The specimens were made by combining sand with varying percentage s of sodium silicate (10%, 15%, and 20%). Subsequently, the resulting mixture was compacted in a mold using a three-layer technique. Following compaction, the specimens were subjected to a curing process, during which they were covered with a nylon sheet.

The geotechnical property improvement resulting from the addition of cement and sodium silicate to sand is illustrated in Figures (11a) to (11d) and summarized in Table (6). The unconfined compressive strength of the sand-cement mixture exhibited rapid enhancement, with the samples displaying signs of hardening within a few hours following the mixing process.

Based on the data presented in Figure (11a), it is observed that the unconfined compressive strength exhibits an upward trend as the sodium silicate content increases. Specifically, the strength increases from 852 Kpa when the sodium silicate concentration is 10% to 1434 Kpa when the sodium silicate concentration is 20%. According to the data presented in Figure (11b), it can be observed that the unconfined compressive strength experiences an increase when the percentage of cement is raised from 10% to 20%. Specifically, the strength rises from 2570 Kpa to 4012 Kpa when the sodium silicate concentration is increased from 10% to 20%. Furthermore, in the case where the cement content was 40%, as depicted in Figure (11c), it is evident that the unconfined compressive strength exhibits an upward trend as the sodium silicate content increases, rising from 2605 Kpa to 3600 Kpa. The unconfined compressive strength experiences a decline when the sodium silicate content increases, when the cement percentage hits 60%. This is evident in Figure (11d), where the strength reduces from 4019 Kpa to 2741 Kpa.

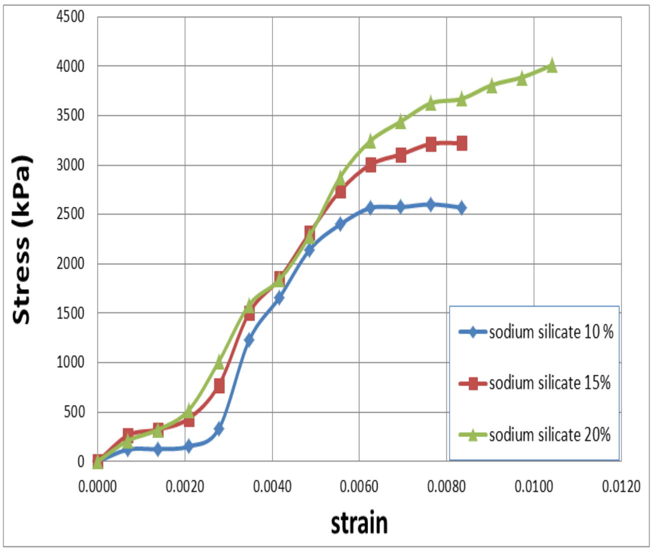
According to the data presented in Table 7, it is evident that the unconfined compressive strength of cement has an upward trend as the percentage of cement increases, particularly when combined with a verified proportion of sodium silicate. The pressure has been seen to rise from 852 Kpa at a cement concentration of 10% to 4019 Kpa at a cement concentration of 60% in the presence of a 10% sodium silicate solution. The pressure ranges from 1169 Kpa to 3385 Kpa when the concentration of sodium silicate is 15%. The pressure range of sodium silicate, at a concentration of 20%, varies from 1434 Kpa to 2741 Kpa.

The most significant improvement percentage is observed in Figure (11b) and Table (7) when the cement percentage is 20% and the sodium silicate percentage is also 20%. The unconfined compressive strength of the material under investigation was measured to be 4092 kilopascals (kPa). This proportion is utilized in the construction of a model test involving the reinforcement of compacted clay soil with sand-cement columns.



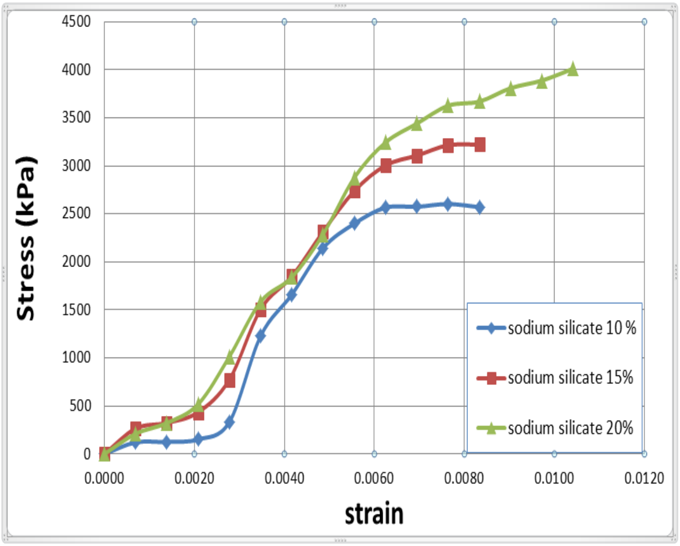
Stress (kPa)
strain
0.0000 0.0010 0.0020 0.0030 0.0040 0.0050 0.0060 0.0070 0.0080 0.0090 0.0100
0 200 400 600 800 1000 1200 1400 1600
sodium silicate 10 %
sodium silicate 15%
sodium silicate 20%

A



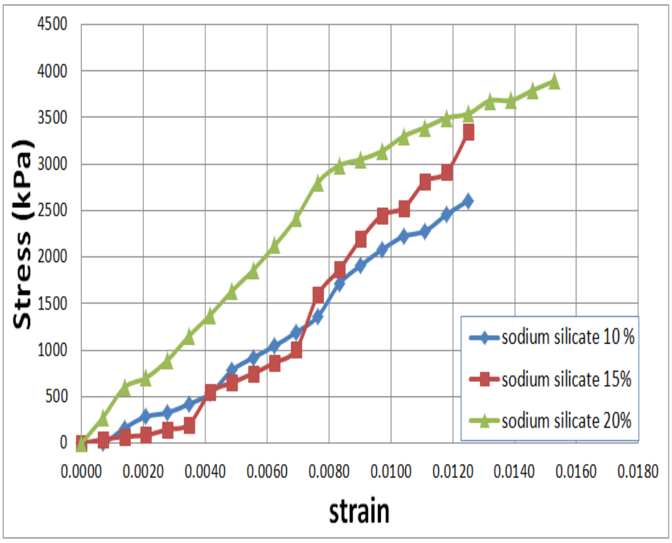
Stress (kPa)
strain
0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120
0 500 1000 1500 2000 2500 3000 3500 4000 4500
sodium silicate 10 %
sodium silicate 15%
sodium silicate 20%

B



Stress (kPa)
strain
0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120
0 500 1000 1500 2000 2500 3000 3500 4000 4500
sodium silicate 10 %
sodium silicate 15%
sodium silicate 20%

C



D

Figure (11): Effect of sodium silicate on unconfined compressive strength for sand mixing with different percentages of cement.

(A): Effect of sodium silicate with 10% cement.

(B): Effect of sodium silicate with 20% cement.

(C): Effect of sodium silicate with 40% cement.

(D): Effect of sodium silicate with 60 % cement.

Table (7): Effect of sodium silicate on UCS for sand mixing with different percentage of cement.

Percentage of cement %	percentage of sodium silicate %		
	10	15	20
	unconfined compressive strength Kpa		
10	852	1169	1434
20	2570	3219	4012
40	2670	3344	3600
60	4092	3385	2741

2- Brick

a- 10% of brick with (10, 15 and 20) % of sodium silicate.

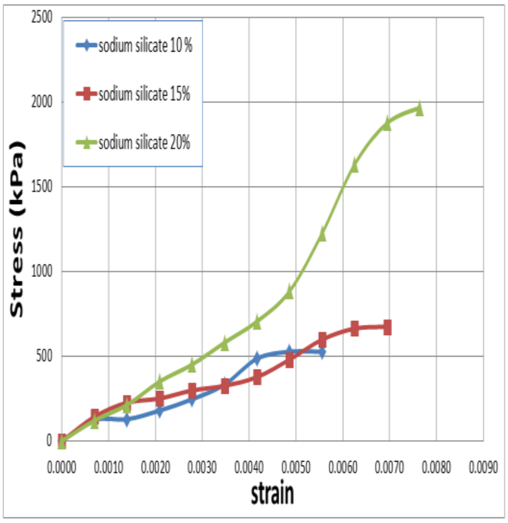
b- 20% of brick with (10, 15 and 20) % sodium silicate.

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

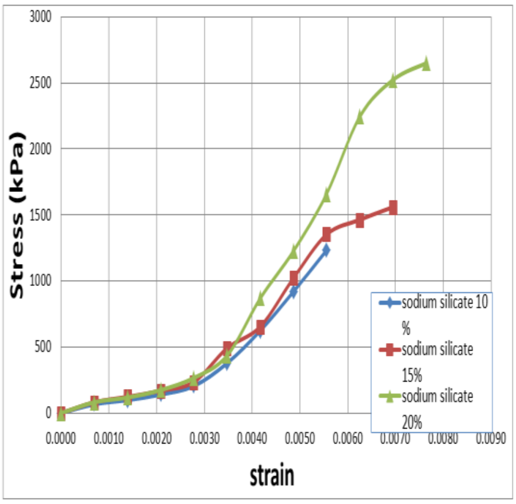
d- 60% of brick with (10, 15 and 20) % sodium silicate.

Based on the observations made in Figure 12a, it can be inferred that there is a positive correlation between the concentration of sodium silicate and the unconfined compressive strength of the bricks. Specifically, the unconfined compressive strength was found to increase from 525 Kpa when the sodium silicate concentration was 10% to 1965 Kpa when the concentration was increased to 20%. According to the data presented in Figure 12b, it can be observed that when the proportion of bricks grew to 20%, the unconfined compressive strength exhibited a notable enhancement. Specifically, the unconfined compressive strength rose from 1232 Kpa when the sodium silicate concentration was

10% to 2648 Kpa when the sodium silicate concentration was increased to 20%. Furthermore, it can be observed from Figure 12c that the unconfined compressive strength exhibited an upward trend as the sodium silicate content increased, from 1125 Pa to 1625 kPa, when the percentage of bricks reached 40%. The unconfined compressive strength experiences a drop as the proportion of bricks reaches 60%. The figure (12d) illustrates a decrease in pressure from 800 KPa at a sodium silicate concentration of 10% to 550 KPa at a sodium silicate concentration of 20%. This decrease in pressure is associated with an increase in sodium silicate concentration. The pressure drops from 800 kPa at a sodium silicate concentration of 10% to 550 kPa at a sodium silicate concentration of 20%, as depicted in Figure 12d. According to the data presented in Table 8, it is evident that the unconfined compressive strength of bricks exhibits an upward trend as the percentage of sodium silicate in the bricks grows, while maintaining a constant percentage. However, this positive relationship ceases once the bricks reach a percentage of 40%, as the unconfined compressive strength begins to decline when the sodium silicate content reaches 10%. The pressure exhibited a rise from 525 kilopascals (kPa) when 10% of bricks were present, to 1232 kPa when the proportion of bricks grew to 20%. Subsequently, the pressure decreased to 1125 kPa as the number of bricks reached 40%. The unconfined compressive strength of the bricks exhibited an upward trend as the percentage of bricks grew. Specifically, when the proportion of bricks rose from 10% to 20%, the unconfined compressive strength climbed from 672 to 1559. Subsequently, with a further increase in the proportion of bricks to 40%, the unconfined compressive strength decreased to 1179. These observations were made under the condition that the sodium silicate concentration remained constant at 15%. However, there was a decrease observed in the pressure as the concentration of sodium silicate reached 20%. Specifically, the pressure dropped from 1965 kPa for bricks with a 10% sodium silicate concentration to 550 kPa for bricks with a 60% sodium silicate concentration. The most significant improvement percentage was observed in Figure 12b and Table 8 when the concentration of sodium silicate was 20% and the percentage of improvement was 20%. The compressive strength of the unconfined bricks was measured to be 2648 kPa. This proportion is utilized in the experimental testing conducted on a model of Compacted clay soil reinforced with sand-brick columns.



A



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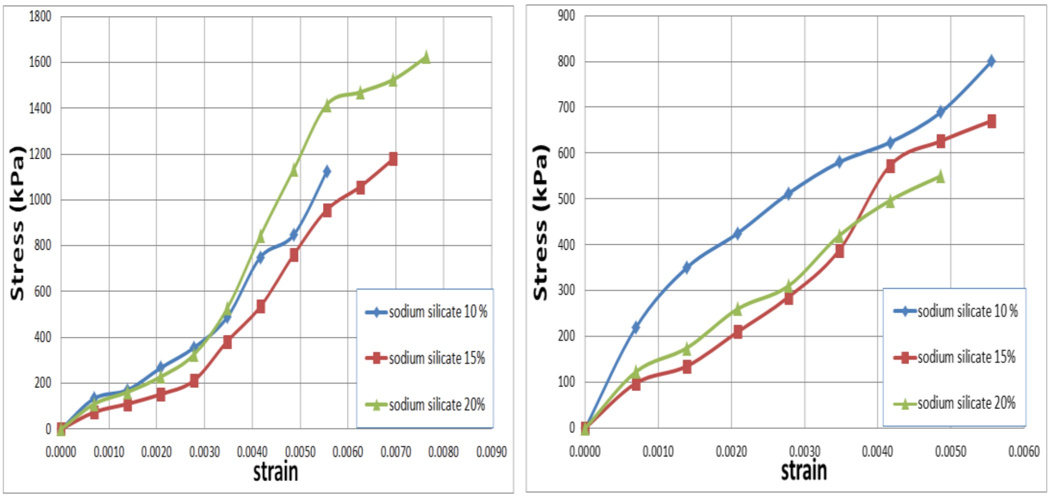

C D

Figure (12): Effect of sodium silicate on unconfined compressive strength for sand mixing with different percentages of brick.

(A): Effect of sodium silicate with 10% brick.

(B): Effect of sodium silicate with 20% brick.

(C): Effect of sodium silicate with 40% brick.

(D): Effect of sodium silicate with 60 % brick.

Table (8): Effect of sodium silicate on UCS for sand mixing with different percentage of bricks.

Percentage of bricks %	percentage of sodium silicate %		
	10	15	20
	unconfined compressive strength Kpa		
10	525	672	1965
20	1232	1559	2648
40	1125	1179	1625
60	800	670	550

6. Comparison between types of sand columns

The model test was performed on reinforced soil in a sand-cement column (stabilized with 10% sodium silicate and 60% cement) and sand-brick column (stabilized with 20% sodium silicate and 20% brick). The diameter of the sand column is selected to be 50 mm, and the spacing between piles (center to center) is 100 mm. And the model test was performed three times for each material. The first time, the soil was reinforced by single sand column. And for the second time, it was reinforced by two sand columns. And there were four columns the third time as shown in figure (10). The provided figures, 13, 14 and 15 depict the relationship between the bearing improvement ratio (q/cu)t/(q/cu)unt and the settlement ratio S/B footing for sand columns that have been stabilized using sodium silicate in combination with cement and bricks. According to the data presented in Figure (13), pertaining to the sand column that is being examined individually. The results indicate that cement was the most suitable material for the treated sand column, as it had a higher bearing ratio (q/cu) of 3.66 compared to brick, which had a bearing ratio of 2.72. Upon observation, a notable disparity exists between cement and brick due to the significantly higher cohesiveness exhibited by cement in comparison to brick. According to the findings presented in Figure (14), it is evident that cement outperformed brick as the superior material. The bearing ratios for the two variables were 4.95 and 3.93, respectively. Based on the data presented in Figure (15), it is evident that there were notable disparities in the outcomes observed for bricks and cement. Specifically, the bearing ratio for cement was recorded as 6.36, whereas for concrete it was measured at 5.10.

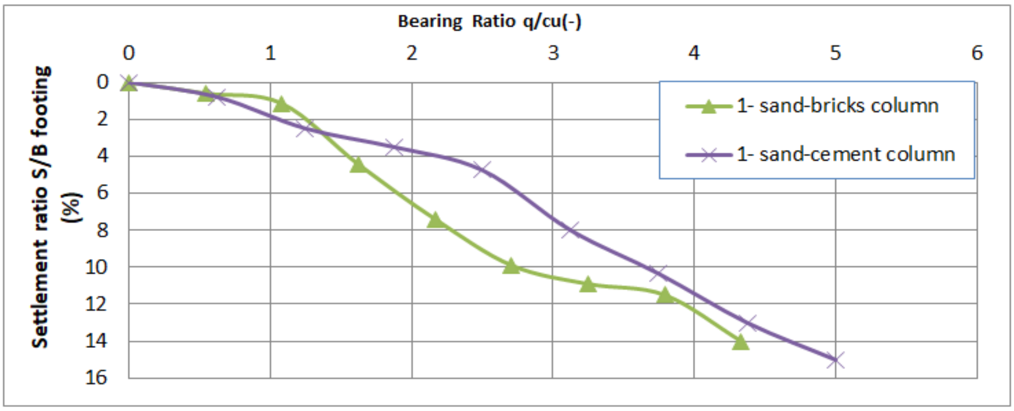

Figure (13): Bearing pressure versus settlement under foundation subjected to static loading for different types of single sand column

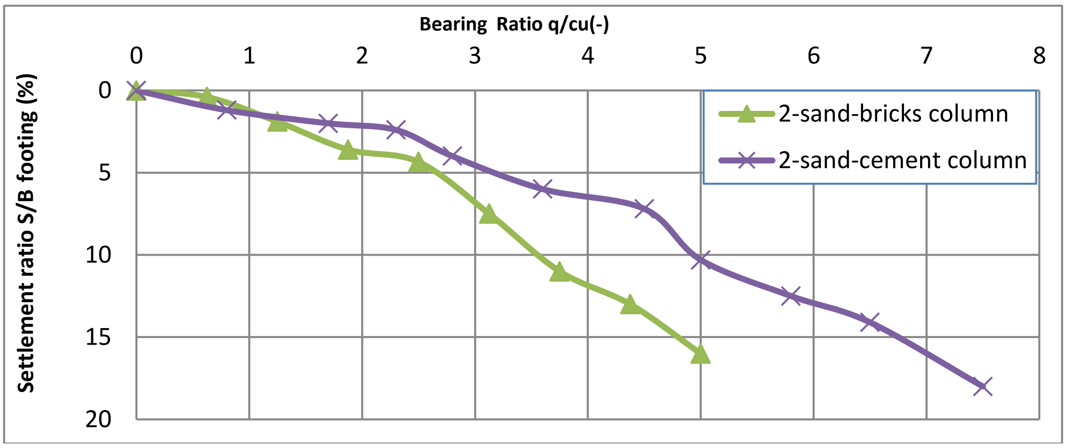

Figure (14): Bearing pressure versus settlement under foundation subjected to static loading for different types of two sand column.

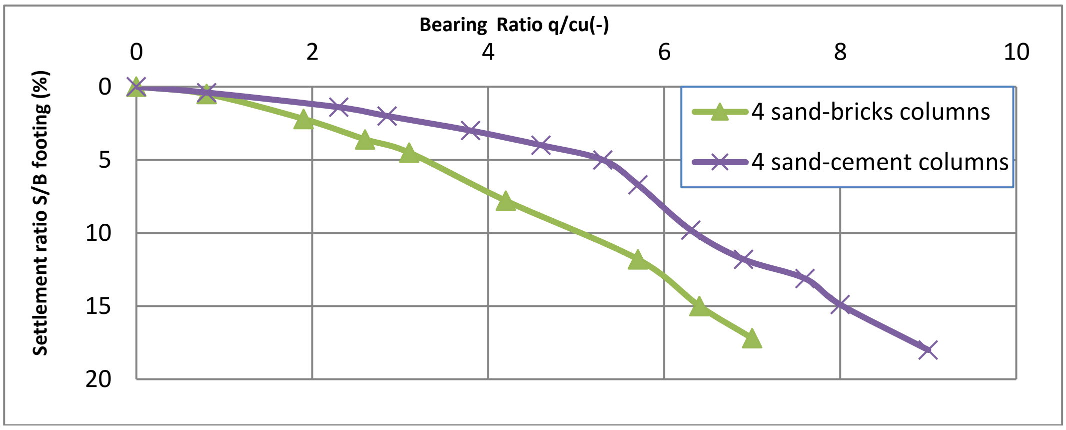

Figure (15): Bearing pressure versus settlement under foundation subjected to static loading for different types of four sand column.

7. Degree of Bearing Improvement Ratio and Settlement Ratio

1- For Sand-Cement column

he graph in Figure (16) illustrates the relationship between the bearing improvement ratio (q/cu)t/(q/cu)unt and the settling ratio S/B of the footing. The curve of the single sand-cement column exhibits a progressive increase, reaching its maximum value at a settling ratio of 10% (S/B footing). The ratio of the bearing improvement (q/cu)t to (q/cu)unt is 2.26.

And in the case of the pair of sand-cement columns, the curve exhibits a progressive increase leading up to a maximum value at the settlement ratio (S/B footing) of 7%. The bearing improvement ratio, denoted as (q/cu)t/(q/cu)unt, has been determined to be 3.76. The bearing improvement ratio (q/cu)t/(q/cu)unt at failure is determined to be 3.56 for the sand column. Also the curve for the set of four sand-cement columns exhibits an increase in magnitude until reaching its maximum value at a settlement ratio (S/B footing) of 5%. The ratio of the bearing improvement (q/cu)t to (q/cu)unt is 5.3. The ratio of the bearing improvement at failure, denoted as (q/cu)t/(q/cu)unt, is measured to be 5.38. The observed behavior of this curve can perhaps be attributed to the increased magnitude of deformation, specifically bulging, that takes place at the central region of the area. It is widely acknowledged that the bulging of sand columns primarily occurs in the upper section, spanning a height approximately four times the diameter (Greenwood, 1970; Hughes et al., 1975). The summary of all results is presented in Table (9). The findings indicated that the soil's enhancement ratio, when reinforced with sand-cement columns stabilized using a 20% percentage of sodium silicate, exhibited a 163% increase for a single column and a 358% increase for a group of four columns.

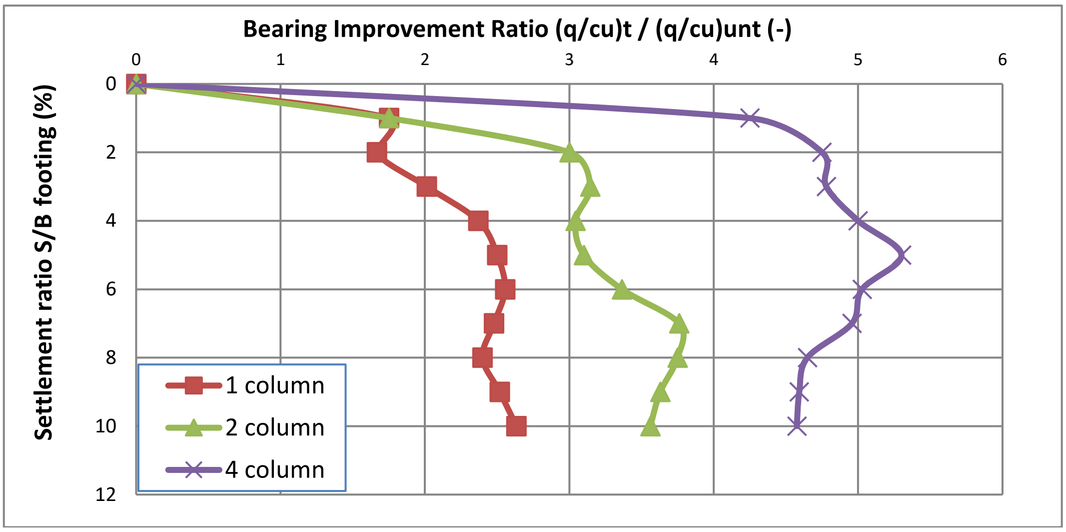

Figure (16): Bearing improvement ratio versus settlement ratio of soil treated with sand-cement column treated with 10% sodium silicate.

Table (9): Summary of S-C column stabilized with treated with 10% sodium silicate.

Iteam	Carrying Capacity Kpa	Improvement Ratio%
Unreinforced soil	55.6	----
Single sand-cement column	146.4	163
two sand-cement column	198	256

2- for Sand-Brick column

Figure (17) illustrates the relationship between the bearing improvement ratio (q/cu)t/(q/cu)unt and the settling ratio S/Bfooting. The curve for the sand-bricks column exhibits an increase in magnitude, reaching its maximum value at a settling ratio (S/B footing) of 10%. The bearing improvement ratio (q/cu)t/(q/cu)unt is seen to be 1.96 at the point of failure. The curve of the two sand-brick columns exhibits an incremental rise, reaching its maximum value at a settling ratio (S/B footing) of 5%. The ratio of the bearing improvement (q/cu)t to (q/cu)unt is 2.75. The bearing improvement ratio (q/cu)t/(q/cu)unt at failure is found to be 2.44 for sand-brick columns. The curve of the four sand-brick columns exhibits an increase in magnitude, reaching its maximum value when the settling ratio (S/B footing) reaches 10%. The bearing improvement ratio (q/cu)t/(q/cu)unt is seen to be 3.6 at the point of failure. Table (10) presents a comprehensive summary of all the obtained results. The findings of the study indicate that the soil's enhancement ratio, when reinforced with sand-brick columns stabilized using a 20% percentage of sodium silicate, exhibited a 96% increase for a single column and a remarkable 261% improvement for four columns.

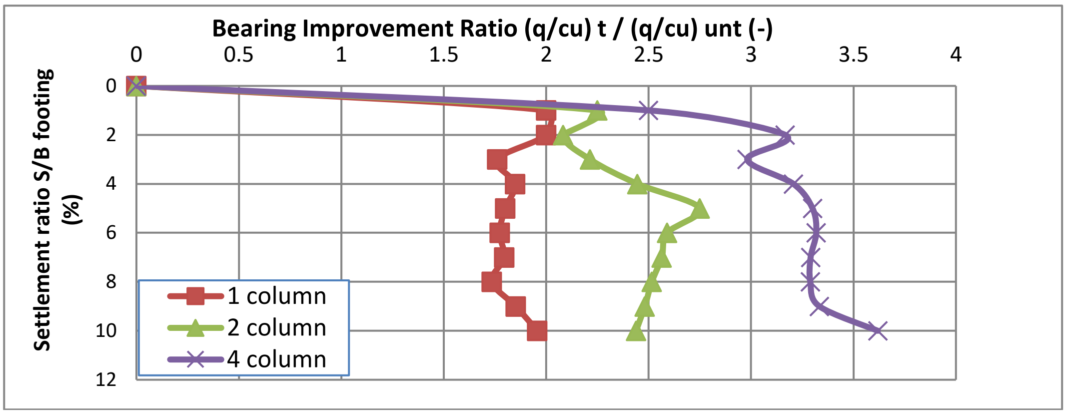

Figure (17): Bearing improvement ratio versus settlement ratio of soil treated with sand-bricks column treated with 20 % sodium silicate.

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

Iteam	Carrying Capacity Kpa	Improvement Ratio%
Unreinforced soil	56.99	----
Single sand-brick column	112	96
two sand-brick column	139	144
four sand-brick column	206.23	261

Conclusions

Based on the talks conducted in the preceding study and additional observations obtained during the experimental process, the following conclusions can be drawn:

1. The hardening durations of the reactions involving sand treated with cement and brick with sodium silicate exhibited variations, specifically classified as very quick, lasting for 7-9 hours, and 10-12 hours, respectively.

2. Sand treated with cemen,t has a higher cohesiveness than sand treat,ed with brick, in that order. It was discove,red that the best treated sand's cohesiveness percentages for each material were:

a- 20% cement and 20% sod,ium silicate by weight.

b- 20% of brick and 20% of sod,ium silicate by weight.

3. The results showed that the improve,ement ratio for the soil reinforced with sand colu,mns treated with different materials was:

a- The sand-cement columns, which were stabilized with a 20% percentage of sodium silicate, exhibited volumetric expansions of 163% for individual columns, 256% for pairs of columns, and 358% for groups consisting of four columns.

b- The sand-brick columns, which were stabilized with a 15% percentage of sodium silicate, achieved a 46% increase in stability for individual columns. When arranged in pairs, the stability increased to 144%, and when grouped in sets of four columns, the stability further increased to 261%.

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

a- The sand-cement column mixture exhibited an efficiency of 68% at failure for the group of two columns, but the efficiency was 43% for the group of four sand-cement columns.

b- The experimental findings indicate a decline in efficiency as the number of sand-brick columns increases while maintaining a constant spacing. Specifically, the efficiency of a configuration consisting of two sand-cement columns was observed to be 62% at the point of failure. In contrast, a configuration with four sand-cement columns exhibited an efficiency of 46%.

References

- Ahmed, S.F. (2015): "Investigation of Adding Organic Material Ashes to Remolded Soft Clayey Soils as a Stabilized Material", M.Sc. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.
- Al-Saoudi, N. K., Joni, H. H., & Al-Gharbawi, A. S. (2014). Single sand column stabilized by lime embedded in soft soil. Engineering and Technology Journal, 32(4), 1028-1037.
- ASTM D 1140. "Standard Test Methods for Amount of Material in Soils Finer Than the No. 200 Sieve", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
- ASTM D 2166. "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
- ASTM D 2435. "Standard Test Method for One-Dimensional Consolidation Properties of Soils", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
- ASTM D 2850. "Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soil", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
- ASTM D 698. "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (600KN-m/m3)", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
- ASTM D 854."Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
- Barksdale, R. D., & Bachus, R. C. (1983). Design and construction of stone columns, vol. I (No. FHWA/RD-83/026; SCEGIT-83-104). Turner-Fairbank Highway Research Center.
- Bergado, D. T., Anderson, L. R., Miura, N., Balasubramaniam, A. S., (1996): Soft ground improvement in lowland and other environments, Published by American Society of Civil Engineers, New York.
- McKelvey, D., Sivakumar, V., Bell, A., and Graham, J. (2004): " Modelling Vibrated Stone Columns in Soft Clay", Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, No.3, pp.137-149
- Najjar, S. S., Sadek, S., & Maakaroun, T. (2010). Effect of sand columns on the undrained load response of soft clays. Journal of Geotechnical and Geoenvironmental Engineering, 136(9), 1263-1277.

- Najjar, S. S., Sadek, S., & Maakaroun, T. (2010). Effect of sand columns on the undrained load response of soft clays. Journal of Geotechnical and Geoenvironmental Engineering, 136(9), 1263-1277.
- NYSDOT. (2013): "Geotechnical Design Manual", Chapter 14 Ground Improvement Technology, pp.14-43.
- Rao, L. and Madhira, M. (2010): "Evaluation of Optimum Spacing of Stone Columns", In Indian Geotechnical Conference. GEOtrendz ,pp. 16-18.