Effect of Backfill Materials on Performance of Granular Pile

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Abstract -The main objective of this experimental study, to investigate the settlement reduction ratio (*Sr*) of soft clay enhanced with granular pile. A steel box mould with dimensions of 240 mm * 240 mm * 260 mm was used for model tests. The axial load was applied by multispeed machine on the soft clay only and soil enhanced with granular pile. The displacement transducer is used to measure the settlement of the model tests. Three backfill materials: crushed stone, gravel and sand are used to prepare the granular piles with diameter of 50 mm, at two ratios of length to diameter (L/D =5.2 and 4). The undrained shear strength of the treated soil are ranged from 13 kPa to 21 kPa. The results of the tests shows that the granular pile using sand as backfill material with (L/D = 5.2) provides the best and the lowest value of settlement reduction ratio. Also the soil with shear strength of 13 kPa exhibits the lowest values of the settlement reduction ratio in all model tests.

I. INTRODUCTION

For low-rise buildings and structures such as liquid storage tanks, abutments, embankments, and factories that can tolerate some settlement, granular piles (also known as granular piles or granular columns) provide an economical method of support in compressible and fine-grained soils. granular piles are either constructed as fully penetrating through a clayey soil layer overlying a firm stratum or as floating (or partially penetrating) with their tips embedded within the clayey soil layer [1].

Ref. [2], showed that the empirical approaches for estimating the settlement of improved soil should be as precise as the mathematical solution thus ensuring computability of granular pile and clay deflections. Ref. [3], showed that the main a assumption necessary for settlement calculation is the radial expansion of the granular pile, as settlement occurs thus retaining constant volume. The pile is divided into layers and the total settlement is the contributions from each layer. Ref. [4], proposed equations for immediate settlement and consolidation settlement, based on stress-strain behavior of both granular pile and surrounding soil. Ref. [5], and Ref. [6], developed analytical expressions from the theory of elasticity for estimated the settlement of rigid foundations supported by clay soil reinforced by granular piles. Ref. [7], used the CRISP finite element program using a nonlinear, modified Cam Clay model to perform settlement and horizontal deformation predictions of two barrel oil storage tank foundations 35 meters in diameter on a soft hydraulic fill soil improved using granular piles at port of Tampa. Ref. [8] proposed a method for estimating the settlement of foundations resting on an infinite grid of granular piles. The basic for this method is the unit cell concept. In this concept, Priebe considered the area of soil surrounding a granular pile at a distance depending on the spacing of the columns. The result of the evaluation is expressed as basic improvement factor n_0.

$$n_o = 1 + \frac{A_c}{A}\left[\frac{5 - A_c/A)}{4.K_{ac}.(1 - A_c/A)} - 1\right] \tag{1}$$

$$k_{ac} = \tan^2(45 - \frac{\varphi}{2}) \tag{2}$$

Where the Ac/A, is the area replacement ratio, A_r [Ac = cross-sectional area of one stone column and A = the area of soil surrounding of each column] and φ is the internal friction angle of stone column.

It can be simplified the basic improvement factor n_0 or Priebe's settlement improvement factor as:

$$n_o = \frac{S_{untreated}}{S_{treated}} \tag{3}$$

Where $S_{untreated}$ and $S_{treated}$ are a Settlement of untreated and treated soil respectively.

Ref. [9] used the centrifuge modeling technique in the examination of the use of the sand compacted pile (scp) for reinforcing soft clay ground. Attention was focused on the settlement response of the improved ground and the effects of the area replacement ratio , soil-column interaction and loading process. Ref. [10], conducted a laboratory tests and found that, the settlement in reinforced granular pile is lesser than the granular pile and the settlement decreased with the increasing stiffness of the encasing material. For smaller loads the settlement reduction ratio is less in granular piles but for higher loads it is less in geogrid encased granular pile. Ref. [11] carried out a laboratory model test with unreinforced and reinforced granular piles in soft soil of cu = 5.0 kPa to 10.0 kPa. It found that the settlement reduction ratio is 0.30 and 0.22 for single granular pile with two and three discs respectively, giving 40% and 54% further reduction in settlement reduction ratio over unreinforced granular revealed on average bearing improvement ratio for single granular pile of 1.25, 1.5 and 1.7 for area replacement ratios of 1.6%, 3.8% and 6.5%. Ref. [12] conducted a thirteen soil laboratory model tests: (1) model for untreated clay soil; (3) models for soil treated with granular piles (1,2 and 3 piles) with 30mm in diameter and 180mm length ; (9) models for soil treated with dynamic compaction using drop weights. It found that in comparison with untreated soil, the maximum cumulative settlement improvement ratios were 69% and 178% at applied stress of 30 kN/m^2 for soil models treated with

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dynamic compaction (5kg drop weight) and 3 stone columns respectively.

Ref. [13] computed the Settlements by using an improved analytical method that considers the coupling between column compression and consolidation and observed that the importance of the radial coefficient of consolidation increases as time increases, hence suggesting that granular pile construction method and quality of workmanship are probably less important if time is "cheap" and we can wait for consolidation to occur.

II. Experimental Work

All experiments were carried out on 30 mm diameter granular pile surrounded by soft clay soil in box tanks of 260 mm high and 250 mm × 250 mm , for an area ratio (Ar) of 9%. Tests were also conducted in homogeneous soil beds consisting of only soft clay. Table I shows the physical properties of the soil used in the experiments. Four series of tests were conducted by varying the backfill materials of granular pile: crushed stone, gravel and sand. The grain size distribution curves of the three backfill materials is shown in Fig 1. The first series of tests was performed on the clay soil beds without granular, the other three series was performed on clay soil with granular pile used three materials as backfill, crushed stone, gravel and sand.The soil used in model tests was prepared to get the specific undrained shear strength varied from 13 to 21 kPa . The soil was packed carefully in five layers to fill the tank i.e. the final height of soil bed is 260 mm. Each layer placed in the tank was pushed lightly to remove the entrapped air. The uniformity in the soil bed was checked by measuring the density at various stages of the soil bed formation. The experimental works were performed in soft soil beds in box tank. A test box tank used in the tests is shown in Fig. 2. The experiments divided in two groups, the first group were conducted on floating granular piles with length of 200 mm, so that L/D ratio (length of the column/diameter of the column) equal to 4, the second group of the experiments were conducted on fully penetrated granular piles with length of 260 mm so that L/D ratio equal to 5.2 i.e. the total height of the soil bed placed in the tank was 5.2 times the diameter of the column. Vertical stress was applied over the plate load test of 100 mm diameter placed on soil only and on soil with granular pile.

The load was applied through a load cell with capacity of 50 kN at a constant incremental load rate 50 N, the displacement transducer reading were recorded for each load increment, the incremental load were stopped when the final settlement reached 40 millimeters. This rate of incremental load is chosen to prevent build-up of excess pore water pressures. The loading test were performed for untreated soil only for comparison purposes. The load was applied through a 8 mm thick mild steel plate. Fig. 3 shows the loading frame and the accessories. Fourteen experimental tests were conducted, seven model tests for soil having shear strength, cu= 13 kPa, included single model test for untreated soil, six model tests for soil treated with granular piles at 50, with three specific materials of backfills (stone or gravel or sand). Seven model tests for soil having shear strength, cu= 21 kPa, include the pervious manner.

TABLE I PHYSICAL PROPERTIES OF THE TREATED SOIL

Property	Value
Liquid limit (LL)	44%
Plastic limit (PL)	22%
Plasticity index (PI)	22%
Specific gravity (GS)	2.71
% Passing sieve No. 200	87%
Sand content	13%
Silt content	35%
Clay content < 0.005 mm	52%
Maximum dry unit weight kN/m3	18.5
Symbol according to Unified Soil Classification System	CL

A. *Properties of Materials Used*

The soil used for tests, obtained from Al-Musaib near Babylon, Iraq. The soil used for all layers in the container is CL of Unfined classification. The physical properties of the soils used are given in Table 1. Based on the preliminary tests on the clayey soil, water content varying from 26% to 32% and maximum dry unit weight of 18.5 kN/m^3 were selected for making five layers of soil placing in the box container and the corresponding shear strength were found to be 13 kPa. and 21 kPa. Crushed stone varying from 2 to 11 mm particle size have been used to form the first model of granular pile, also coarse aggregates varying from 5 to 11 mm particle size have been used to form the second model of granular pile. The sand used (for preparing the third model of granular pile) is clean sand of size less than 4.75 mm. The maximum dry unit weight of the backfire materials is 18 kN/m3.

B. *Preparation of Soil Bed and Construction of Granular pile*

The inner surface of tank wall was covered with a very thin coat of grease that was applied to reduce the friction between clay and the tank wall. Soil was filled in the tank in layers with measured quantity by weight. Each layer was subjected to uniform compaction with a tamper to achieve approximately, 50 mm height and the corresponding unit weight. Granular pile was constructed by replacement method. Thin open-ended plastic pipe of 50 mm outer diameter and wall thickness 2 mm were used to construct the granular pile. After the top layer was prepared, the plastic pipe was placed at the centre of the soil bed and construction of granular pile was carried out simultaneously. Outer surface of the pipe was lubricated by applying a thin layer of grease for easy withdrawal without any significant disturbance to the surrounding soil. The auger with outer diameter of 30 mm is used to removed the soil inside the plastic pipe. The pipe was then raised in stages.

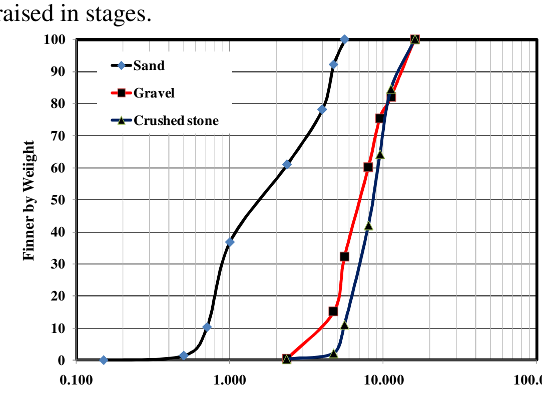

Fig. 1. Grain size distribution of granular pile materials (crushed stone, gravel and sand)

Crushed stones gravel or Sand were charged into the hole in layers in measured quantities to achieve a compacted height of 50 mm for each layer. To achieve a uniform unit weight, compaction was done with a 2 kg circular steel tamper. This light compaction effort was adopted to ensure that there is no significant lateral bulging of the column which creates disturbance to the surrounding soft soil. Unit weight of granular pile was estimated with the quantity of sand or gravel or crushed stone consumed for the construction and the volume of the granular pile. The corresponding unit weight of granular pile was found to be 18 kN/m3. The procedure was repeated until the granular pile was completed to the full length . Two length of granular pile are used, 260 mm and 200 mm i.e. fully penetrated or (L/D = 5.2) and partially penetrated or (L/D = 4.0). Fig. 4 shows the installation process of the granular pile.

C. Test Procedure

The load-deformation behavior of the column/treated soil has been studied by applying vertical load with the help of a multispeed machine according testing program (Table II). To load the granular pile and surrounding soil area, a steel plate "footing" of 10 mm thickness and a diameter of 100 mm was placed over the soil treated with granular pile or without. In all the cases, the prepared test bed in tank along with granular pile was placed under a loading frame.

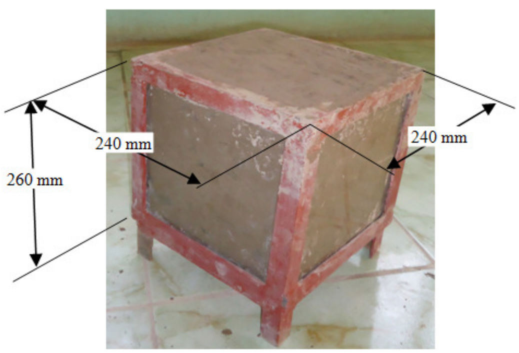

Fig. 2 The Mould used in the tests

TABLE II TESTING PROGRAM

No.	cu (kPa)	Type of improvement
1	13	Untreated soil
2	13	Soil trrated with granular (stone) pile of L/D=5.2
3	13	Soil trrated with granular (gravel) pile of L/D=5.2
4	13	Soil trrated with granular (sand) pile of L/D=5.2
5	13	Soil trrated with granular (stone) pile of L/D=4
6	13	Soil trrated with granular (gravel) pile of L/D=4
7	13	Soil trrated with granular (sand) pile of L/D=4
8	21	Untreated soil
9	21	Soil trrated with granular (stone) pile of L/D=5.2
10	21	Soil trrated with granular (gravel) pile of L/D=5.2
11	21	Soil trrated with granular (sand) pile of L/D=5.2
12	21	Soil trrated with granular (stone) pile of L/D=4
13	21	Soil trrated with granular (gravel) pile of L/D=4
14	21	Soil trrated with granular (sand) pile of L/D=4

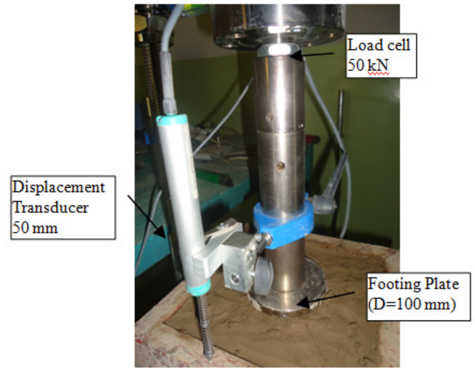

Fig. 3 The Loading frame and the accessories

Loading was applied through a footing resting on the prepared soil bed and resistance offered by test bed with or without granular pile was measured with the help of load cell connected with a digital unit to read the applied load with accuracy of 0.001 kN. Short-term loading test was conducted in all the cases. Load was applied in equal increments and each increment of the load was maintained until negligible change in the settlement was observed. The settlement due to increment of each equal interval of loading step was observed through displacement transducer fixed on the edge of the test tank with help of the same digital unit having least unit of 0.001 mm . Settlements were monitored for equal intervals of loads up final settlement of 40 mm. Fig. 5 shows the granular pile model after the completion of the test.

III. RESULTS AND DISCUSSION

Fourteen laboratory tests are conducted to demonstrate the impact of the use of granular pile in improving the settlement of the soft clay soils. The laboratory tests were divided into two, first includes seven tests in the soil with shear strength equal to 13 kPa, and one of them in the untreated soil for comparison, others in the soil treated with granular pile.

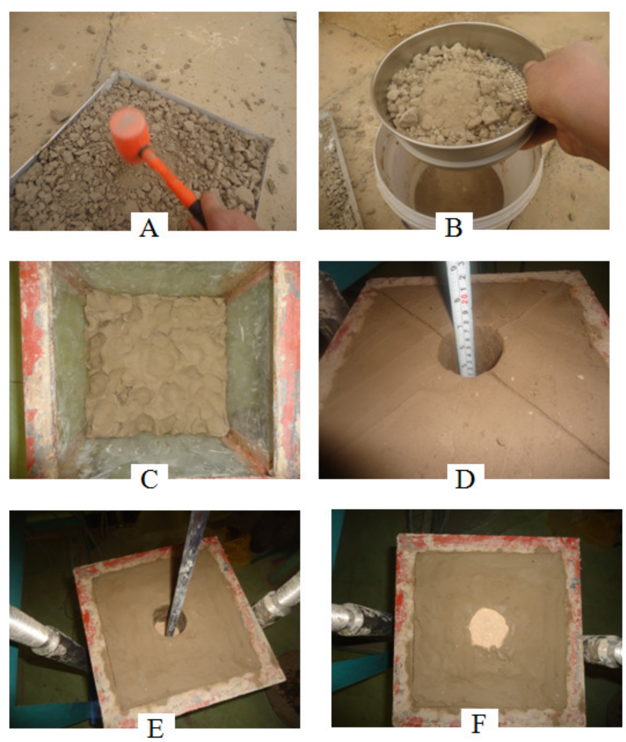

Fig. (4-A to 3-F) Installation of the granular material (sand) pile, L/D = 4

Fig. (5A and 5B) Granular pile model after the completion of the test

The same the previous seven tests were carried out in the treated soil having shear strength equal to 21 kPa. Three materials are used to prepare the granular pile, crushed stone, gravel and sand. Two case of granular pile are used, fully penetrated or(L/D = 5.2) and partially penetrated or (L/D = 4.0).

Figs. from 6 to 9 show the load-settlement characteristics of the untreated clay bed, clay bed treated by granular pile. The improvement in settlement under different conditions has been computed at the end of the test. It has been observed from Fig. 6 that the use of granular pile to improve the soft clay decrees the settlement of the improved soil clearly. The settlement has been reduced by 63%, 82% and 82% when the soil of cu= 13 kPa is improved by granular pile for three backfill materials crushed stone, gravel and sand respectively. The values of settlement reduction are decreased when the length of granular pile is decreased i.e. the full penetrated granular pile (L/D= 5.2) exhibits the best values of settlement reduction than the floating granular pile (L/D=4). The reduction in settlement are 58%, 39% and 47% for the soil having shear strength of 21 kPa, treated with granular pile, for three materials crushed stone, gravel and sand respectively. Thus, it can be said that the granular pile is more effective for the soil of lower values of shear strength. The Figs. from 6 to 9 also demonstrate that the reduction in the settlement is decreased when the loading intensity is increased.

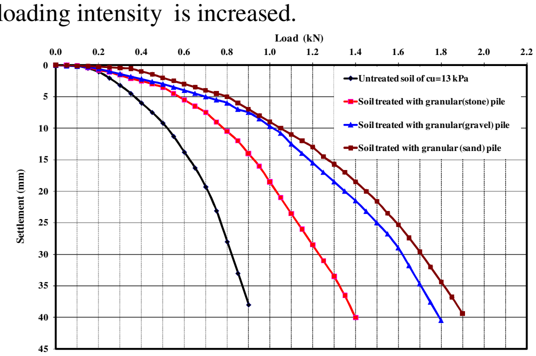

Fig. 6 Load-settlement characteristics of various backfill materials of granular pile, L/D= 5.2, cu = 13 kPa.

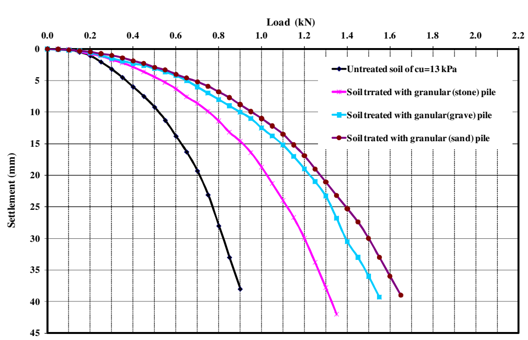

Fig. 7 Load-settlement characteristics of various backfill

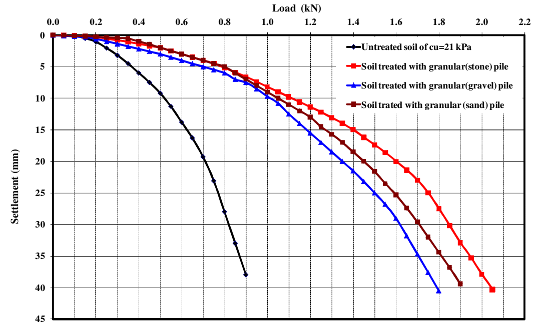

Fig. 8 Load-settlement characteristics of various backfill materials of granular pile, L/D= 5.2, cu = 21 kPa.

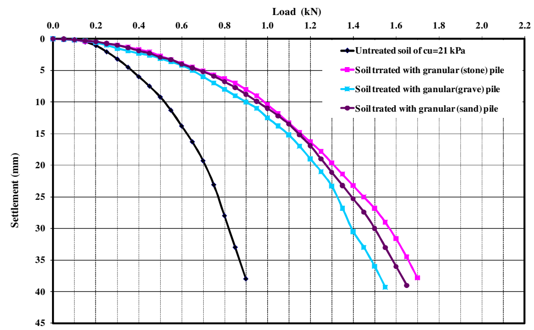

Fig. 9 Load-settlement characteristics of various backfill materials of granular pile, L/D= 4, cu = 21 kPa.

To simplify the results of the tests, it can be used the parameter of settlement reduction ratio, ***Sr***. In the current work, the settlement reduction ratio is defined as the ratio of the settlement of soil treated by granular piles to the settlement of untreated soil (without granular pile) at the same level of stress, the stress level are taken as the last load applied on the untreated soil which causes a settlement of approximately equal to 40 mm.

Fig. 10 represents the relationship between the stress ratio **q/cu** where the **q** representing the applied stress and **cu** representing undrained shear strength with the settlement reduction ratio ***Sr***. It can be noticed from Fig. 10 that the settlement reduction ratio ***Sr*** changes almost from 0.2 to 0.5 in soil of a shear strength equal to 13 kPa treated with granular piles for all three model tests (crushed stone, gravel and sand). Also that the granular pile of sand demonstrates the lowest values of the settlement reduction ratio, ***Sr*** and the granular pile of crushed stone shows the highest values of ***Sr*** and the column used the gravel as backfill materials reveals the values between them. In all model tests, the full penetrated granular pile with a ratio of length to the diameter of the column (L/D) equal to 5.2 exhibits the lower values of settlement reduction ratio than the floating granular pile with the ratio of (L/D) of 4 because the long column rest on rigid base of the mould i.e. it can said that the full penetrated granular pile behaves as end bearing pile, but the floating granular pile resists the load by adhesion only. The values of settlement reduction ratio are collected in table III.

TABLE III SETTLEMENT REDUCTION RATIO FOR THE SOIL TREATED WITH GRANULAR PILE.

Shear strength	Stone		Gravel		Sand	
	L/D		L/D		L/D	
	5.2	4	5.2	4	5.2	4
cu= 13 kPa	0.37	0.38	0.20	0.26	0.18	0.23
cu= 21 kPa	0.42	0.65	0.61	0.88	0.53	0.73

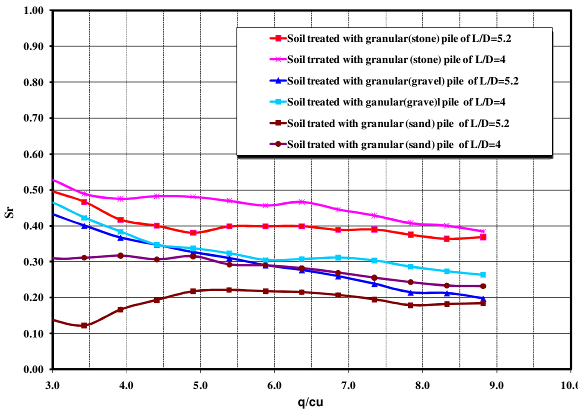

Fig. 10 q/cu versus ***Sr*** for the soil treated with granular (stone, gravel and sand) Pile, , L/D= 5.2 and 4, cu = 13 kPa.

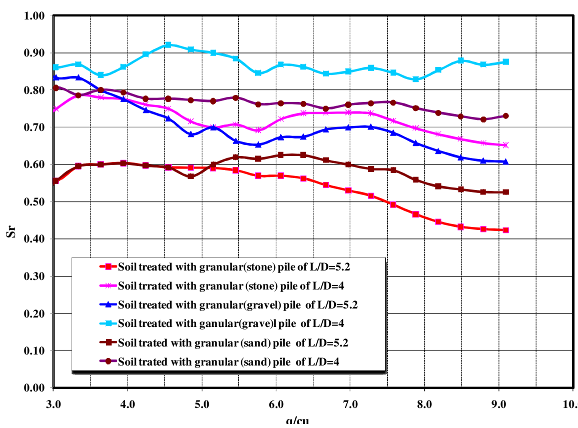

Fig. 11 q/cu versus ***Sr*** for the soil treated with granular (stone, gravel and sand) Pile, , L/D= 5.2 and 4, cu = 21 kPa.

Fig. 11 relates the stress ratio q/cu plotted versus the ***Sr*** for the soil with undarined shear strength equal 21 kPa. It is clear from Fig. 11 that the settlement reduction ratio ***Sr*** obtained from tests is larger than ***Sr*** in Fig. 10 i.e. the granular pile is more effective in soil with low shear strength. This behaviour is attributed to the truth that the calculation of stresses is dependent on the stress applied on the soil replaced from the zone of granular pile only, disregarding the stress applied to the soil surrounding the pile. It can be observed from Fig. 11 and table (III) that the settlement reduction ratio ***Sr*** are ranged from 0.4 to 0.9 for the soil having (cu = 21 kPa) treated with granular for three backfill materials: crushed stone, gravel and sand in two length to the diameter ratios, (L/D = 5.2) and (L/D= 4). Also it can be distinguished from Fig. 11 that the values of ***Sr*** is enhanced when the L/D is increased.

IV. CONCLUSIONS

1) The settlement reduction ratio ranges between (0.2) to (0.5) for soil having shear strength, cu= 13 kPa , and (0.4) to (0.9) in soil of cu= 21 kPa.

2) The settlement has been reduced by percentage of 63%, 82% and 82% when the soil of cu= 13 kPa is improved by granular pile used crushed stone, gravel and sand as backfill materials respectively.

3) The reduction in the settlement is decreased when the loading intensity is increased.

4) In all model tests, the full penetrated granular pile with a ratio of length to the diameter of the column (L/D) equal to 5.2 exhibits the lower values of settlement reduction ratio than the floating granular pile with the ratio of (L/D) of 4

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