University of Thi -Qar Journal for Engineering Sciences
https://doi.org/10.31663/tqujes13.1.468(2023)
Vol 13.1(January2023)

ISSN :2664- 5572 (online)
ISSN:2664-5564 (print)
Available at http://jeng.utq.edu.iq
utjeng@ utq.edu.iq

Bearing Capacity Characteristics Of Sand Columns Stabilized With Recycled bricks and Glass Material In Soft Soil

Moamal Aqeel Abd-Alhusein [†], Dr. ALI MAJID AL-KINANI[‡]

† Civil engineering, College of engineering - Thi_Qar university, The Republic of Iraq, Muamal.A.H@utq.edu.iq.
† Civil engineering, College of engineering - Thi_Qar university, The Republic of Iraq, ali-majid@utq.edu.iq.

Abstract

The aim of the current investigation is to examine the usefulness of reinforced compacted soil with the utilization of sand columns constructed from recycled construction materials, notably brick and glass, which have been stabilized using colloidal silicate. The goal is to install columns that exhibit enhanced rigidity compared to the adjacent soil. The testing schedule has been divided into three separate sections with the purpose to produce columns. The first stage entails choosing the most suitable mixing proportions for each material and colloidal silicate, taking into account three distinct weight percentages of liquid colloidal silicate (10%, 15%, and 20%). The second methodology entails the investigation of augmented characteristics of recycled materials, namely brick and glass, by integrating them with different ratios of sand (10%, 20%, 40%, and 60% based on weight) %. The specimens received an investigation in the lab to ascertain their unconfined compressive strength. The experiment findings demonstrated that including (20 %) cement and (20 %) colloidal silicate led to a higher cohesiveness value in the composite of brick and sand. Furthermore, it was noted that mixing of a glass-sand mixture resulted in a higher mathematical outcome, namely when the mixture contained (40 %) glass and (15 %) colloidal silicate. The next step entailed employing a laboratory model to evaluate the effectiveness of each blend on sand columns. During this phase of the laboratory attempts, the model test took place on three separate occasions. The installation of a single column initially reinforced the soil. During the subsequent illustration, the reinforcement was achieved by employing two columns. In the third happening, there were an entire of four columns observed. The outcomes revealed that the soil's enhancement ratio encountered significant enhancements when subjected to reinforcing with sand-brick columns infused with colloidal silicate. Specifically, a single column exhibited a (163 %) enhancement, while the presence of two columns resulted in a (144%) increase. Notably, the most substantial enhancement of (261%) was observed when four columns were utilized. The empirical results obtained from the sand-glass column experiment demonstrate that the enhancement ratio observed was (39 %) for a single column, (82 %) for a pair of columns, and (145 %) for a configuration consisting of four columns.

Keywords: Sand column, colloidal silicate, brick, glass and bearing improvement.

1. Introduction

Iraq is a nation whereby a significant amount, about 30 to 40 percent, of its landmass is classified as soft saturated silty clay. The loose soil in question is widely distributed across the alluvial plain, extending from the northern vicinity of Baghdad and extending southwards until it reaches the Arabian Gulf. Based on the findings of the study conducted by Al-Saoudi et al**. [1],** it is anticipated that there would be significant advancements in the infrastructure of the region. Consequently, the undertaking of ground improvement assumes a crucial role within the construction sector. The utilization of sand columns has received significant international recognition as a viable, ecologically sustainable, and effective method for enhancing the load-bearing capacity and managing settlement in soft soil conditions. In certain instances, it has been noted as a cost-effective alternative to deep foundation systems **[2].** Sand columns are created by the displacement process, wherein sand is introduced into the soft clay foundation beneath. The phrase "composite ground" is frequently employed in academic discourse to denote to soil that has endured enhancement by the implementing of sand columns**[3].** Upon the application of a load, the pile undergoes deformation, which is distinguished by its tendency to bulge into the underlying subsurface strata. The deformation process outlined in this study facilitates the efficient distribution of stresses primarily within the upper layer of the soil profile, rather than transmitting these stresses to lower layers. Consequently, this particular activity enhances the soil's capacity to provide structural reinforcement to the pile [**4].** Consequently, the composite soil demonstrates the ability to enhance its strength and load-bearing capacity, while simultaneously reducing its compressibility. The utilization of sand columns has seen a significant increase in recognition over the past four decades as an attractive replacement to traditional sand columns**[5].** The bearing capacity and relaxing movement of soft soil that underwent reinforcing with sand columns are influenced by the influence of different variables. The analysis contains multiple variables, such as the area substitution ratio, the intensity and speed of load application, the size and arrangement of the sand columns after their assembly ,and the circumstances that impact the positioning of backfill materials**[6].** The positioning conditions of the backfill materials are of paramount importance in establishing the stiffness of the sand columns. According to the findings of Maakaroun et al. (2009) [**7**], the utilization of sand columns in soft clay soils has proven to be effective in enhancing several mechanical features, such as settlement, bearing capacity, and physical characteristics. The aforementioned improvement is achieved by mitigating the excessive accumulation of pore water pressure during loading situations.

And from researchers who have done similar studies Rajab (2013**) [8]** who aimed to enhance the geotechnical characteristics of so/ft soils by the utilization of sand columns and cement-stabilized sand columns as a means of introducing more rigid inclusions inside the soft soil stratum. The study determined that the optimal cement content for the floating type was 9% for models that underwent a 7-day curing period, resulting in a bearing improvement ratio of 3.19. For models cured for 28 days, the optimal cement content was found to be 7%, with a bearing improvement ratio of 3.08. On the other hand, for the end bearing type, the optimal cement content was determined to be 8% for models cured for 7 days, resulting in a bearing improvement ratio of 3.92. Additionally, an in-depth study was carried out by Najjar et al. (2011)[9], which encompassed a series of consolidated drained (CD) and consolidating undrained (CU) tests on specimens of Kaolin clay that were reinforcing with sand columns of dissimilar diameters. The clay samples revealed dimensions of 7.2 cm in terms of diameter and 14.4 cm in relation to height. The sand columns, with diameters ranging from 2.5 to 3.5 cm, were pedantically pop in into predrilled holes that penetrated the clay specimen completely. The researchers made an observation that the drained strength, when subjected to a specific confining pressure, consistently exhibited a higher magnitude when compared to the undrained strength.

2. Experimental work

2.1 Materials used

2.1.1 soil

The acquisition of soft clay took root in the southern region of the country of Iraq, namely within the city of Al-Nasiriyah situated in the Thi-Qar governorate. The soil sample was obtained from a subsurface layer that spans a vertical distance of 5.5 to 7.5 meter. To assess the chemical and physical aspects of the soil spacemen, a series of unvarying tests were conducted. The analysis of the physical countryside of a soil reflects procedures defined by the American Society for Testing and Materials (ASTM)[10], as depicted in Table 1. The observed parameters of clay during the consolidation test are presented in Table 2. The cohesion value (Cu) of the soft soil was determined to be 18.5 kN/m^2 by the execution of an unconfined compression test.

2.1.1.1 Physical tests

2.1.1.1.1 Particle size distributed

The clay specamens underwent hydrometer measurements in accordance with the ASTM D 422[11] standard. The objective of the experiment was to investigate soil samples containing particles smaller than 0.075 mm in size, as determined by their capacity to traverse a 0.075 mm (200 no.200 sieve). Figures 1 elucidates the distribution of soil particles, indicating that 2% of the particles are categorized as sand, 34% as silt, and 64% as clay.

2.1.1.1.2 Atterberg's limits

In order to gauge the firmness of the clay material, the clay specamens undergone limits set by Atterberg testing, namely the estimation of plastic limit (PL) and the liquid limit (LL), aforementioned to conducting any physical tests. The sympathy of the liquid limit of the soil was accomplished utilising the Casagrande method, which is consistent with the guidelines outlined in the ASTM-D423 standards. The determination of the plastic limit has been carried out uses the methodologies outlined in the ASTM-D424 standard, as depicted in Figure 2 and documented in Table 1.

2.1.1.1.3 Specific gravity

The test for the measurement of the specific gravity of the soft soil had been carried out using the techniques laid out by the American Institute for Testing and Materials (ASTM), as depicted in Figure 3 and laid out in Table 1.

2.1.1.1.4 Compaction test

The experiment has been carried out adopted the guidelines indicated in the ASTM-D698 standard to identify the ideal ratio of moisture and minimal dry unit weight. A visualization of the information collected during the experiment might be observed in Figure 4.

2.1.1.1.5 Consolidation test

The inspection of the clay's compressible material in the above study happened utilizing the typical consolidation test. The research encompassed the use of the standard consolidation test, as laid out in ASTM-D 2435, on a specimen of naturally-occurring soil that is cohesive. The Odometer ring has a diameter of 74 mm and a height of 2mm. The variables of soft clay soil measured during the hardening test are presented in Table 2.

2.1.1.2 Chemical tests

The chemical individualities of the soil are vacant in Table 1.

2.1.2 Sand

The fine aggregate used to conduct the current investigation was gathered from the Zubair locality in Basrah the Citizens and constituted of naturally produced sand. The fine aggregate was subjected to a sieving procedure utilizing a screen size of 4.75mm in order to distinguish the aggregate particles that possess a diameter exceeding 4.75mm. The qualities of the sand that was used are displayed in Table 3. The outcomes of the research indicate that the grading of the fine aggregate and the amount of sulfate were both found to be within the specified limitation mentioned in the Iraqi regulation No. 45/1984.

2.2.3 Colloidal silicate

Table (4) pageants the practical specifications of colloidal silicate.

2.1.4 Brick powder

The waste brick powder that was utilized in the lab experiment comes from garbage fire bricks composed of clay through an acquisition method. The waste brick powder utilized in the field test was acquired from waste fire clay bricks via the crusher stationed inside the testing facility at the College of Engineering, which is the University of Thi-Qer, as shown in Figure 5. The specimen displays a chromatic composition of red and yellow hues, accompanied by a fragile tactile quality. The measurement of the specific gravity of waterborne polyurethane (WBP) yielded a value of 2.76. The incorporation of WBP into the natural soil resulted in an observed rise in the specific gravity of the mixtures, as compared to the specific gravity of the natural soil alone. The chemical compositions are presented in Table 5 and Figure 5. The composition of WBP mostly comprises silica, constituting around 56.20% of its overall makeup.

2.1.5 Waste glass

The laboratory performed manual transportation of waste glass, and the portion that successfully went through filter #200 was utilized for the experiment.

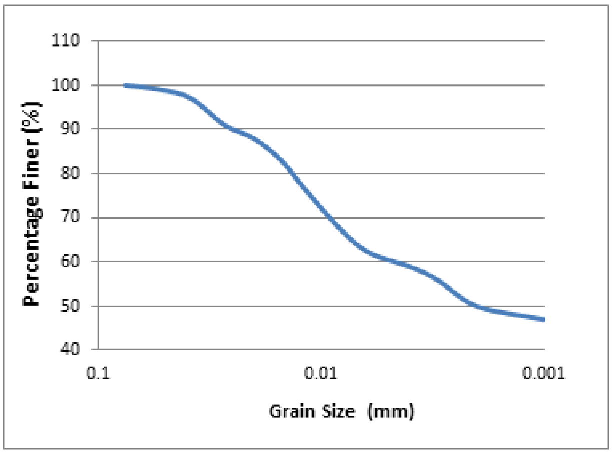


Fig. 1 Particle size distribution of soil sample

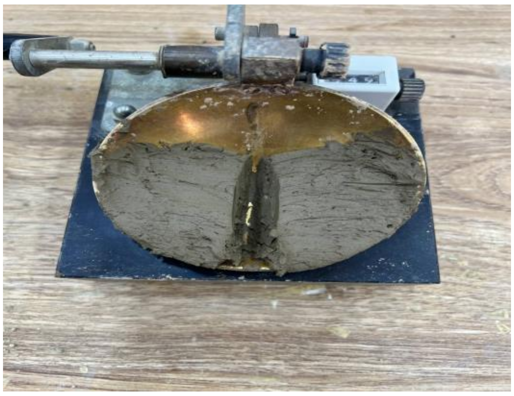


Fig.2 liquid limit test.

Fig. 3 Specific Gravity Test.

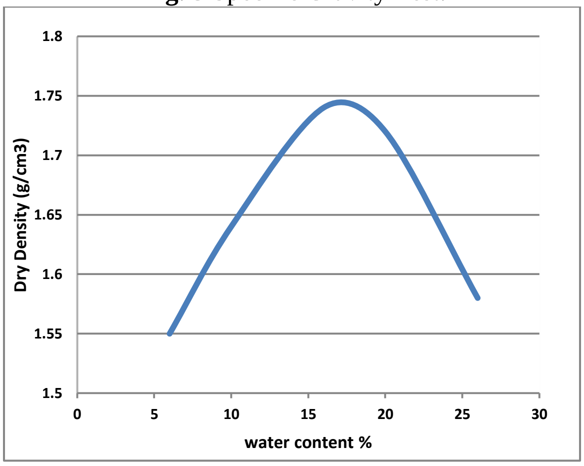


Fig.4 Compaction test results

Table 1 Physical and chemical properties of natural soft soil.

Test	Unite	Property	Standard
LL	%	42	ASTM D 423
Plastic Limit (P.L)	%	19	ASTM D 424
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)
Gypsum content	%	0.37	
SO3 Content	%	0.17	Salts Test for Soil
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	ASTMD 2435
Coefficient of Compressibility (kN/m²) (av)	7.12*10⁻⁴	
Coefficient of Volume Change (mv) (m²/kN)	3.4*10⁻⁴	
Compression Index (Cc)	0.37	
Swelling Index (Cr)	0.047	
Pre-consolidation Pressure (kN/m²) (pc')	62	

Table 3 Physical and chemical properties of sand

Index Property	Index Value	Standard
Max. Dry Unit Weight (g/cm³)	1.74	ASTM D 4253
Min. Dry Unit Weight (g/cm³)	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 colloidal silicate (EL Chemical Inc).

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

Fig.5 brick used for this study after crushing.

Table 5 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

2.2 Experimental program

The model tests were categorized into two distinct classifications. The initial set of model tests involved the examination of soil that had been fortified with sand columns that were stabilized using colloidal silicate and brick. This was done after careful consideration and determination of the optimal mixing ratio for these materials. The second study focuses on the utilization of colloidal silicate and glass to support soil reinforced with sand columns. This study examines the failure point, which is defined as settlement equivalent to 10% of the breadth (B) of the footing. This approach is deemed more appropriate for this task due to its ease of implementation. The flowchart illustrating the testing program for experimental work is depicted in Figure 6.

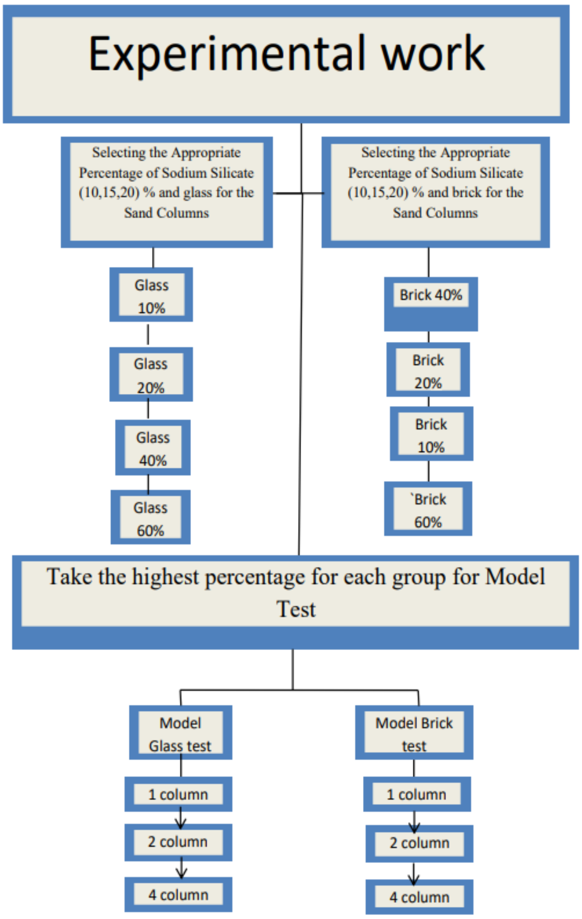


Fig.**6** Flow chart of the testing program.

3. Loading tests model

To conduct an extensive investigation of the capacity for bearing (BC) and obtaining behavior of a sand column under many different circumstances, it is crucial to precisely replicate the actual conditions throughout the experimental setup. To attain these objectives, a customized testing equipment has been came up with and build, encompassing a number of unique tools and accessories. The setup for testing depicted in Figure 7 is being used in current work.

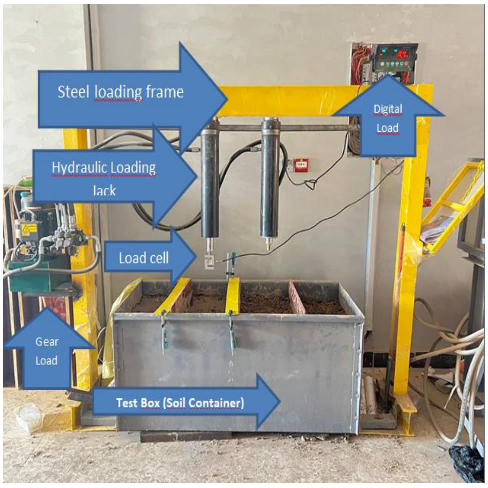


Fig.7 Laboratory test machine manufactured.

4. Construction of sand column

The construction the process of the columns of sand commenced shortly after the cleanup of the soil bed, utilising the area replace ratio (ar = 9%). The next phases will be adhered to:

1.supple conduit with an inside diameter measuring sixty-three millimeters was pushed into the dirt bedstead to the necessary depth, as represented in figure (8).
2.When trying to clean the soil from the extensible pipe, an automatic auger specifically designed for this task was applied.
Subsequently, the flexible tubing was delicately removed.
3.The sand has been combined with varying proportions of sodium silicate, chosen based on their ability to enhance the strength of the sand and other materials used in this investigation (see Figure 9).
4.In this investigation, the sand and rest material, which were the materials utilized, were combined with colloidal silicate mixtures. These mixtures were painstakingly placed into the hole in a total of five layers. To reach a unit weight of 1.7 g/cm3 in a condensed state, minor compression was applied using a shaft with a diameter of 25 mm. The cross-sectional representation of the model is shown in Figure 10.

The sand columns have an even diameter of 50 mm, with a constant space of 50 mm amongst every column, as measured from the center of one of the columns to the center of the adjacent column. In the opinion of Rao and Madhira (2010), it was suggested that for order to obtain optimal outcomes, the most suitable distance between sand columns should be within a range of two to three times the diameter of the sand columns. The determination of column length is frequently impacted by the length-to-diameter ratio (L/D), which commonly spans 6 to 10. Referring to the findings of Mckelvey et al. (2004), it was suggested that achieving a length-to-diameter (L/D) ratio of 10 doesn't end up resulting in significant improvements in the ability to bear loads. The area replacement ratio (AR) will usually vary from 0.1 to 0.4. However, it ought to be noted to acknowledge that in most cases, the replacement ratio exceeds 0.2. The area substitute ratios can be interpreted as suggesting that a proportion of 10 to 40 percent of the depleted soil is replaced with sand columns, with a significant number of applications opting for a replacement supply around 20% (Nysdot, 2013) [16]. The measurement of the area replacement ratio is dependent on the particular ratio that is being investigated. In order to fully analyze the bearing capacity (BC) and agreement behavior of a sand column under various parameters, it is imperative to replicate the real-world conditions using simulation. In order to accomplish this objective, it makes sense to employ a specialized testing apparatus that is equipped with a variety of tools and accessories. The present examination utilizes the field test design illustrated in Figure 7.

Fig.8 Soil preparation.

Fig.9 Preparation sand column.

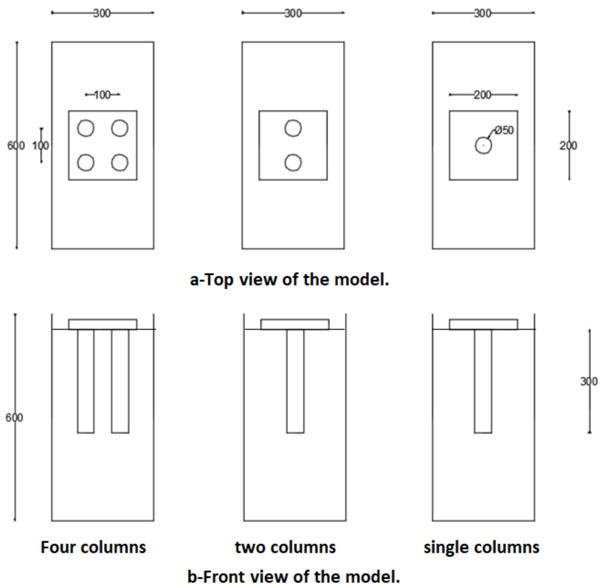


Fig.10 modeling test.

5. Selecting the appropriate percentages for cement and brick

For determining the best proportions of glass and brick, in combination with colloidal silicate, for the construction of columns employed in modeling experiments on compacted clay soil reinforced with sand strengthen columns remained stable with colloidal silicate (referred to as S-C column with CS) and Sand-brick the columns (referred to as S-B column and CS), an in-depth analysis is required. An experiment in the laboratory has been done to ascertain the compressive strength in open spaces of sand samples with various proportions of cement and particles silicate. The specimens underwent a cure period lasting three days. The method of experimentation is outlined in the accompanying manner:

1- brick

a) Ten percent of the bricks were treated with colloidal silicate solutions containing 10%, 15%, and 20% concentrations.

b) Twenty percent of the bricks were subjected to treatment with colloidal silicate solutions including 10%, 15%, and 20% concentrations.

c) Forty percent of the bricks underwent treatment with colloidal silicate solutions containing 10%, 15%, and 20% concentrations.

D) sixty percent of the brick composition consists of colloidal silicate, with varying concentrations of 10%, 15%, and 20%.

The inspection of the untainted compressive strength of all items has been carried out pursuant with the protocols described in the ASTM D-2850 regulation. A mold measures 8.5cm in height and 3.5cm in breadth was utilized. The tested samples are created by combining sand with different levels of colloidal silicate, precisely 10%, 15%, and 20%. After that, the product of this process had to be subjected to compaction within a mold using a three-layer approach. after the compaction process, the specimens were subjected to a curing phase within which they were encased with a nylon cloth.

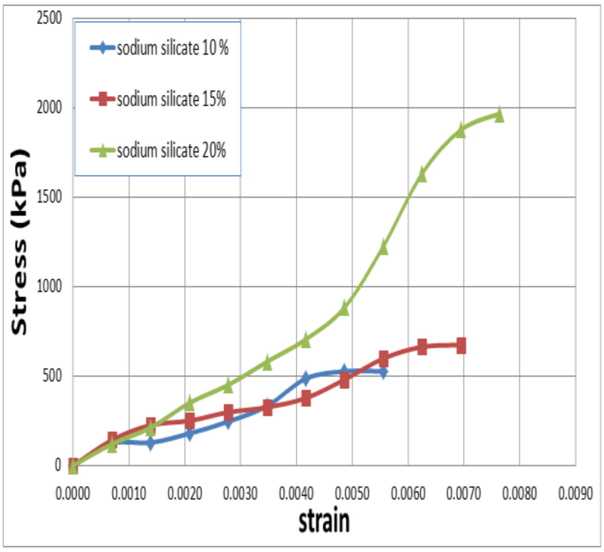
The data represented in Figure 11a indicate that there is an upward correlation between the concentration of colloidal silicate and the general compressive strength of the bricks. The research conducted for this study confirmed a significant increase in the unconfined compressive strength. More precisely, the strength jumped from 520 Kpa when the colloidal silicate proportion was at ten percent to 1965 Kpa when the concentration was increased to twenty percent.

The data presented in Figure 11b readily shows a substantial augmentation in the compressive strength without restriction as the proportion of bricks increased to twenty percent. The without restriction compressive strength demonstrated an enormous increase, increasing from 1232 Kpa when the colloidal silicate concentration was a tenth to 2648 Kpa when the colloidal silicate concentration was increased to 20%. Furthermore, it can be observed from Figure 10c that there exists an unmistakable positive correlation between the unconfined compressive strength and the colloidal silicate content. More specifically, as the proportion of bricks neared 40%, there became an observed rise in the compressive strength when unconfined from 1225 Pa to 1625 kPa. The unconfined compressive value demonstrates a decrease as the ratio of blocks reach sixty percent.

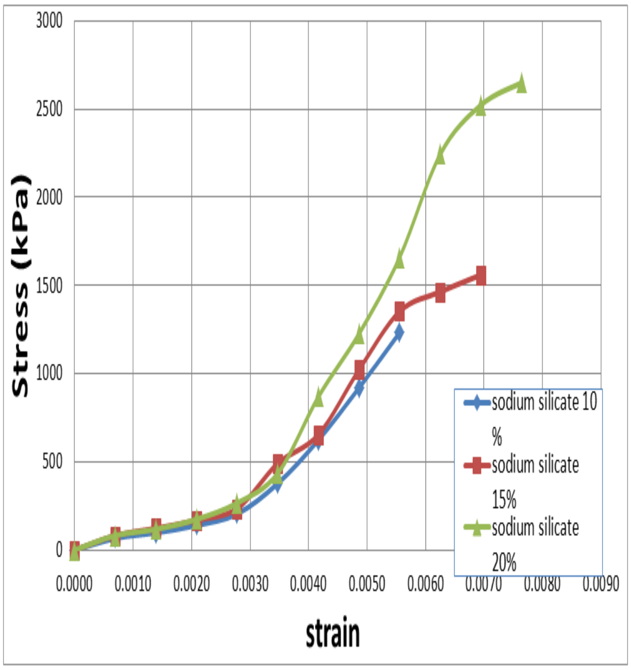
The diagram (Figure 11d) depicts a decline in pressure from 800 (KPa) when the colloidal silicate concentration is 10% to 550 KPa when the colloidal silicate concentration is increased to 20%. The observed reduction in pressure is correlated with an elevation in the content of colloidal silicate. The pressure decreases from 800 (kPa) when the colloidal silicate concentration is 10% to 550 kPa when the colloidal silicate concentration is 20%, as illustrated in Figure 11d.

Based on the data provided in Table 6, it is apparent that there is a positive correlation between the percentage of colloidal silicate in bricks and their unconfined compressive strength. This relationship holds even when the proportion of colloidal silicate remains constant. Nevertheless, this correlation between the two variables terminates once the bricks attain a threshold of 40% in terms of percentage. This is because the unconfined compressive strength experiences a reduction when the colloidal silicate content reaches 10%. The pressure experienced an increase from 525 (kPa) at a brick concentration of 10%, to 1232 kPa when the brick fraction increased to 20%. Following this, the pressure experienced a reduction to 1125 (kPa) concurrent with the attainment of 40% of the total number of bricks. The unconfined compressive strength of the bricks showed a positive correlation with the increase in the percentage of bricks. In particular, an increase in the amount of bricks from 10% to 20% resulted in a corresponding rise in the unconfined compressive strength from 672 to 1559. Following this, as the quantity of bricks was further increased to 40%, there was a subsequent decline in the unconfined compressive strength, resulting in a value of 1179. The aforementioned observations were conducted with the prerequisite that the content of colloidal silicate remained consistent at a level of 15%. Nevertheless, a decline in pressure was noted when the colloidal silicate content reached 20%. The pressure experienced a decrease from an initial value of 1965 kPa for bricks containing a colloidal silicate concentration of 10% to a final value of 550 kPa for bricks having a colloidal silicate concentration of 60%.

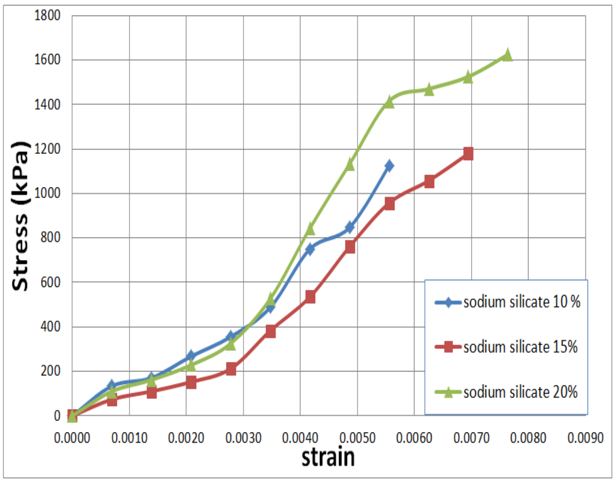
The most notable increase in percentage improvement was noted in Figure 10b and Table 6 at a colloidal silicate concentration of 20%, resulting in a 20% improvement. The compressive strength of the unconfined bricks was determined to be 2648 (kPa). The aforementioned ratio is employed in the experimental investigation carried out on a prototype of Compacted clay soil that has been strengthened with sand-brick columns.



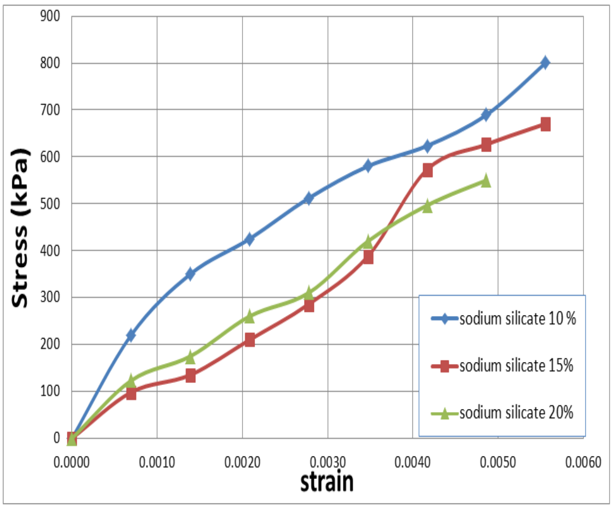
A



B



C



D

Fig. 11 Effect of colloidal silicate on unconfined compressive strength for sand mixing with different percentages of brick.
A:imapct of colloidal silicate with ten % brick.
B: imapct of colloidal silicate with tenty % brick.
C : imapct of colloidal silicate with fourty % brick.
D: imapct of colloidal silicate with sixty % brick.

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

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

2- glass

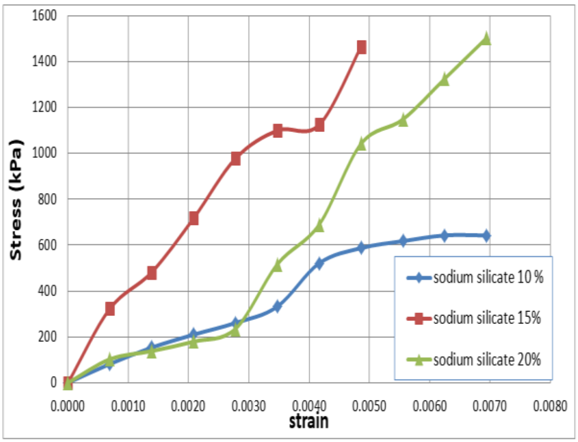
a- A proportion of ten % of glass is composed of colloidal silicate, with varying concentrations of ten %, fifteen %, and twenty %.

b- A proportion of 20% of glass is composed of colloidal silicate, with varying concentrations of ten%, fifteen %, and twenty %.

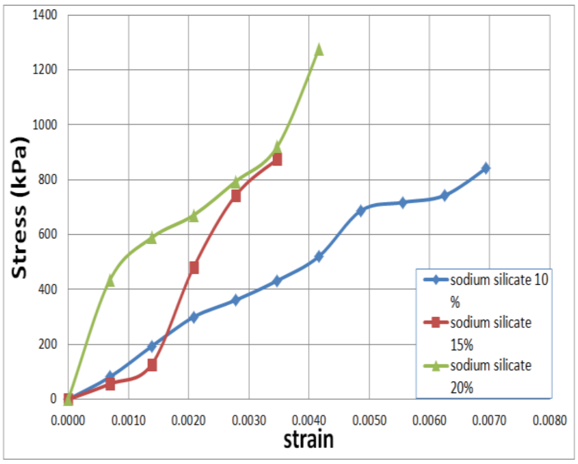
c- A significant proportion, specifically 40%, of the glass composition consists of colloidal silicate at varying concentrations of ten %, fifteen %, and twenty %.

d- A significant proportion, specifically 60%, of the glass composition consists of colloidal silicate at concentrations of ten %, fifteen %, and twenty %.

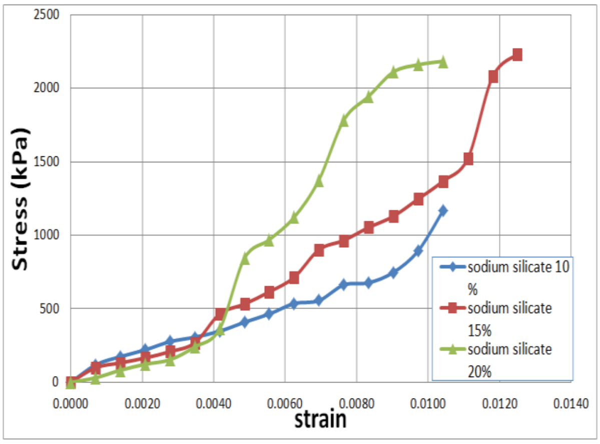
The data displayed in Figure (12a) emphatically shows the beneficial connection between the total amount of colloidal silicate with the compressive strength of the material unconfined. The compressive value demonstrates a notable rise, with values increasing from 644 Kpa when the colloidal silicate level is at ten percent, to 1500 Kpa when the colloidal silicate content is increased to twenty percent. The data presented in Figure 11b reveals a substantial improvement in without restriction compressive strength as the concentration of colloidal silicate increases from ten percent to twenty percent. This is apparent from the corresponding increase in strength values, which rise from 844 Kpa to 1277 Kpa. This phenomenon becomes apparent when the percentage of eyewear keeps constant at twenty percent. In addition, as depicted in Figure (12c), it is evident that the compressive strength without confines exhibited a rising pattern when the fraction of glasses neared forty percent and the concentration of colloidal silicate was elevated. A substantial improvement in tensile strength was observed, with values rising from 1168 Pa to 2229 Kpa, after approaching a colloidal silicate content of fifteen percent. Subsequently, the pressure reduced to 2183 Kpa as the volume of colloidal silicate was further increased to twenty percent. The findings exhibited in Figure 12d suggest an immediate connection between the percentage of glass content and the unconfined compressive strength. The general compressive strength exhibits a significant rise with an increase in the amount of colloidal silicate. For instance, it had been observed that at a colloidal silicate concentration of ten percent, the compressive strength in its unconfined form measures 465 kPa. The observed rise of pressure to 850 kPa is ascribed to the elevation of colloidal silicate content to fifteen percent. However, upon educating the concentration of colloidal silicate to twenty percent, the unconfined compressive strength reveals a decrease, ultimately attaining a value of 492 kPa. The analysis of the data presented in Table 7 reveals a clear positive relationship between the quantity of glass content and the broad compressive strength of glass materials. A favorable correlation has been seen between the compressive strength and the volume of colloidal silicate, until the glass content reaches a threshold of sixty percent. However, a significant decrease in compressive strength is observed when the proportion of colloidal silicate is reduced to 10%. The observed pressure exhibited a progressive increase, rising from 640 kilopascals (kPa) with a glass composition of 10% within the entirety, to 843 kPa when the glass content reached forty percent. Subsequently, the pressure saw a decrease to 465 kilopascals (kPa) due to the presence of glasses, which accounted for sixty percent of the total composition. The unconfined compressive property exhibited a decline from 1466 to 876 as the concentration of glassware increased from ten percent to twenty percent. Subsequently, upon reaching a glass concentration of four percent and a colloidal silicate concentration of 15%, the compressive strength without confines demonstrated an increase, reaching a value of 2229. However, a decrease in pressure was seen once the colloidal silicate content reached a concentration of twenty percent. The pressure exhibited a decline from 1504 kilopascals (kPa) in glasses containing a concentration of 10 percent to 492 kPa in glasses containing a sixty percent concentration. The most significant rise in improvement percentage was observed in Figure 11c and Table 7, specifically when the fraction of glasses was set at forty percent and the level of colloidal silicate was changed to fifteen percent. The freestanding compressive strength of the material was measured and found to be 2229 kilopascals (kPa). The previous proportion is employed in a model experiment conducted on consolidated clay soil that the has been augmented with sand-glass columns.



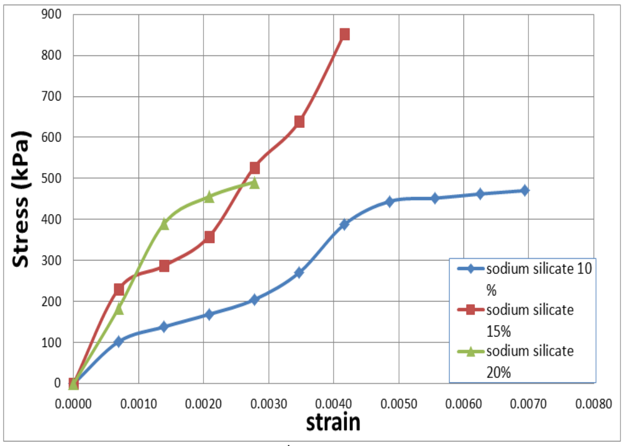
A



B



C



D

Fig. 12 Effect of colloidal silicate on unconfined compressive strength for sand mixing with different percentages of glass.
A:Impact of colloidal silicate with 10% glass.
B: Impact of colloidal silicate with 20% glass.
C : Impact of colloidal silicate with 40% glass.
D: Impact of colloidal silicate with 60 % glass.

Table 7 Effect of colloidal silicate on unconfined compressive strength for sand mixing with different percentage of glasses.

Percentage of glasses %	percentage of colloidal 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

Figures 13 to 15 indicate the link between the bearing enhancement ratio (q/cu)t/(q/cu) unit and the settling ratio S/Bfooting for sand columns produced with brick and glass ingredients, subsequently followed by stabilizer using colloidal silicate. The data provided in Figure 13 points out that the sand column has a solitary characteristic. The evaluation results reveal that the brick material provided superior performance when utilised as the treatment sand column. This is proven by the greater bearing ratio (q/cu) of 2.52 seen for the brick material, as opposed to the glass material which had a bearing improvement ratio of 1.94. A significant disparity exists between masonry and glass products in order mostly due to the significantly higher cohesiveness exhibited by cement in brick as instead of glass. Information presented in Figure 14 indicates that the effectiveness of bricks as a material surpasses that of glass. The bearing ratios of the two variables were 3.94 and 2.55, correspondingly. The inspection of the data presented in Figure 15 reveals a notable disparity between the results produced from bricks and glass, as indicated by a bearing ratio of 5.1. The piece of glass exhibits a measurement value of 3.41.

The present results are consistent with the findings documented by Juran and Riccobono (1988) [17], as well as Karim et al. (2018) [17].

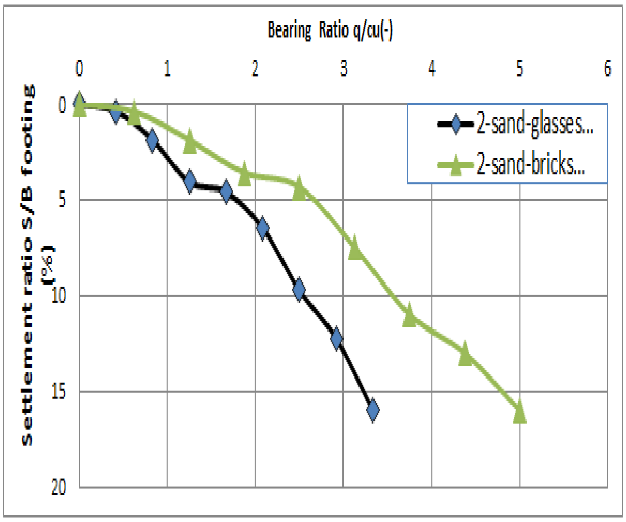


Fig.12 Bearing pressure versus settlement under foundation subjected to loading for different types of single sand column

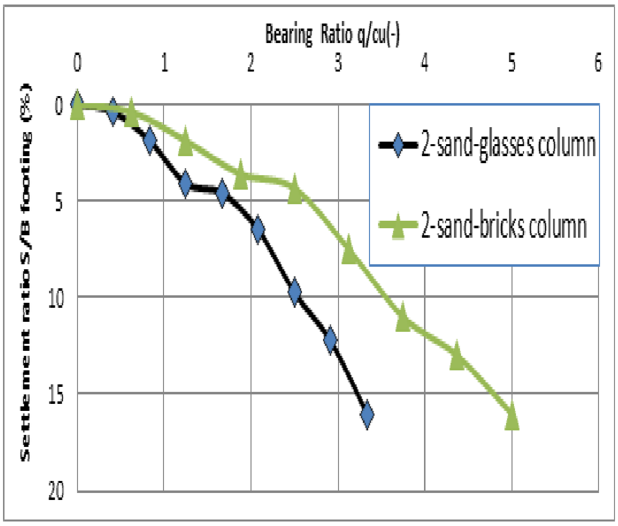


Fig.13 Bearing pressure versus settlement under foundation subjected to loading for different types of two sand columns

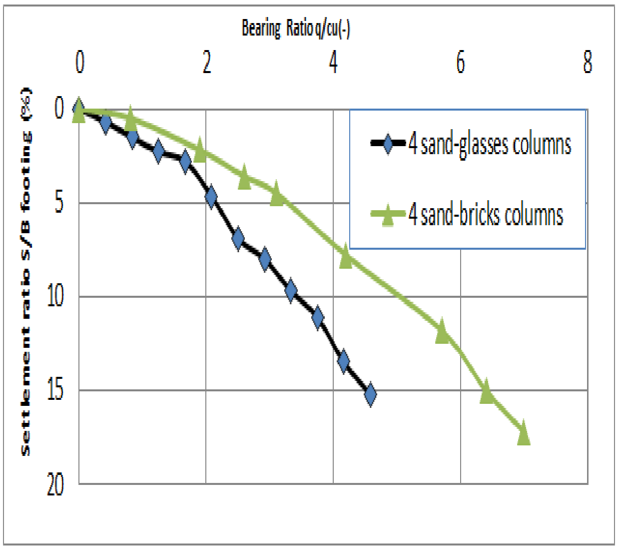


Fig.14 Bearing pressure versus settlement under foundation subjected to loading for different types of four sand column.

7. Degree of Bearing Improvement Ratio and Settlement Ratio

1- for Sand-Bricks column

Figures 13 to 15 exhibit the relationship between the bearing efficiency ratio (q/cu)t/(q/cu) unit plus the settlement ratio S/Bfooting for sand columns that had been built using brick and glass supporters, followed by stabilizers with colloidal silicate. Based on the data shown in Figure 13, it is evident that the sandy column indicates a solitary characteristic. The experimental proof indicates that the brick material shown greater durability when utilised as the treated sand column. The brick material demonstrated a higher bearing ratio (q/cu) of 2.72, which is whereas the glass material showed a bearing improvement ratio of 1.94. A significant disparity exists between masonry and glass materials, mostly attributable to the much greater cohesion exhibited by cement in brick as opposed to glass. The data laid out in Figure 14 suggests that the performance of brick as a material surpasses that of glass. The bearing ratios of the two variables were 3.93 and 2.54, respectively. The review of the data presented in Figure 15 reveals a notable disparity in the outcomes achieved from bricks and glass, as indicated by a bearing ratio of 5.2. The glass exhibits a measurement value of 3.42.

Table 8 Summary of S-B column stabilized with 10% colloidal silicate.

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

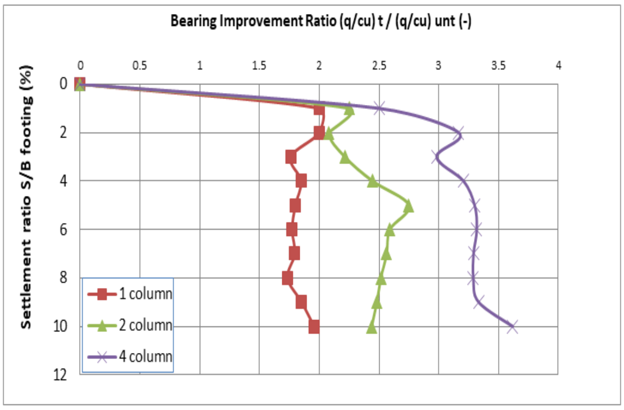


Fig. 15 Bearing improvement ratio versus settlement ratio of soil treated with sand-bricks column treated with 20 % colloidal silicate.

2- for Sand-Glass column

Figure 17 displays the link between the bearing strengthening ratio (q/cu)t/(q/cu) unit and settling ratio S/Bfooting. The sand-glass column has an identifying curve wherein its maximum magnitude is attained at a settlement ratio of approximately ten percent, signalling the threshold of failure. The measured ratio of the bearings improvement, represented as (q/cu)t/(q/cu) unit, is 1.40.

The sand-glass columns have a curves pattern that progressively rises, finishing at a settlement ratio (S/B footing) of ten percent before experiencing failure. The amount of difference between the improvement in bearing at time t and the improvement in bearing at the moment in the unit is 1.80. The sand-glass columns indicate a gradual pattern, culminating in a peak when the movement ratio (S/B footing) attains a value of 10%. At the point of failure, it is observed that the ratio entre the bearing's improvement (q/cu)t and the joint advance (q/cu)unt is 2.46, respectively. Table 9 provides an extensive overview of the findings. The results suggest that the addition of sand-glass columns, stabilized using a 15% content of colloidal silicate, significantly improved the soil's enhancement ratio. The implementation of a single column led to a significant rise in the enhancement ratio by 39%, and making use of four columns caused an impressive rise of 145 percent.

Table9 Summary of sand-glasses column stabilized with treated with 10% colloidal 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

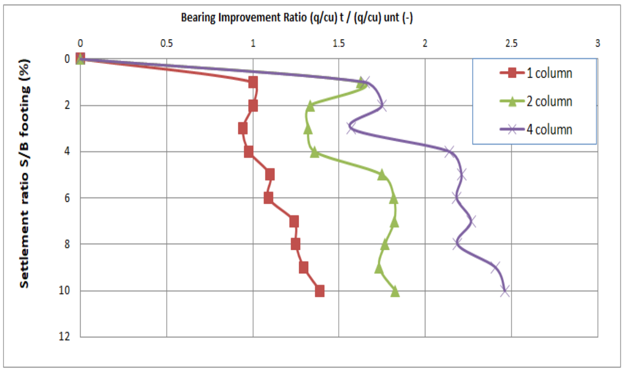


Fig.17 Bearing improvement ratio versus settlement ratio of soil treated with sand-glasses column treated with 20 % colloidal silicate.

The current findings align with the findings reported by Nazir and Azzam, (2010) [19], also Al-Khalidi et al. (2022) [3].

Conclusions

This paper presents a summary of the conclusions drawn from the analysis of the experimental test data. Based on the talks conducted in the preceding study and additional observations collected throughout the experimental technique, the following findings have been drawn:

1. The hardening durations of the reactions involving sand treated with glass and brick, in the presence of colloidal silicate, were seen to exhibit varying rates. Specifically, the hardening time for the sand-glass reaction was found to be quite rapid, taking around 9-12 hours. On the other hand, the sand-brick reaction demonstrated a slightly faster hardening process, with a duration of approximately 7-9 hours.

2. The addition of brick to sand results in a greater degree of cohesiveness compared to the addition of glass to sand. The investigation revealed that the sand with the most effective treatment exhibited cohesiveness percentages of 40% glass and 15% colloidal silicate by weight for each respective ingredient. The composition consists of 20% brick and 20% colloidal silicate, measured by weight.

3. The results of this research indicated that the increased strength ratio of the soil, which had been bolstered with sand columns and treated with various supplies, exhibited variations. The sand-glass columns, after stabilized with a fifteen percent level of colloidal silicate, demonstrated enhancement percentages of 39 percent for individual columns, eighty-two percent for pairs of columns, and 145 percent for a total of four columns. The sand-brick columns, which underwent stabilization using a colloidal silicate solutions with a concentration of fifteen percent, revealed consolidation rates of 46 percent, 144%, and 261% for single columns, pairs of columns, and groups of four columns, respectively.

4. The beneficial effects of sand columns, irrespective in pairs or quadruples, shown a decrease as the total amount of columns awoke while keeping the spacing constant. In the context of a sand-glass column mixture, it found that the efficiency of a group consisting of two columns was 67 percent at the point of failure, whereas the efficiency of a group consisting of four columns was determined to be 44 percent.
The study's findings indicate which there may be a decrease in the efficiency of the sand-brick column as the number of columns grows while maintaining the spacing between the columns constant. The study aimed at evaluating the efficiency of a sand-cement column configuration with two columns, which exhibited a failure point efficiency of 62 percent. However, when the number of columns was expanded to four, the efficiency lowered to 46 percent.

References

[1] Abbawi, Z. W. (2010): "Proposed Techniques for Improving Soft Soil underneath a Ballasted Track", Ph.D. Thesis, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.
[2] Chen, Z., Chen, J., Du, Y., Zhang, Y., Zhen, Z., Liu, Y., & Zhan, L. (2023). Seismic behaviors of tailings and recycled aggregate concrete-filled steel tube columns. Construction and Building Materials, 365, 130115.
[3] Al-Khalidi, E. E., Ahmed, M. D., Sheikha, A. A., & Alshamoosi, A. A. (2022, May). Assessment of Bearing Capacity and Settlement Characteristics of Compacted Clay Soil Reinforced by Sand Dune and Colloidal silicate Columns. In *International Conference on Geotechnical Engineering-IRAQ* (pp. 352-364). Singapore: Springer Nature Singapore.
[4] Brand, E. W. and Brenner, R. P. (1981) Soft clay engineering. Elsevier Scientific Published Company, Amsterdam.
[5] 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.
[6] 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.
[7] 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, 136,1263.
[8] Rajab, N.A. (2013): "Sand Columns Stabilized with Cement Embedded in Soft Soils", M.Sc. thesis, Building

and Construction Engineering Department, University of Technology, Iraq.

[9] Najjar, S.S., Maalouf, Y., Sadek, S. and Maakaroun, T., (2011): "Drained and Untrained Response of Soft Clays Reinforced with Fully Penetrating Sand Columns", Department of Civil and Environmental Engineering, American University of Beirut, Beirut, Lebanon.

[10] 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,.4.8.

[11] ASTM D 2166. "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM,.4,.8.

[12] ASTM D 2435. "Standard Test Method for One-Dimensional Consolidation Properties of Soils", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM,.4,.8.

[13] 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,.4,.8.

[14] 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,.4,.8.

[15] 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,.4,.8.

[16] Nysdot. (2013): "Geotechnical Design Manual", Chapter 14 Ground Improvement Technology,.14.

[17] Juran, I., & Riccobono, O. (1991). Reinforcing soft soils with artificially cemented compacted-sand columns. Journal of geotechnical engineering, 117(7), 1042-1060.

[18] Karim, H. H., Samueel, Z. W., & Mohammed, M. S. (2016). Sand column stabilized by silica fume embedded in soft soil. Engineering and Technology Journal, 34(6 Part (A) Engineering).

[19] Nazir, A.K. and Azzam, W.R. (2010):"Improving the Bearing Capacity of Footing on Soft Clay with Sand Pile with/without Skirts", Alexandria Engineering Journal, 49,. 371.