THE ROLE OF GRANULAR MATERIALS FOR THE STRENGTH OF GRANULAR PILES FOR SOFT GROUND IMPROVEMENT

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ABSTRACT

Granular piles, which consist of granular materials, are widely used as a soil improvement technique for increasing the bearing capacity of soft soil and reducing the settlement. In this study laboratory tests were conducted to find out the effectiveness of granular materials and the granular piles constructed to improve the soft soil conditions. To overcome the limitations of the conventional foundation systems, the development of modern foundation practices, namely ground improvement techniques have been proved to be viable both technically and economically. Installing granular pile as a ground improvement technique has been adopted as one of the most cost effective and efficient methods for its ability in increasing the bearing capacity and reducing the settlement. This study mainly deals with the performance of the granular materials used for the construction installed in soft ground. Reconstitute clay is prepared into a plastic cylindrical mold. For investigating the performance of the granular materials, sand piles were constructed of coarse sand and the stone columns were constructed by stone chips and sand mixing in equal ratio. The load tests were done individually for all the cases. The results found from the study indicate that load bearing capacity of soft ground can be increased significantly by installing sand pile and stone column. The laboratory test results show that the load carrying capacity of the improved ground is averagely 5.53 times more for the ground treated by sand column and averagely 6.09 times more for the ground treated by stone column, in comparing with the untreated ground. From this study, it can be concluded that although the combined using of sand and gravel in equal ratio gives slightly higher improvement, both sand and gravel can be effectively used for construction of granular piles.

Keywords: *Granular Piles, Ground Improvement, Suitability of Granular Materials, Bearing Capacity, Load vs. Settlement*

1. INTRODUCTION

1.1. General

Granular Piles, which consist of granular materials, are widely used as a soil improvement technique for moderate increase in bearing capacity of soil and reduction of settlement. Granular piles are found economically viable and environmentally acceptable ground improvement technique (Santos2017). In this study laboratory tests were performed to determine the effectiveness of granular piles constructed to improve the poor soil condition. This chapter contains the historical background with scope and objective of the study.

1.2. Historical Background

The oldest historical evidence makes us know that the French military engineers used granular piles in 1890's. Sand compaction piles were constructed in Japan during the same period, i.e. between 1830 to 1850 (Ichimoto 1981). However, modern organics of the use of the stone columns or granular piles foundations truly began in 1930's in Germany as a bi-product of the technique of vibro-floatation for the compaction of cohesion less soils both above and below the water table. In 1955, large diameter compacted sand columns were built in Japan using the composer technique (Aboshi et al. 1979). Murayama developed the vibro-composer method of sand compaction piles in Japan in 1958 (Murayama 1962). Since the beginning of using the granular piles as ground improvement technique, various researchers have developed the theoretical background, design consideration and installation techniques. Among the different methods of ground improvement techniques like preloading, sand drains, granular piles, lime stabilization and vacuum pressure, granular piles are most effectively used for its higher drainage ability (Elsawy and El-Garhy 2017).

At first, Thornburn and Mac Vicar (1968) suggested an empirical design for composite ground constructed by vibro-floatation method. This was followed by development of a rotational method by Gibson and Anderson (1961) to assess the limiting stress of a cylindrical cavity, which, is used to obtain the load carrying capacity of compound ground. Since then, several analytical and numerical methods for the deformation of the supporting capacity and load settlement behavior of granular piles reinforced ground have been developed. Various laboratory tests have been performed for investigating the load settlement behavior and failure mechanism of granular piles to assess the engineering application of this ground improvement technique.

Vibro-floatation method is adopted widely in Europe and USA. In Belgium, rammed sand column and rammed stone were constructed by Franki Pile Company. Debon Project Engineering Pvt. Limited, a consulting firm of India has developed various methods of constructing Rammed Stone Columns. Sand Piles have been used successfully for improving the soft ground in the coastal region of Bangladesh. Recently, a significant number of sand piles were installed in a small-scale water resource project for six vent regulator's foundation weak soil treatment in the southwestern region of Bangladesh (Alamgir and Zaher 1999a and 1999b). In this project very soft fine-grained soil was improved by the sand piles by using vibro-displacement installation technique.

1.3. Soft Ground

In general, the following soil types are considered as soft ground- clayed soil which have large fractions of particles as fine as silt, clayed soils which have high moisture content, peat foundation and sand deposits with a loose state under water table. From a geological view point, weak grounds which are accumulated naturally into alluvial layers in alluvial plains, and swamps or man-made lands which are reclaimed around the off-shore areas, lakes and marshes are likely susceptible to formation as soft ground. From a mechanical point of view, soft grounds are soil deposits, which have high compressibility but low strength.

1.4. Sand Pile

Sand compaction piles are granular columns consisting of granular materials compacted by heavy hammer. In this process, a steel case is driven into the designed level of weak ground with the help of heavy vertically aligned vibratory hammer placed at the top of the piles. Then, the casing, filled with the sand is withdrawn partially and partially retrieved with the vibratory hammer. The bottom of the casing is open during the withdrawal process and sand backfilled the voids in the ground. The casing is completely removed from the soil and backfilling prevents the collapsing of soil surrounding the pipe. Soil becomes densified during this process and bearing capacity of the soil is increased. Thus, sand piles stabilize the soft clay. It is also used for ground improvement to increase the load carrying capacity and to reduce the settlement and liquefaction potential of soft ground (Barksdale and Bachus, 1983). Sand column can be used economically where the initial soil resistance (N-value) is very low.

1.5. Stone Column

Stone columns are vertically constructed piles filled with compacted gravel or sand. Sometimes mixture of stone chips and sand can be used to construct stone columns. Stone columns are used to increase the bearing capacity of the soft ground, increase the stability of soil against the rotational failure and decrease the settlement and liquefaction potential. Differential settlement of the soil can be reduced effectively by installing stone column. The performance of the stone column significantly influenced by the diameter of the column. The larger diameter gives the higher value of resistance. For sand column installation, an open or close ended pipe is driven into the ground and stone is placed at the bottom end of treatment. Generally, two techniques like vibration and ramming are used for installing stone column. Between them, vibration technique is more expensive than that of ramming. Stone column increase load bearing capacity of soft ground by increasing density and inserting reinforcement affect.

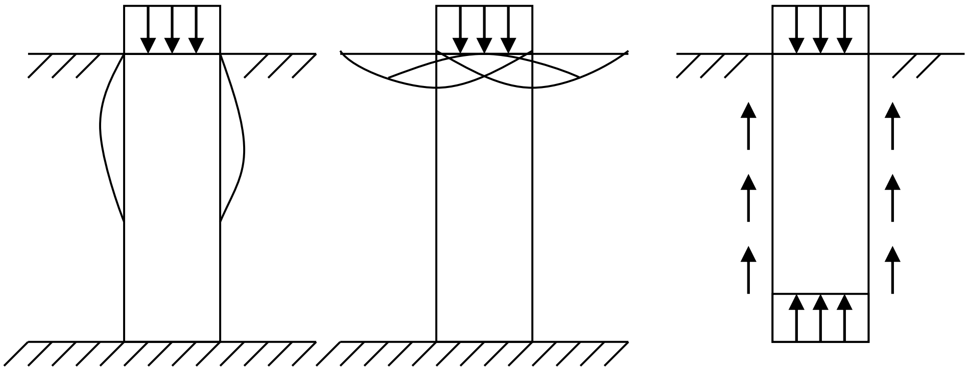
1.6. Some Case Studies of Sand Piles

Kimura et al. (1985) conducted centrifuge tests to identify the mechanical behavior of clay treated by sand compaction piles under inclined loading. It was found that the bearing capacity of soil treated by sand compaction piles was increased by 200 to 700% and it was extremely effective in reducing the lateral displacement of caisson. Hughes et al. (1975) constructed a field test on a single stone column to investigate its performance and also to verify the theory proposed by Hughes and Withers (1974) on filed scale. Vibro-replacement technique was taken to construct the column. The cylindrical stone column was installed at 10m long and 0.65m in diameter which was estimated on basis of stone consumption. Cambridge supplemented a standard site investigation (Worth and Hughes 1973) and the Menard Pressure- meter tests provided the basis soil parameters. Then the stone column is tested by loading. In this case it is seen that the column substantially improves the bearing capacity of the natural soil. It was also observed that the prediction is excellent if allowance is made for transferred of load from to clay through side shear and accurately designed column size. They commented that an accurate estimate of the column diameter is a major factor that significantly affect the measurement of ultimate load and the settlement characteristics.

A case study on improving soft ground soils by sand compaction piles was conducted by Alamgir and Zaher (1999). In the study, they examined the effectiveness of the sand compaction pile to improve the bearing capacity of soft ground of Bangladesh. They also investigated whether the ground improvement by sand compaction pile was effective for water control structures. 765 sand piles of 0.02-meter diameter and 8.8 to 9.4-meter-long were installed in squire grid at 0.75 meter spacing by vibro-displacement method to improve the site. A typical sand of Bangladesh, named Sylhet sand was used for installation of the sand piles. To investigate the amount of ground improvement, they conducted sub-soil exploration and found that the installation of sand compaction piles substantially increased the bearing capacity of natural ground.

1.7. Failure Mechanism

Generally, granular piles are constructed fully penetrating a soft soil layer overlaying a firm stratum. It may be constructed also as floating piles with their tips embedded within the soft clay layer. Granular piles may fail individually or as a group. The failure mechanism for a single pile is illustrated in Figure 1. indicating the possible failure as a) bulging, b) general shear, c) sliding. For pile groups, additional failure mechanism such as lateral spreading and shear failure across the granular pile cross-section may occur.



a) Bulging failure b) Shear failure c) Punching failure

Figure 1: Failure mechanism of a single stone column in a homogenous soft layer.

2. MATERIALS AND METHODS

This study deals with the efficiency of using different types of granular materials to construct granular piles, a particular improvement technique used to upgrade the soft soil condition. In this process reconstitute clay media was prepared for the test. Physical properties of soils were identified through laboratory tests. Then, sand piles and stone columns were installed into the soils to evaluate the improvement of load carrying capacity. The ultimate load bearing capacity of the treated ground was obtained from settlement tests. Finally, the results were compared to calculate the value of improvement in terms of load bearing capacity for treated grounds.

2.1. Collection of Materials

In this study, clay media is used to construct the pile & then a fixed weight is given to the pile for certain period to drain water. Then they are treated by sand & the combination of the both sand and stone chips. The clay sample was collected from a construction site for the academic building of Khulna University of Engineering and Technology (KUET) at a depth of about 12 ft below the ground level. The coarse sand is used in the study and is collected from the engineering material laboratory of KUET.

2.2. Preparation of Test Set Up

The equipment used for the laboratory study are:

- Plastic cylinder
- Wooden box support
- Slurry mixing machine
- Concrete cylinder

Plastic cylinder:
Nine plastic cylinders of 45.72 cm height & 20.32 cm diameter were used.
Wooden box support: Nine wooden boxes were used to support the concrete cylinder.
Concrete cylinder: Solid concrete cylinder of 45.72 cm height and 20.32 cm diameter is made of ratio of 1:2:3 to consolidate soil slurry enclosed by plastic cylinders.

Soil slurry machine: Slurry mixed machine was used to prepare slurry.
Marshal Testing Machine was used for load test of treated and untreated soils.

2.3. Preparation of Reconstitute Clay Media

Collected clay media is kept with water into a plastic cylinder for some days. Then the soil is mixed properly with water by the machine. This soil slurry is poured into the plastic cylinder into three layers. Total nine cylinders are filled with soil slurry. Then the soil slurry is kept without loading for five or six days for the drainage of water of its own weight. Concrete cylinder of weight 68 kg is then placed on the soil slurry enclosed by plastic cylinder placed on the wooden box for 28 days. Thus, the soil slurry is kept under pressure by weight for final consolidation.

2.4. Moisture Content Test

The moisture content is defined as the ratio of the weight of water to the weight of soil solid, generally expressed as a percentage. The moisture content is shown in Table 1.

Table 1: Moisture Content

No.	Can + Wet sample (gm)	Can + Dry sample (gm)	Can (gm)	Weight of Sample (gm)	Weight of Water (gm)	Moisture Content (%)
Sample1	88.9	73.2	22.2	51	15.7	30.8
Sample2	88.2	72	22.2	49.8	16.2	32.5
Sample3	96.9	72	22.2	56.4	18.5	32.8

2.5. Grain Size Analysis by Hydrometer Method

The grain size distribution curves are useful for soil classification and they are used in designing soil filters. The hydrometer is an apparatus, which determines the densities of a liquid or a liquid mixture. The distribution of particle size, finer than 0.074 mm can be measured by sedimentation analysis using a hydrometer and thus help to obtain the grain size distribution curve. The grain size distribution is presented in Figure 2 and Table 2.

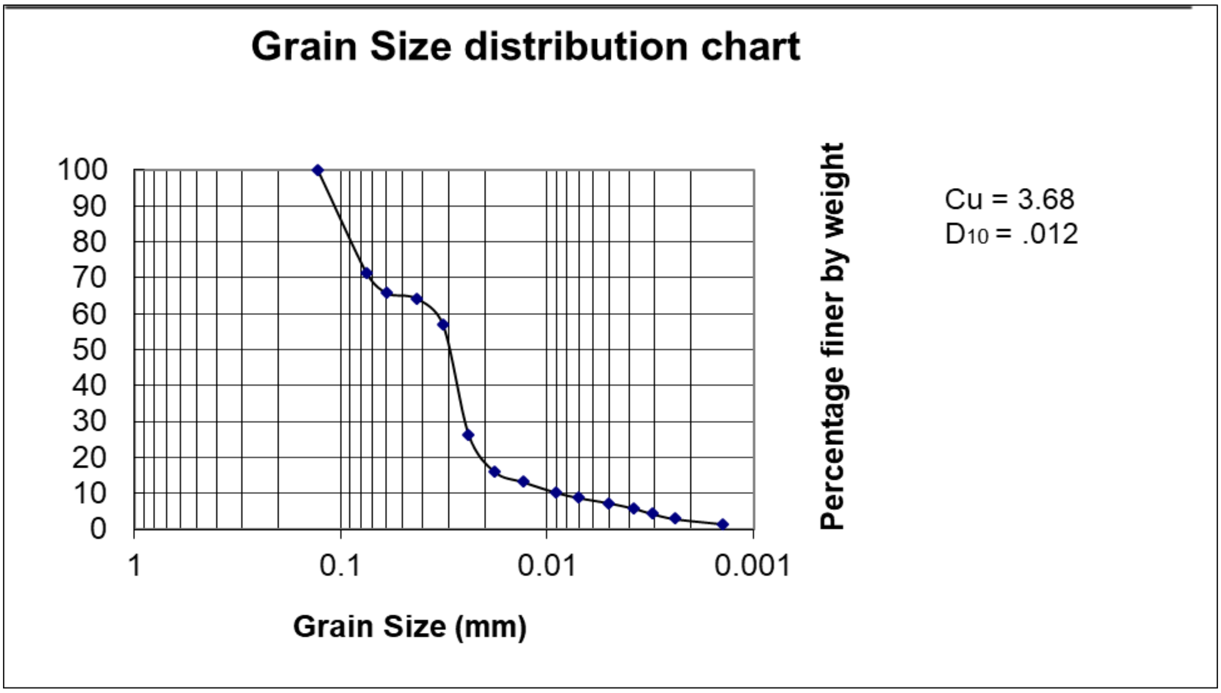


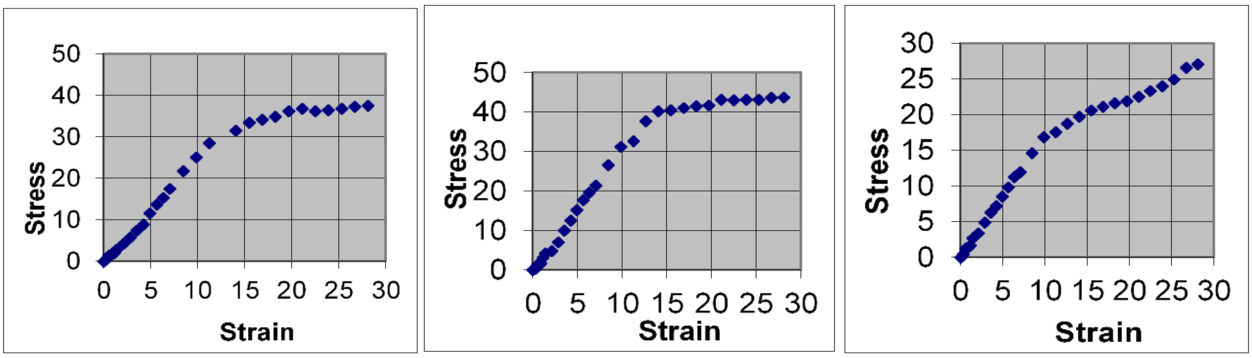
Figure 2: Grain size distributions by Hydrometer Analysis.

2.6. Unconfined Compression Strength (q_u)

Unconfined compressive strength can be measured by unconfined compressive test. In this test, no confining pressure acts on the specimen. The stress-strain diagram for 3 samples are illustrated in Figure 3.

Table 2: Grain Size Distribution

Elapsed Time (min)	R	Rw =100* (r-1)	Temperature °C	R-Rw	N (%)	Zr (cm)	√(Zr/t)	D (cm)	N
0.25	46	-1	22	23	71.85	10.6	6.51	.075	71.18
0.5	45	-1	22	22.5	70.28	10.8	4.65	.06	65.71
1	44	-1	22	22	68.72	11	3.32	.043	64.25
2	39	-1	22	19.5	60.9	12.1	2.46	.032	56.94
4	18	-1	22	9	28.11	14.3	1.89	.024	26.28
8	11	-1	22	5.5	17.18	15.5	1.39	.018	16.06
15	9	-1	22	4.5	14.06	15.8	1.03	.013	13.14
30	7	-1	22	3.5	10.93	16.2	0.73	.009	10.22
60	6	-1	22	3	9.37	16.3	0.52	.007	8.76
120	5	-1	22	2.5	7.81	16.5	0.37	.005	7.3
180	4	-1	22	2	6.24	16.6	0.3	.0038	5.83
300	3	-1	22	1.5	4.68	16.7	0.24	.0031	4.37
480	2	-1	22	1	3.12	16.8	0.19	.0024	2.92
1440	1	-1	22	.5	1.56	17.1	0.11	.0014	1.46



a) Sample-1 b) Sample-2 c) Sample-3

Figure 3: Stress vs Strain Diagram for a) Sample-1, b) Sample-2 and c) Sample-3

The value of unconfined compression strength for Sample-1, Sample-2 and Sample-3 are 37.5 kPa, 44 kPa and 26 kPa respectively.

2.7. Consolidation Test

According to Tarzaghi (1943), reducing water from the saturated soil mass without replacing the water by air is termed as consolidation. Graphs for consolidation test are shown in Fig. 5. Consolidation rate is directly related to the permeability of the soil, because permeability indicates the speed at which water is squeezing out. It determines the required soil data in the laboratory by which the rate of settlement can be evaluated. Figure 4 illustrates the void ratio vs effective pressure curve for three samples. Void ratio vs. effective stress curves indicate the accurate representation of the behavior of the soil. However, during laboratory preparation, most of the soils are sensitive to the disturbace.

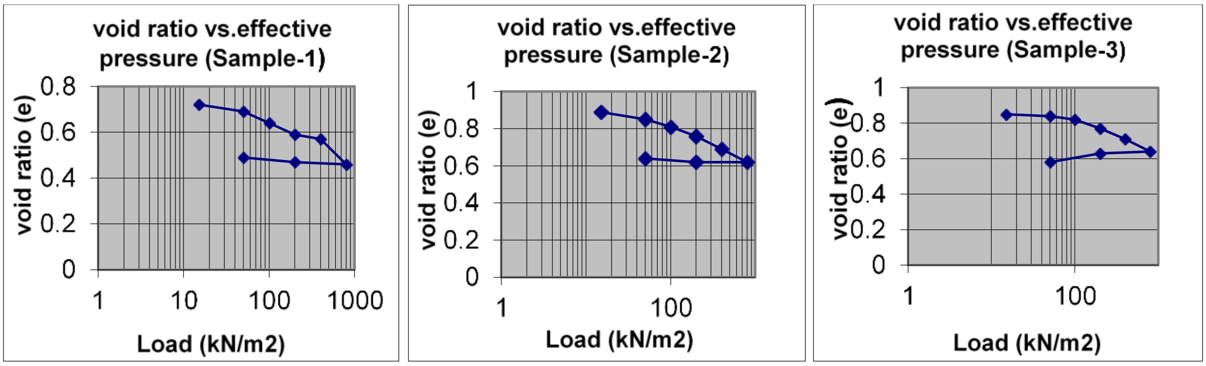


Figure 4: Void Ratio vs. Effective pressure

2.8. Properties of Granular Materials

In this studies Sylhet sand & stone chips are used for the construction of granular piles. The grain size distribution curve for the granular materials is shown in the Figure 5.

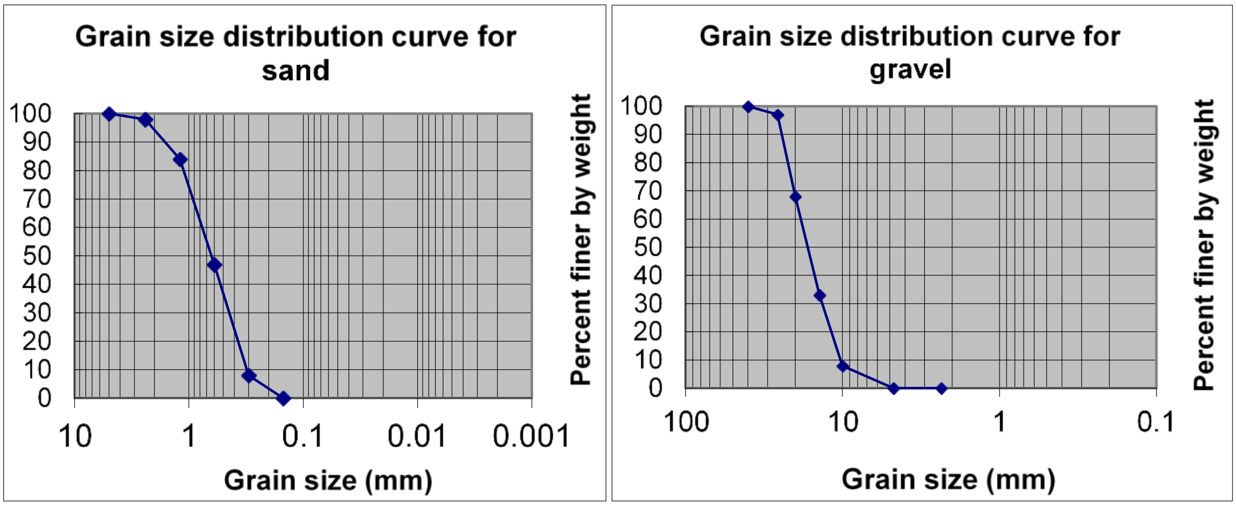


Figure 5: Grain Size distribution curve for Sand and gravel

3. RESULT AND DISCUSSIONS

3.1. Installation of Granular Piles

First wooden support boxes are placed at a suitable height so that the drainage of water has been completely done. Then nine plastic cylinders of 40.72 cm height & 20.32 cm dia are placed on the box support. The collected soil samples were mixed thoroughly with water to get uniform slurry. This slurry is then poured into the plastic cylinder.

After about one week of pouring the slurry into the cylinder, a concrete cylinder of the same dimension of the plastic cylinder (68kg weight) is then placed on the clay slurry and kept it for 28 days. It was expected for the completion of primary settlement and finally reconstitutes clay media was formed.

Load test is done in three different grounds. They are-

1. Untreated ground
2. Treated ground with sand
3. Treated ground with sand and gravel

3.2. Sand Pile

Three soil samples were treated by sand. First reconstitute clay column was made of 20.32 cm & 35.5 cm height. In this case, sand piles were installed at the middle of the untreated ground for improvement. A steel casing of 7.62 cm diameter is driven to 35.5 cm depth of clay media inside the plastic cylinder. The sand is placed in three layers and each layer is compacted by hammer (5.5lb) and free fallen from 18" height. 15 blows are given in each layer during the placing. Then load test is done for measuring the settlement. Schematic diagrams of the loading condition on sand and stone column are illustrated in Figure 6.

The following common instruments are used to install a sand pile-

- Steel Scale
- Soil Cutter
- A steel casing

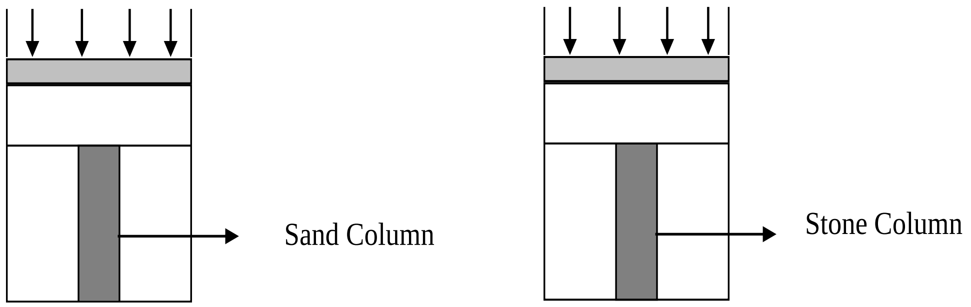


Figure **6:** Schematic diagrams showing the loading condition on sand and stone column

3.3. Stone Column

Steel Column was constructed by driving a steel casing of 7.62 cm diameter at a 35.56 cm depth at the middle of the plastic cylinder. Clay is thus removed from the inside of the reconstitute clay and the hole is filled with sand and stone chips in a equal ratio of three layers and each layer is compacted with hammer.

3.4. Set Up for Loading Test

The load bearing capacity of the untreated ground and treated ground is obtained from the loading test. The load test is done in Marshal and Universal testing machine.

Untreated Ground

In this case the untreated reconstitute clay media is directly taken for load test. Load test is completed for three samples. Before setting this in machine, the cylinder containing the clay media was fixed by rod so that the clay could not coming out while load is given to measure the ultimate load bearing capacity.

Sand Pile

The reconstitute clay media treated with sand was also set in the machine after fixing the cylinder with wooden box and load bearing capacity is measured in similar way,

Stone Column

Ground improved by the stone chips and gravel was also set in the machine similar way and the load carrying capacity is measured.

3.5. Settlement of the Ground Due to the Weight of the Concrete Cylinder

The settlement of the reconstitute clay for the fixed weight of the concrete (68kg) is measured. The settlement of the clay media vs. duration (days) is shown in Figure 7.

3.6. Load Bearing Capacity of Untreated Ground

The load bearing capacity of untreated ground is obtained from laboratory test. The results are graphical presented in Figure 8. The ultimate load bearing capacity of the untreated ground is found 120.22 kPa, 135.53 kPa and 117.14 kPa for sample 1, 2 and 3 respectively corresponding to the settlement of 24 mm.

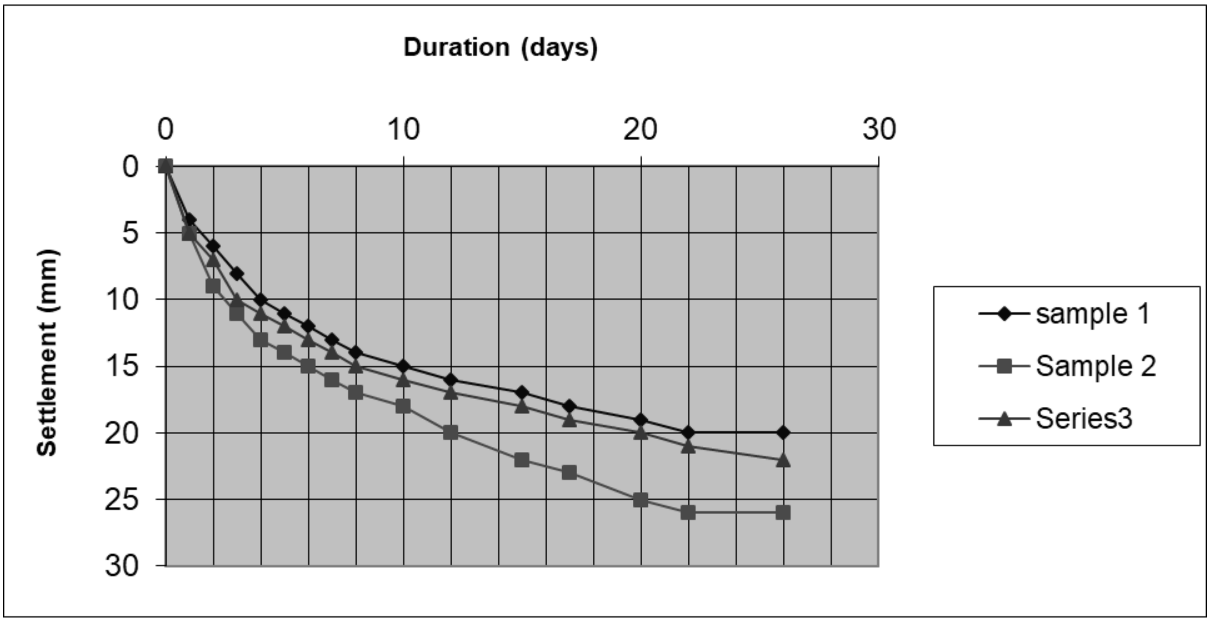


Figure **7.** Settlement of soils for constant weight of concrete block (68kg)

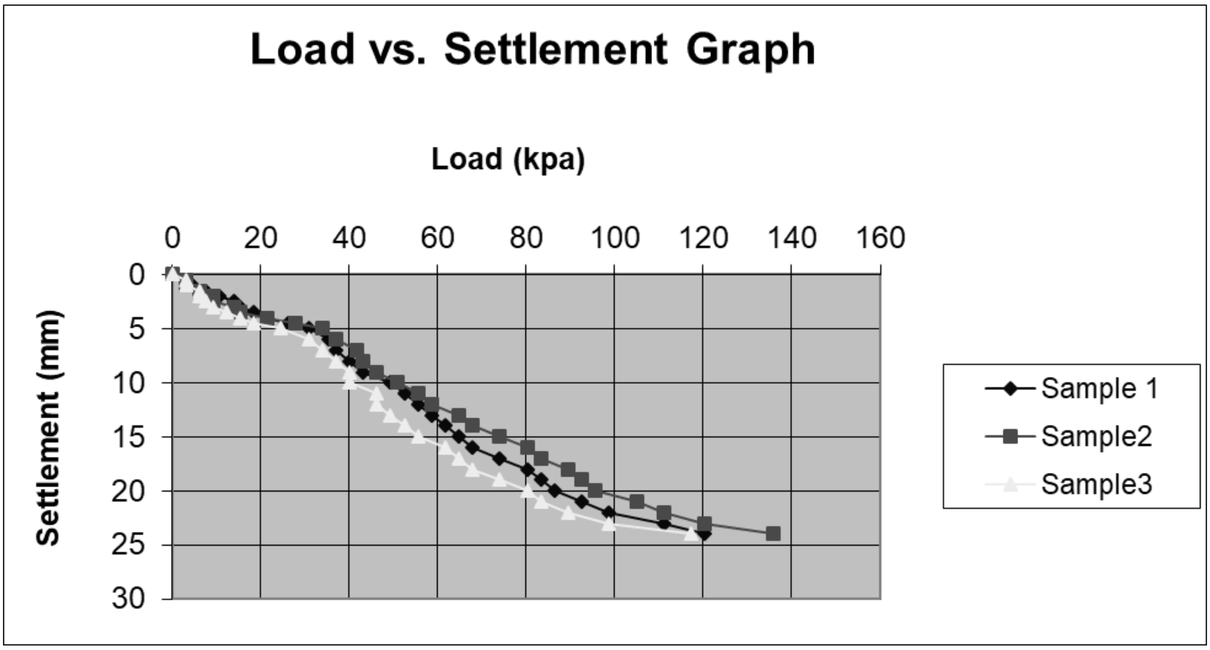


Figure **8:** Load vs. settlement graph for untreated ground

3.7. Load Bearing Capacity of Sand Pile for Treated Ground

The load bearing capacity of sand pile is obtained from the laboratory test is graphically presented in Figure 9. The graphical representation show that the ultimate load carrying capacity of sand pile is 693.81 kPa, 690.73 kPa and 672.2 kPa corresponding to the settlement of 24 mm. This figure shows that there is no distinct failure of the improved ground even after the settlement of 24 mm.

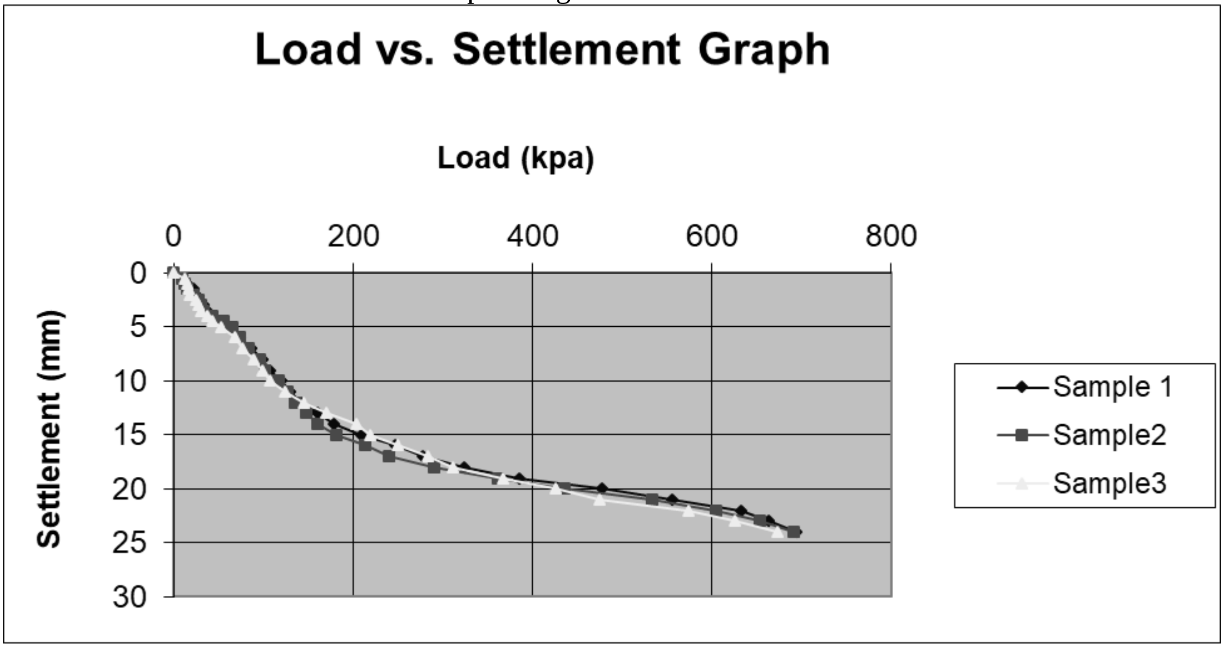


Figure **9.** Load vs. Settlement Graph for Treated Ground by sand

3.8. Load Bearing Capacity of Stone Column for Treated Ground

The load bearing capacity of the ground treated by sand and stone chips obtained from the laboratory test is graphically presented at Figure 10. From figure, the ultimate load bearing capacity of the sand column is found 783.23 kPa, 718.48 kPa and 755.48 kPa for sample 1, 2 and 3 respectively correspondence to the settlement of 24 mm.

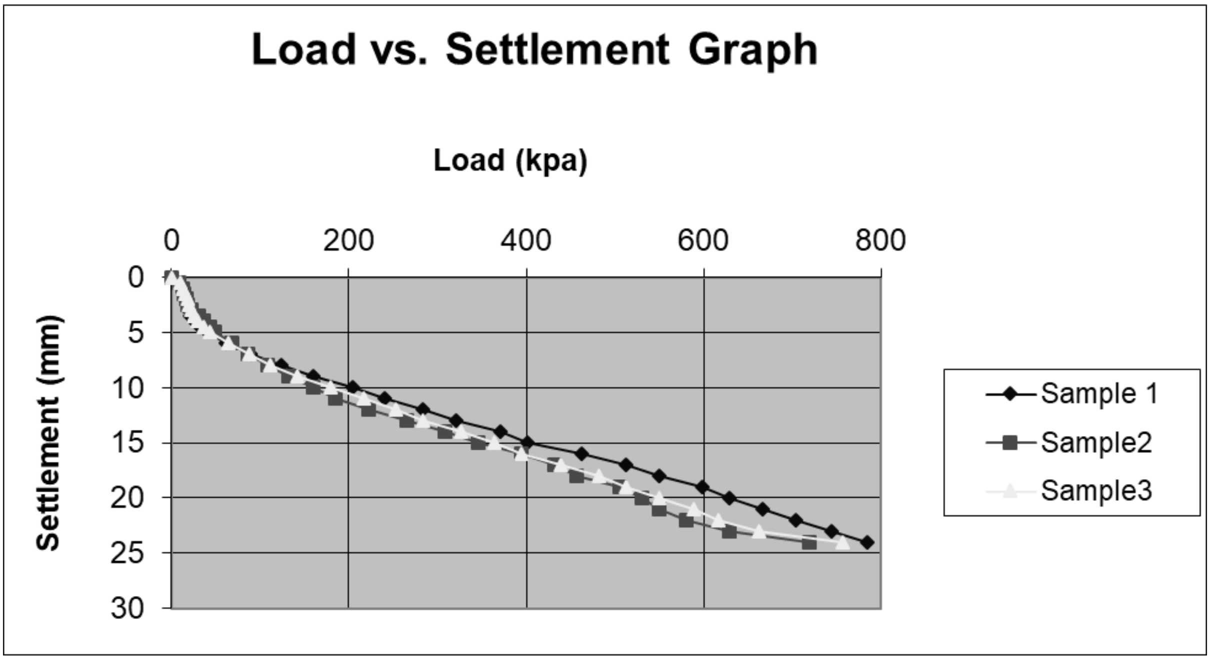


Figure **10:** Load vs. settlement graph for treated ground

3.9. Comparison of Load Bearing Capacity for Different Types of Ground

To measure the effectiveness of the granular piles to enhance the load bearing capacity of the ground and also to find out the effectiveness of the granular materials for the construction of granular piles, a comparison is made based on the load test results. The comparison is shown in Figure 11.

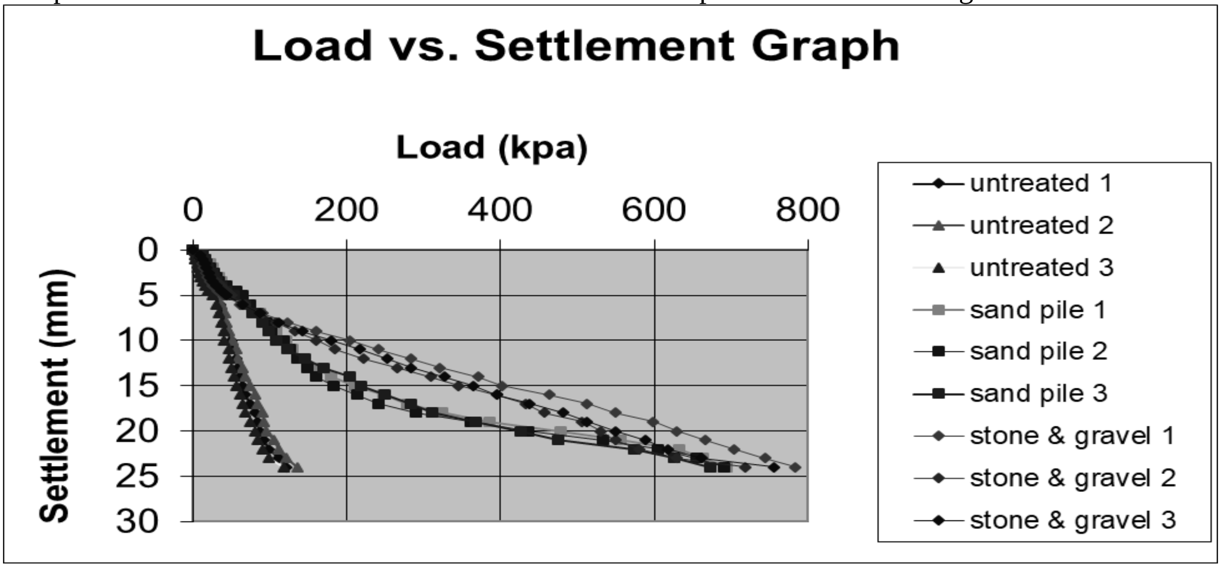


Figure **11:** Comparison of the Load Test Results

Comparison of the ultimate load bearing capacity of the treated ground with respect to untreated ground at 24 mm settlement is shown in Table 3.

Table **3:** Comparisons of Load Test Results

	Applied Load			Degree of improvement		
	S-1	S-2	S-3	S-1	S-2	S-3
Untreated Ground	120.22	135.63	117.14	*	*	*
Treated Ground by Sand	693.81	690.73	672.23	5.77	5.09	5.74
Treated Ground by Sand & Gravel	783.23	718.48	755.48	6.51	5.3	6.45

The results show that the load bearing capacity of soft ground can be increased significantly by installing sand pile and stone column. From the table it is found that the load carrying capacity of the treated ground is about 5 to 7 times more than the untreated ground. For the ground treated by sand, possess the load carrying capacity 5.09 to 5.77 times more than the untreated ground & the ground treated by sand and gravel, possess the load carrying capacity 5.3 to 6.51 times more than the untreated ground.

From the load test results, it is found that both sand and gravel can be effectively used for construction of granular piles. By using these materials for the granular piles construction, the granular piles can be successfully used for the improvement of soft ground. The combined use of sand and gravel in equal ratio gives the slightly higher improvement. But for the existing point of view, the additional increment can be considered as non-noticeable.

4. CONCLUSIONS

This study is based on the evaluation of performance of granular piles through load carrying tests. The following conclusions can be drawn on test results:

1. Using of sand as the granular materials, for the construction of granular piles, increases the load bearing capacity of the treated ground 5.07 to 5.77 times more than that of untreated ground.
2. Using the mixture of sand and gravel of equal proportion as the granular materials increases the load bearing capacity of the treated ground 5.3 to 6.5 times more than the\at of untreated ground.
3. The increment of load bearing capacity by using the mixture of sand and gravel instead of sand can be neglected from the engineering point of view.
4. The load bearing capacity of the soft ground can be increased significantly by installing granular piles.

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