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Field investigations on a soft ground of Bangladesh reinforced by granular piles

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ABSTRACT: The effectiveness of granular piles in improving a typical soft ground of Bangladesh, was investigated in the field and thus presented in this paper. Sand piles and stone columns of 200mm diameter and 6m long were installed by dry-displacement method in single and group pattern with triangular arrangement at 750mm spacing. The effectiveness was measured by the plate load test on reinforced ground. The field measurement shows that the bearing capacity of soft ground is increased significantly due to the installation of granular piles irrespective of the types of granular materials. The result reveals that the stone columns can carry 2.4 times higher load than that of the sand piles. The investigation further shows that the spacing ratio of granular piles is to be less than 2.5 to get the group effect. Standard penetration test results show that the consistency of sub-soil was increased by 2 to 3 times due to the installation of granular piles.

1 INTRODUCTION

The development of modern foundation practices, namely, earth reinforcement, to overcome the limitations of the conventional foundation system, has been proved to be viable both technically and economically for the construction works in marginal sites. Earth reinforcement of soft ground by granular piles is considered as one of the versatile and cost effective method. Installation of granular piles transforms the soils into a stiffer composite mass with intervening native soil providing lower overall compressibility and higher shear strength. In the recent years, this technique has also been adopted in Bangladesh in various projects to improve the marginal sites. However, the effectiveness of this method has not been well recorded or monitored due to the lack of required field investigations and the monitoring system.

At the present time, more granular piles projects in the USA have been constructed in silty sands rather than cohesive soils. World wide the reverse is true. Reinforcement of soft cohesive soils for construction purposes by granular piles have been established for the last few decades (Engelhardt & Golding 1975, Mitchell & Huber 1985, Okiawa et al. 1992, Bergado & Miura 1994, Alamgir 1996). The installation technique has the big influence on the performance of this ground improvement method (Datye 1978, Barksdale & Bachus 1983, Aboshi & Suematsu 1985). There is a record of successful application of the technique to improve the fine-grained soft ground site in a water front structure at Fakirhat, Khulna, Bangladesh (Alamgir & Zaher 1999a,b, Alamgir et al. 2001). The applicability of such ground improvement technique to improve the soft cohesive soil deposits containing organic is needed to investigate critically.

The effectiveness of granular piles in improving soft ground exists in the south-western region of Bangladesh, was investigated in the field and thus presented in this paper. Sand piles and stone columns of 200mm diameter and 6m long were installed by dry-displacement method in single and group pattern with triangular arrangement at 750mm spacing in a typical soft ground site exists in BIT campus, BIT, Khulna, Bangladesh. Sand prepared by mixing of two-thirds of local sand (available in the south-western region of Bangladesh) and one-thirds of Sylhet sand (a widely used construction sand of Bangladesh) was used in sand piles and crushed stone of 19mm down well graded was used in stone columns. Single sand pile, seven sand piles in group, single stone column and three stone columns in group were installed. Effectiveness was measured by the plate load test on reinforced ground. The field measurement shows that the load carrying capacity of soft ground is increased significantly due to the installation of granular piles irrespective of the types of granular materials. The result reveals that the stone columns can carry around 2.4 times higher load than that of the sand piles. The investigation shows that the spacing ratio of granular piles is to be less than 2.5 to get the group effect. The change of soil consistency along the depth was also examined by conducting Standard penetration test (SPT) after ten months of ground improvement. SPT results show that the penetration resistance increases along the depth by 2 to 3 times, due to the installation of granular piles.

2 CONSTRUCTION OF GRANULAR PILES

The sub-soil condition of the site and the installation of granular piles are discussed here. The soft ground is reinforced by two types of granular piles, namely, sand piles and stone columns.

2.1 *Location of project site*

This field investigation is performed within the campus of BIT, Khulna, Bangladesh, which can be treated as an ideal place for such field experiment since the sub-soil consists of soft soil to a great depth. The campus is located in the south-western part of the country, as shown in Figure 1.

2.2 *Sub-soil condition of the site*

In the upper horizons, the sub-soil of vast areas of Bangladesh is composed of very soft fine grained soil deposits of Recent origin. In the south-western coastal districts, sub-soils are consist of fine grained soil deposits predominantly peat and muck, due to presence of World's biggest mangrove forest, the Sundarbans, which was extended in these regions in the past. The field and laboratory investigations reveal that the sub-soil of BIT campus consists of fine-grained soil of very soft to soft consistency till the depth of 65ft. A layer of filling sand of very loose to medium relative density exists at the top 10ft, after that a layer of organic clay of black and dark gray exists at a depth of 15 to 25 ft. The physical and mechanical properties of sub-soil up to 65ft. depth are shown in Table 1.

2.3 *Selection of granular piles*

Selection of the most suitable ground improvement technique in any case only be made after evaluation of several factors specific to the problem at hand (Mitchell 1981). Schlosser and Juran (1979) made an excellent comment that when dealing with techniques of soil improvement, experience has almost always preceded theory. However, in this field study, granular piles, which has a proven record of success as a versatile and cost effective ground improvement technique and have been started to use successfully in Bangladesh in several marginal sites, is considered. Here, granular piles cylindrical in shape were installed in single and group patter. Granular piles are categorized as sand piles and Stone columns based on the types of granular materials.

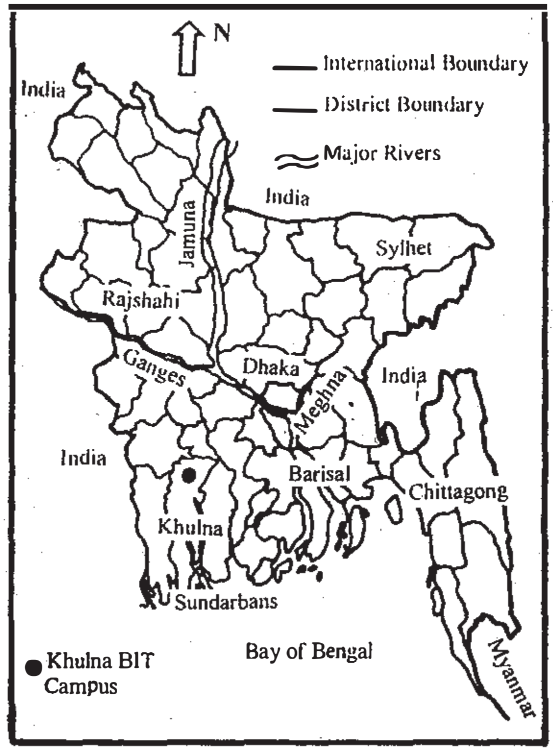

Figure 1. Project site shown in Bangladesh map.

Table 1. Geotechnical engineering properties of sub-soil of the site.

		Physical properties		Compressibility Properties			Strength properties	
Depth (ft.)	Soil strata	Water content, Liquid Limit, Plastic limit ($w\%$, $w_l\%$, $w_p\%$)	Unit weight γ (kN/m^3), Specific gravity, G_s	Initial void ratio, e_0	Compression index, C_c	Coefficient of consolidation C_v (m^2/sec)	Undrained shear strength, S_u (kPa)	N-Value
0-5	Fine	33, ---, ---	------, 2.75	---	---	---	----	6
5-10	sand	39, ---, ---	-------,2.73	---	---	---	----	2
10-15		45, 59, 31	25.56, 2.73	1.706	0.257	$3.83x10^{-7}$	12.0	2
15-20	Organic	58,77,39	17.50,2.57	2.170	0.391	$5.00x10^{-7}$	26.0	4
20-25	clay	223, 112, 55	7.46, 2.50	7.962	1.308	$3.66x10^{-7}$	30.0	4
25-30		36, 51, 39	14.93, 2.50	1.207	0.249	$7.20x10^{-7}$	43.0	7
30-35		36,47, 31	18.58,2.71	1.404	2.176	$12.2x10^{-7}$	44.0	7
35-40	Clay	46, 42, 32	13.96, 2.67	1.501	0.137	$8.83x10^{-7}$	25.0	4
40-45		47, 49, 33	14.25,2.88	1.464	0.154	$9.96x10^{-7}$	40.0	7
45-50		24, 37,36	13.45, 2.64	1.568	0.169	$7.81x10^{-7}$	37.0	6
50-55		47, 50, 35	14.47, 2.62	1.474	0.156	$14.8x10^{-7}$	46.0	8
55-60	Silty clay	39,48,34	13.80,2.65	1.502	0.166	$6.60x10^{-7}$	55.0	11
60-65		45,50,36	14.50, 2.62	1.480	0.154	$13.6x10^{-7}$	48.0	8

2.4 *Materials of granular piles*

Two types of granular materials, namely, sand and stone chips, were considered for the construction of granular piles. Sylhet sand, a yellowish-brown river sand of Sylhet, Bangladesh having FM=2.507, D_{10}=0.23mm, D_{30}=0.43mm, D_{60}=0.73mm, C_u=3.17 and C_c=1.1025 and a Local sand, available in the south-western region of Bangladesh having FM= 0.69, D_{10}=0.09mm, D_{30}=0.12mm, D_{60}=0.2mm, C_u=2.20 and C_c=0.80, were used in sand piles. Here, FM=Fineness modulus, D_{10}=Effective diameter of particle size of which 10% sample is smaller, D_{30}= Effective diameter of particle size of which 30% sample is smaller, D_{60}= Effective diameter of particle size of which 60% sample is smaller, C_u=Co-efficient of uniformity and C_c=Co-efficient of curvature. To increase the cost effectiveness, a combined prepared by one-thirds of Sylhet sand and two-thirds of Local sand were used. Such combination provided an effective and cheap material to improve marginal sites (Alamgir & Zaher 1999a, b). 19mm down well graded stone chips of Sylhet, Bangladesh was used in stone columns. It is originated from crushed bolder and color is whitish and light gray. The grain size distribution of granular materials is shown in Figure 2.

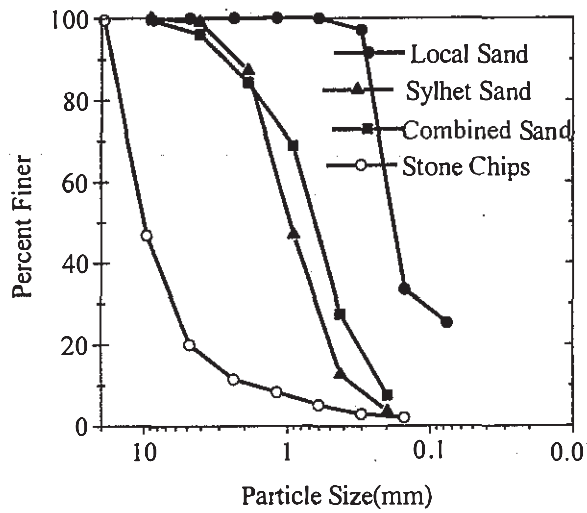

Figure 2. Grain size distribution curves of granular materials used in the sand piles and stone columns.

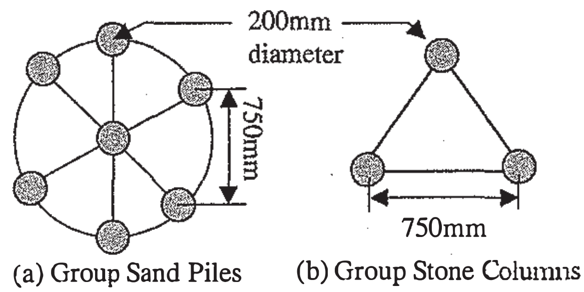

Figure 3. Layout plan of granular piles.

2.5 *Installation of granular piles*

Granular piles with a diameter of 200mm and a length of 6m were installed in a group and single patter. The layout of the constructed sand piles and stone columns is shown in Figure 3. The granular piles were constructed by dry-displacement method. The installation equipment mainly consists of a 1500rpm traditional rig machine, a two end open casing pipe of 200mm diameter, 6m long and 8mm thick. The granular materials were compacted by a hammer of weight 450kg, 175mm diameter and 3m long. The installation procedures as shown in Figure 4 in a schematic diagram, are briefly described as:

1. The casing pipe was placed vertically at the designated point and inserted into the ground about 450mm depth manually. A plug of coarse sand about 750mm is then made at the bottom of casing pipe to seal the pipe.
2. The soil beneath the plug of casing pipe was then displaced by dropping the hammer inside the casing and the casing was then driven to the designated depth by its own weight.
3. At this stage the sand plug was broken by giving excess energy and additional water, the hammer was then withdrawn from the casing.
4. Casing was then lifted by 1m from its original position and the designated granular materials were then poured to have a 1m thickness and compacted by the hammer to obtain designated compaction.
5. Casing was then withdrawn further and hole was poured by the same granular materials to have same thickness and compacted. In general, free fallheight of hammer was 0.75 to 1.0m and the thickness each layer was about 1m and 0.65 to 0.75m before and after compaction, respectively.
6. Step 5 was then continued till the granular piles reached the ground surface to have a completed granular pile.

3 FIELD INVESTIGATION

To establish the effectiveness of granular piles in reinforcing soft fine-grained soil, some field investigation were carried out. Plate load tests, with a square plate of 300x300mm, were conducted on natural and reinforced ground at a depth of 1.2m from the existing ground surface. On reinforced ground, plate was placed on the top of granular piles for single patter, on the top of middle sand piles and on the top of soil encircled by stone columns for group pattern. In natural ground the load intensity was increased from 10.9 to 98.1kPa at an interval of 10.9kPa. The load intensity was increased from 32.7 to 228.9kPa at an interval of 32.7kPa and 21.8 to 218kPa at an interval

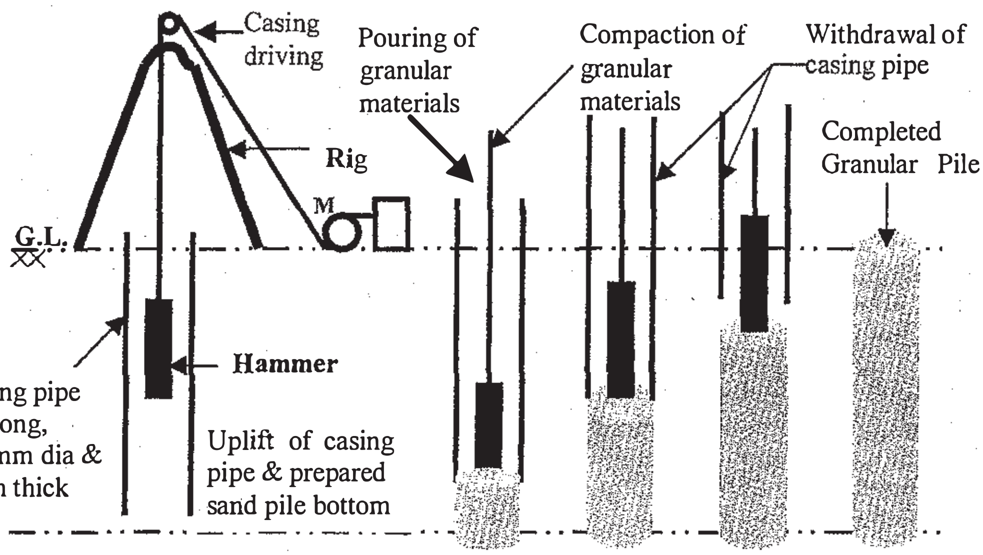

Figure 4. Schematic diagrams of granular piles installation process by dry – displacement method.

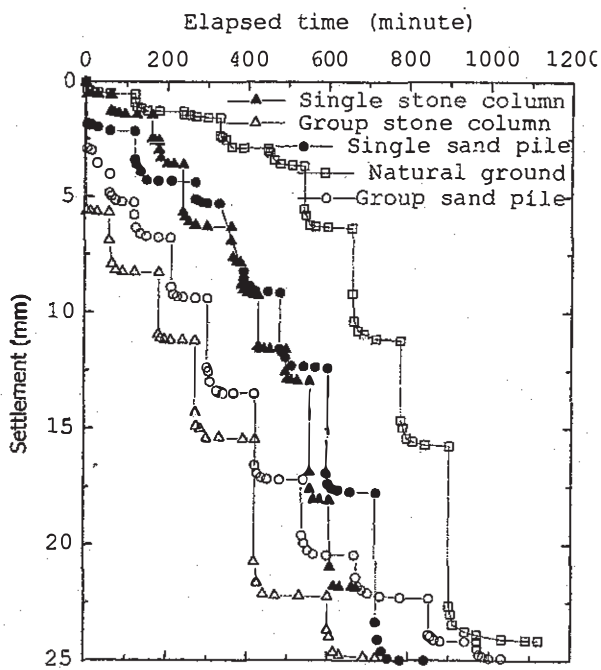

Figure 5. Time-settlement response of the ground.

of 21.8kPa for single and group sand piles, respectively. In case of stone columns, the load intensity was increased from 32.7 to 523.2 at an interval of around 50kPa and 21.8 to 130.8kPa at an interval of 21.8kPa for single and group, respectively. In each load increment, settlements were measured till the rate of deformation less than 0.25mm/hr. Load increment was continued till the failure or up to 25mm settlement. The results are represented in Figure 5.

To depict the change of consistency of sub-soil, standard penetration test was performed at the two locations of the reinforced ground till the depth of 30ft. after ten months of granular piles installation.

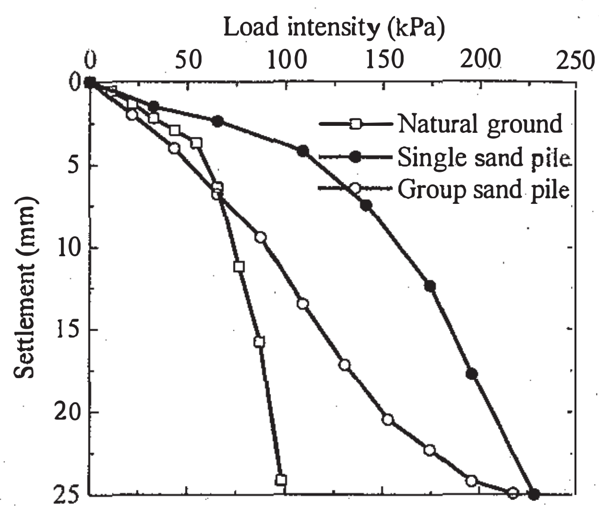

Figure 6. Load-settlement curve for sand piles.

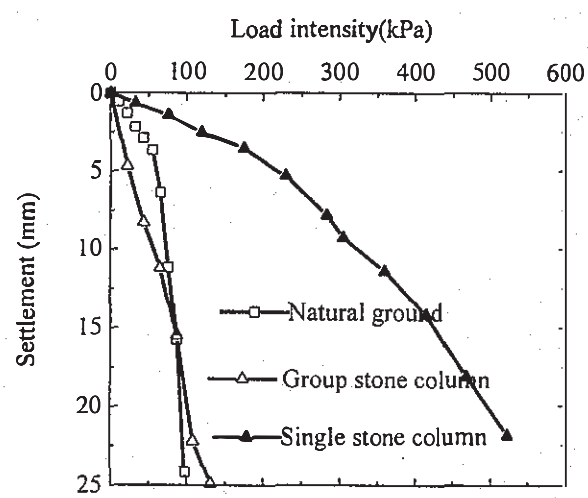

Figure 7. Load-settlement curve for stone columns.

The bore hole one is located in between the peripheral and central sand piles while bore hole two is encircled by the three stone columns. The results indicate the remarkable improvement of consistency of sub-soil along the depth.

4 RESULTS AND DISCUSSIONS

The results obtained from field investigations by plate load tests and sub-soil investigations are presented and hence discussed in this chapter. Results obtained from reinforced ground are compared with those of natural ground.

4.1 *Response of ground reinforced by sand piles*

The load-settlement response of ground reinforced by sand piles is shown in Figure 6. This figure shows that load intensity taken by single and group sand piles are 230 and 220 kPa, respectively, corresponding to 25mm settlement, while it is 98kPa for natural ground. The improvement for the installation of single and group sand piles is almost same, which is 2.3 times greater than that of natural ground, which reveals that the group can not be obtained for the spacing ratio larger than 2.5.

4.2 *Response of ground reinforced by stone columns*

Figure 7 shows the load-settlement response of stone column-reinforced soft ground. This figure shows that corresponding to 22mm settlement, the load intensity taken by single and group stone columns are 525 and 110 kPa, respectively, against of 95kPa for natural ground. The improvement for the installation of single stone column is 5.5 times greater than that of natural ground, while it is 1.15 times greater in case group stone columns. In case of group stone

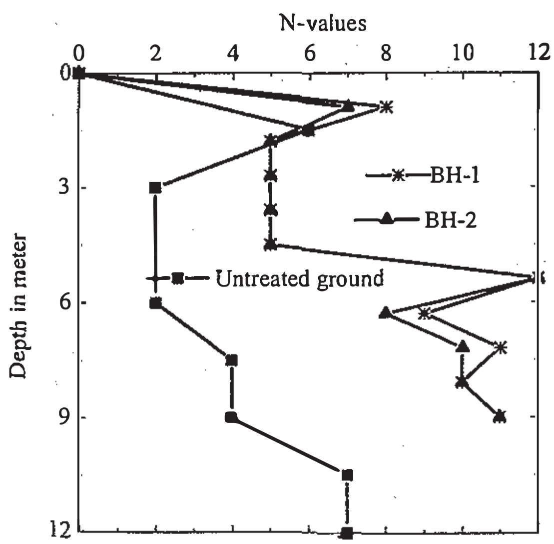

Figure 8. Comparison SPT results.

columns plate was placed on soil in plate load test. Since capacity for natural ground and group stone columns are almost same, this result again indicates that group effect can not obtained for a spacing ratio of 2.5. This finding is agreed with other researchers.

4.3 *Comparisons of settlement response*

A comparison of load carrying capacity due to the installation of sand piles over stone columns is described here. For the same settlement, the load carrying capacity of single stone column is 2.4 times higher than that of single sand pile. In case of group, it can be seen that the sand piles carried more loads than that of stone columns. The reason is that the test conditions for group stone columns is different from the group sand piles and single stone column. In case of group stone columns, plate load test was done on the top of the excavated ground encircled by the three stone columns. The test results obtained from both the group sand piles and stone columns reinforced ground, it is revealed that group effect can not expected for a spacing ratio ≥2.5.

4.4 *Improvement of sub-soil conditions*

The penetration resistance obtained on natural and reinforced ground is shown in Figure 8. This figure reveals that the penetration resistance of the soft ground increased significantly due to the installation of granular piles. N-value ranges from 2 to 7 for natural ground but in reinforced ground it increases from 5 to 11 and 5 to 12 for bore hole one and two, respectively. Result also shows that the increment of N-value does not depend on granular materials.

5 CONCLUDING REMARKS

Based on this study the following conclusions can be made:

1. Field observation reveals that the dry-displacement method is a suitable installation technique for the construction of granular piles in a soft fine-grained soil.
2. Plate load test result shows that the granular piles improved substantially the bearing capacity of natural ground.
3. The stone columns constructed by 19mm down well graded stone chips provide better improvement. The load carrying capacity is around 2.4 times higher than that of sand piles.
4. The result indicates that the spacing ratio of granular piles should be less than 2.5 to obtain group effects.
5. Sub-soil investigation shows that the shear strength of soil was increased along the depth due to the installation of granular piles.

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