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Ground Improvement Methods Recently Practiced to Solve the Geotechnical Engineering Problems in Bangladesh

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GROUND IMPROVEMENT METHODS RECENTLY PRACTICED TO SOLVE THE GEOTECHNICAL ENGINEERING PROBLEMS IN BANGLADESH

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ABSTRACT

The field performance of the foundation systems recently practiced in the soft ground of Khulna region to solve the geotechnical engineering problems is described in this paper. The foundation systems adopted to construct the structures in Khulna Medical College, Khulna University, BIT Khulna and a Six-vent regulator on Passur River at Fakirhat are considered for study. In Khulna Medical College project, a shallow foundation system using Geotextilies at the foundation base was employed, while in Khulna University and BIT Khulna, a foundation system using replacing the soft compressible soil layer by compacted sand was used. The soft compressible soil at the site of the constructed six-vent regulator on Passur River at Fakirhat was improved by the installation of sand piles by dry-displacement method. The performance was measured in terms of the improvement of ground strength and the long-term settlement monitored in the field. It is observed that the performance of the adopted systems is quite satisfactory. However, in some cases the foundation systems do not work as per design and requirements.

INTRODUCTION

The subsoil of vast region of Bangladesh is composed of very soft to soft fine-grained soil materials of Recent origin. In the south-west coastal districts, sub-soils are consisting of fine-grained soil deposits predominantly peat and muck. The peat deposits extend south-west coastal districts through Satkhira to Patuakhali. Due to the existence of these alluvial deposits with organic substance, the soil is soft and compressible. Practicing engineers are facing many difficulties to solve the several geotechnical engineering problems such as very large total and differential settlements, bearing capacity failure and slope stability problem. In many situations, the conventional foundation systems could not be chosen to solve such geotechnical engineering problems in soft ground due to the several environmental constraints and because of their expensive and time consuming nature. The inherent limitations of conventional foundation systems lead to the development of modern foundation practice, namely, ground / soil improvement, which has been proved as a viable alternative both technically and economically and practiced recently in the south-west region of Bangladesh. However, it should claim a lot of study to observe the performance of structures built on such soil condition due to the presence of thick highly compressible soil layer in Khulna sub-soil. Due to lack of professional commitment, the performances of such foundation system in this soil were not recorded properly which the practicing engineers can use as a reference in future.

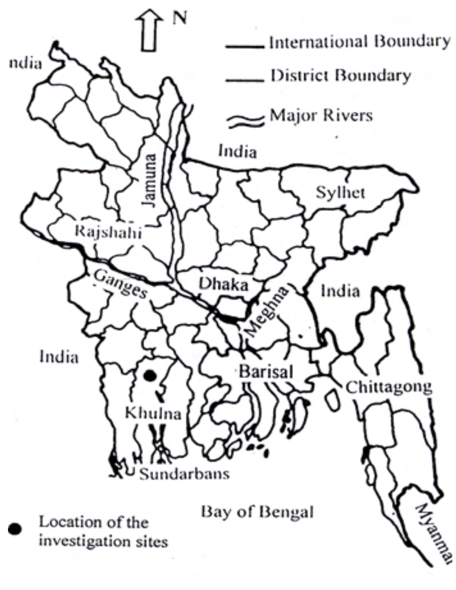


Fig. 1. Projects sites shown in the Map of Bangladesh.

Table 1. Geotechnical engineering properties of sub-soil of typical site of Khulna region

Depth (m)	Soil strata	Physical properties: Water content, Liquid Limit, Plastic limit ($w\%, w_l\%, w_p\%$)	Physical properties: Unit weight γ (kN/m^3), Specific gravity, G_s	Compressibility Properties: Initial void ratio, e_0	Compressibility Properties: compression index, c_c	Compressibility Properties: Coefficient of consolidation C_v (m^2/sec)	Strength properties: Undrained shear strength, S_u (kPa)	Strength properties: N-Value
0-1.5.0	Fine sand	33, ---, ----	-------, 2.75	---	---	---	----	6
1.5-3.0		39, ---, ---	-------, 2.73	---	---	---	----	2
3-4.5.0	Clay	45, 59, 31	25.56, 2.73	1.706	0.257	$3.83x10^{-7}$	12.0	2
4.5-6.0	Organic clay	58, 77, 39	17.50, 2.57	2.170	0.391	$5.00x10^{-7}$	26.0	4
6-7.5.0		223, 112, 55	7.46, 2.50	7.962	1.308	$3.66x10^{-7}$	30.0	4
7.5-9.0	Clay	36, 51, 39	14.93, 2.50	1.207	0.249	$7.20x10^{-7}$	43.0	7
9.0-10.5		36, 47, 31	18.58, 2.71	1.404	2.176	$12.2x10^{-7}$	44.0	7
10.5-12.0		46, 42, 32	13.96, 2.67	1.501	0.137	$8.83x10^{-7}$	25.0	4
12.0-13.5		47, 49, 33	14.25, 2.88	1.464	0.154	$9.96x10^{-7}$	40.0	7
13.5-15.0		24, 37, 36	13.45, 2.64	1.568	0.169	$7.81x10^{-7}$	37.0	6
15.0-16.5	Silty clay	47, 50, 35	14.47, 2.62	1.474	0.156	$14.8x10^{-7}$	46.0	8
16.5-18.0	Clay	39, 48, 34	13.80, 2.65	1.502	0.166	$6.60x10^{-7}$	55.0	11
18.0-20.0	Silty	45, 50, 36	14.50, 2.62	1.480	0.154	$13.6x10^{-7}$	48.0	8

The study presented in this paper depicts the performance studies of some ground improvement techniques recently practiced in Khulna region, south-west part of Bangladesh as shown in Fig.1. Geotechnical engineering properties of typical sub-soil of this region is presented in Table 1. The studied foundation systems are employed recently to construct the structures in Khulna medical college, Khulna University, BIT Khulna, water front structure on Passur River and the research projects on granular piles to improve soft ground at the campus of BIT Khulna.

A shallow foundation system using geotextiles at the base with compacted brick aggregates mixed with selected sand was used in most of the newly constructed buildings at Khulna medical college project while in Khulna University, a foundation system replacing the soft compressible soil layer till the considerable depth by compacted sand was used to construct the Academic building-I. Long-term settlements were measured in these two projects to depict the performance of such ground improvement techniques. Measurements were taken for more than three years in Khulna medical college site and six years in Khulna university site. In Khulna medical college, the foundation system served satisfactorily for the Academic building, Hostels and some residential buildings despite large uniform settlement. But excessive total and differential settlements were observed particularly at two residential buildings resulting severe tilting of the buildings. In Khulna University site very large uniform settlement, 765mm, higher than the designed value was observed at the Academic building-I resulting adverse effect on serviceability.

A six-vent regulator was constructed on Passur River, Fakirhat, Khulna by improving the soft deposits with the installation of total 765 sand piles, 200mm diameter and 8.8 to 9.4m long, in a square grid of 0.75m spacing. Improvement of the site determined by standard penetration test (SPT) showed that the strength of the ground increased by 2 to 3 times along the depth. In a research project, field investigation was carried out at BIT, Khulna, to depict the effectiveness of granular piles in improving soft ground. Granular piles such as sand piles and stone columns of 200mm diameter and 6m long were installed both in the single and group pattern by using dry-displacement and wet-replacement methods. The improvement was measured by conducting plate load test and standard penetration test. At BIT Khulna, a five storied Student's Dormitory is under construction on individual column footing by replacing a 4.35 m thick soft compressible soil layer with a designated compacted sand. A research project is undertaken to monitor the performance of such foundation system in a soft compressible soil deposits. The investigations reveal the success of the adopted foundation systems as an alternative of the conventional foundations.

KHULNA MEDICAL COLLEGE PROJECT

Khulna medical college located at Sonadanga area of Khulna city. The old 250 bed hospital complex was extended to accommodate the infrastructural facilities required for a medical college campus. The sub-soil investigation (MSEL 1984 and CRTS 1995) reported that the project site geologically lies on a thick highly compressible clay and organic deposits. The location of ground water table varies with season. During the rainy season the water-table lies at ground surface to 4.5m depth while in dry season the water table goes down to 1 to 1.5m depth from the existing ground surface. In general, a layer of brownish gray of very soft clayey silt exists up to 1.5m from the existing ground surface and between 1.5 to 6m, a layer of dark decomposed organic and very soft clayey silt encountered. Beyond this layer, from 6 to

13m a layer of very soft to soft clayey silt exists while dark gray decomposed organic clayey silt exists from 13 to 18m. The Public Works Department (PWD) of Khulna, took the responsibility to construct the infrastructure in Khulna medical college. Due to the presence of thick highly compressible organic soil layer in the site, a foundation system using Geotextiles at the base was suggested and hence constructed recently in the academic building, boys and ladies hostels and residential buildings. Foundation system at academic building (Fig.2) and the typical cross section of the foundation system used at residential buildings (Fig.3) are shown in Fig's. 4 and 5, respectively. The properties of used Geosynthetics are presented in Table 2. The foundation of academic building and two hostels were designed by two different authorities. The supervision and the quality control at the construction phase were ensured by the PWD and the consultants. To examine the performance of this innovative type of foundation system in Khulna sub-soil, employed for the first time in Bangladesh, settlements were monitored in all these constructed building for more than three years. Result shows that the settlement behavior is not uniform to the same type of building. The settlement of some buildings is much higher than that of predicted value. Settlement of the heavily loaded academic building is very low, 60mm as measured on June 2000, while it is very large, 600mm as measured on June 2000, for the lightly loaded residential building. The settlement profiles with time are shown in Fig. 6 as measured for more than three years in some apartment buildings suffered from large settlement. The large settlement effects the serviceability of the building and the questioned the effectiveness of such foundation system. The sub-soil condition shows that there exists a organic clayey silt layer in between the depth of 2.4 and 6.4m and again in between 13 to 18m from the existing ground surface. Due to these two thick compressible layers, the structures faced serious settlement problem.

There is a compressible layer just beneath the foundation, which will be obviously compressed when greater load imposed on it. Again due to the smaller nature of the residential buildings, the load intensity spreads over a smaller area. In residential buildings the plinth area of individual

Fig. 2. Academic Building of Khulna Medical College.

Figure 3. Residential Building of Khulna Medical College

Table 2. Properties of Geosynthetics used in Khulna Medical College.

Properties	Standard	Values
Polymer	-	Polyester/ Polypropylene
Weight (gm/m^2)	ASTM-D-3776	≥ 200
Grab Tensile Strength (N)	ASTM-D-4632	≥ 750
Permeability (10^{-3} m/s)	ASTM-D-4491	≥ 1.0
Geotextile rolls:		
Width (m)	-	≥ 4.0
Length (m)		≥ 40

buildings is small and also the buildings were constructed individually. In spite of that the load intensity is more in the residential area than that of academic building. Due to this load and weak compressible soil, the buildings settled more quickly but the settlement occurs uniformly except two residential buildings and cracks in the buildings do not visible.

The differential settlements in the two buildings occurred for the different soil consistency in horizontal soil layer due to the presence of a deep ditch, which was not encountered in the sub-soil report. However no cracks were observed in the constructed buildings. Investigations reveal that a general sub-soil profile were considered for the design of foundation in all the buildings, which is not appropriate for the site where highly compressible organic and erratic soil conditions exist. For the design, the sub-soil for the individual buildings should be investigated and the design must be based on the actual soil conditions of this site. However, this experience shows that the geosynthetics based foundation system can be used successfully in such a soil condition if all the necessary steps such as sub-soil investigation, design and construction are done properly. Details about this foundation system and the performance study are given in Haque (2000) and Haque et al. (2001).

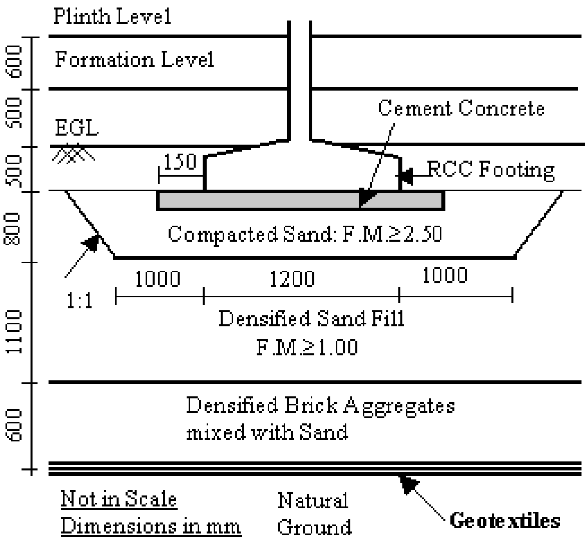


Fig. 4. Foundation system at academic building.

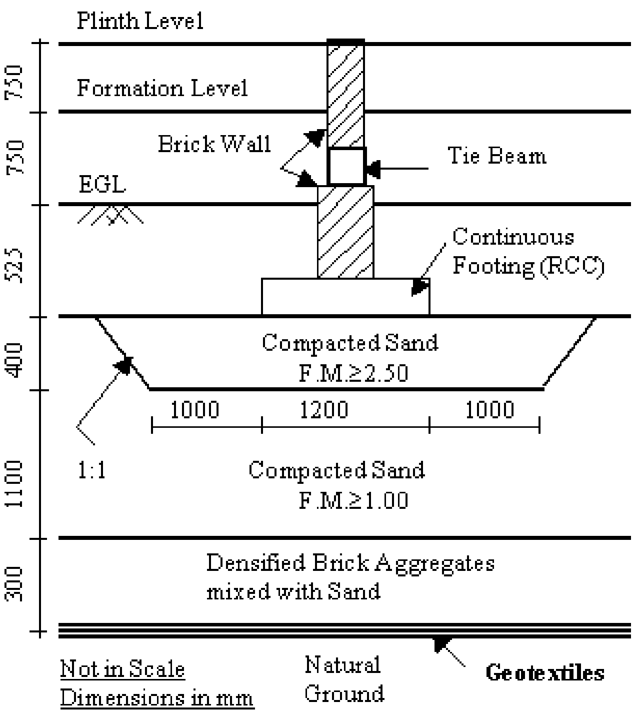


Fig. 5. Foundation system for the residential buildings.

ACADEMIC BUILDING OF KHULNA UNIVERSITY

Khulna University is situated on the Khulna-Satkhira highway about 4.0km from the center of Khulna city. The sub-soil investigation (BRTC 1988) reveal that the top 1.5m. consists of soft clay. Beyond this layer, a soft fine-grained soil layer with decomposed wood and vegetation extends up to the depth of 5m. This layer is followed by a thick layer (5m to 20m) of soft clay with silt and organic. After this layer, a sand layer of

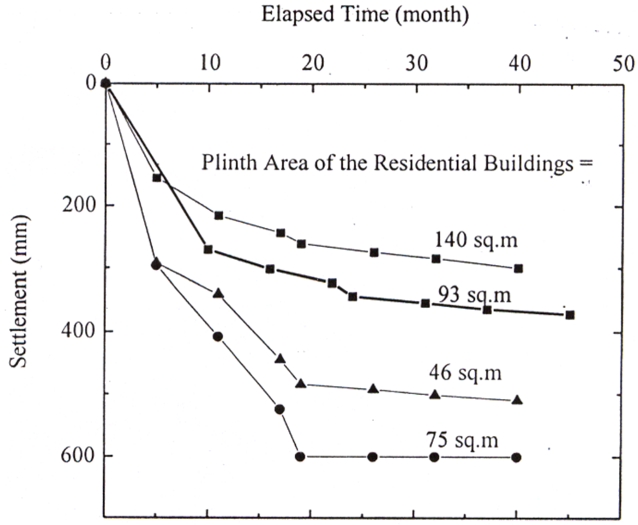


Fig. 6. Settlement profiles with time for the buildings suffered from very large settlements.

medium to very dense relative density exists up to the end of boring, ranged from 30m to 50m depth from the existing ground surface.

In Khulna university campus several structures have been and are being constructed since 1988, first of which is academic building-I shown in Fig.7 started in the year of 1992 and completed in the year of 1994. Considering the sub-soil condition, the entrusted consultant (SARM 1992) suggested a foundation system of the replacement of 6m thick soft fine grained soil from the existing ground surface. This excavated area was refilled by the compacted sand cushion and than the building was rested on a mat foundation. The excavation of 4.27m measured from the bottom was filled by sand having Fineness Modulus of 2.20 and 1.20 mixed at a ratio 1:1 and compacted properly by sheepsfoot roller. Optimum moisture content and the thickness of sand layer were maintained properly to ensure 90 to 95% degree of compaction in the field. Mat foundation of thickness 300 to 450mm was than prepared over the compacted sand filling. From the top of mat up to plinth, fine sand having Fineness Modulus of 0.80 was used as filling materials. Typical cross section of the foundation system adopted in the academic building-I is shown in Fig. 8.

To examine the performance of the adopted foundation system, the academic building-I was instrumented during the construction simply by installing some settlement plates at the important locations. The settlement of the building has been observed as shown in Fig.9 for about 6 years since the commencement of the construction with the help of these settlement plates. Very large settlement measured as 765mm was observed which is about three times higher than that of the designed value. Settlement measured as about 500mm occurred during the first one year and a half. The rate of settlement decreases with time and no further increase of settlement was recorded for the last one year.

Fig. 7. Academic building of Khulna University.

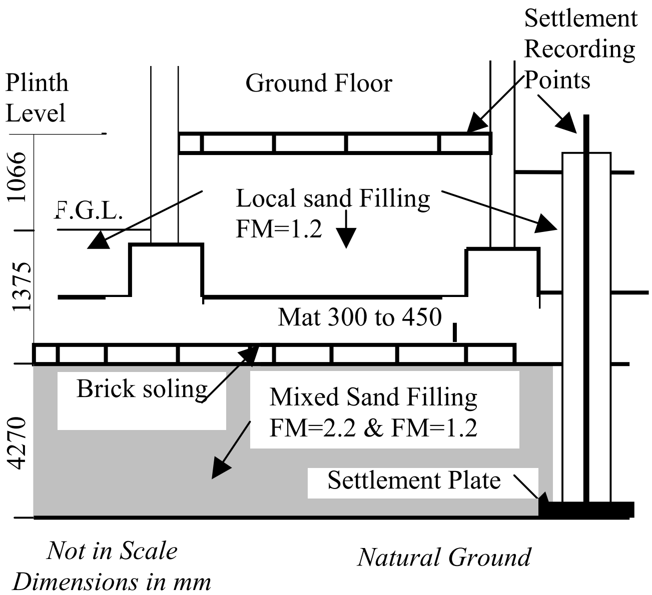


Fig. 8. Foundation system for academic building-I.

Due to the replacement of peat layer by compacted sand cushion, the load on the sub-soil has increased. The compacted sand cushion with mat foundation pushed the underlying soft soil layer downward. Despite the large settlement any distress was not visually apparent but the serviceability is effected up to some extent due to large settlement. However, despite the very large settlement the serviceability of the structures can be retained even with this foundation system by the accurate prediction of the allowable settlement at the design. For details the reference can be made as Razzaque and Alamgir (1999a and 1999b).

SIX-VENT REGULATOR ON PASSUR RIVER AT FAKIRHAT

A six-vent regulator at Passur river at Fakirhat, was built as a part of a small scale water resource development project as shown in Fig.10. The soil conditions indicate that the sub-soil at the regulator site consists of very soft to soft alluvial deposits till the depth of 12m. Due to poor soil conditions the six-vent regulator could not be built without using any appropriate type of foundation. Considering the limitations of conventional deep foundation soil improvement is considered as an economic solution. Installation of sand piles was considered as one of the suitable ground improvement technique to improve the soft soil deposits. Total 528 sand piles, 300mm diameter and 8.50m long in a square grid of 0.90m spacing, was proposed for the site improvement at the initial design. Later due to the construction difficulties faced to install 300mm diameter sand pile, the consultant changed the dimensions and spacing of sand piles. Finally, total 765 sand piles, 200mm diameter and 8.80 to 9.40m long, in a square grid of 0.75m spacing, were suggested and hence installed successfully (Alamgir and Zaher 1999a and b). A schematic diagram of the construction sequence is shown in Fig. 11. Sylhet sand, a yellowish-brown river sand of Sylhet, Bangladesh, was used in sand piles. The conventional rig used for driven pile was used here for sand pile construction. Improvement of the site was examined before commencement of concreting for floor construction of the regulator.

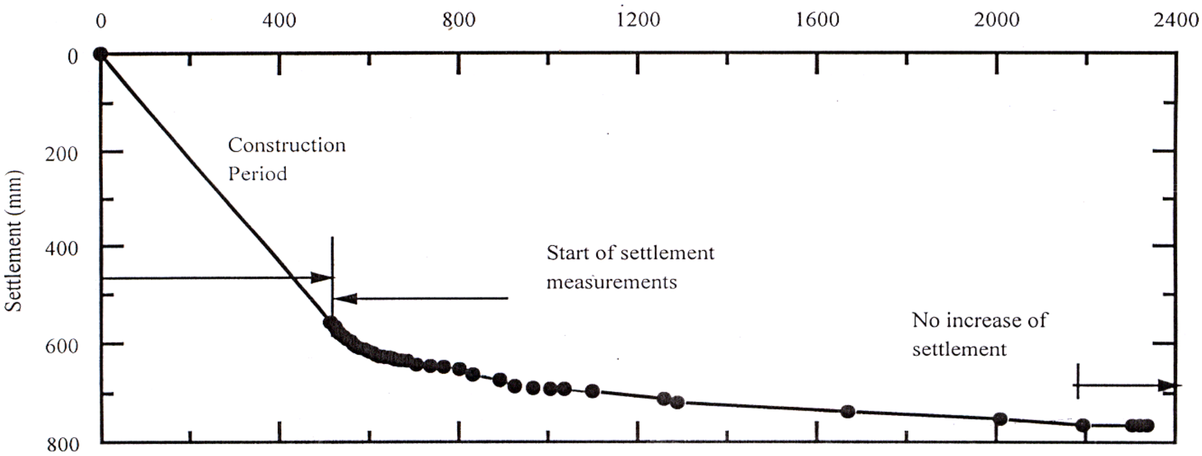


Fig. 9. Time settlement observation at academic building-I.

Standard penetration test (SPT) was carried out till the tips of the constructed sand piles in the three selected locations of the regulator. The field test result shows that the sand piles substantially improved the bearing capacity of the natural ground and hence the concreting for the floor construction was done successfully. The N-values almost increased by three to four folds compared with the natural ground as shown in Fig. 12. Results reveal that the sand piles effectively improved the whole area.

GRANULAR PILES CONSTRUCTED IN BIT KHULNA

The effectiveness of granular piles in improving the soft ground is described here. Experiments were conducted at the

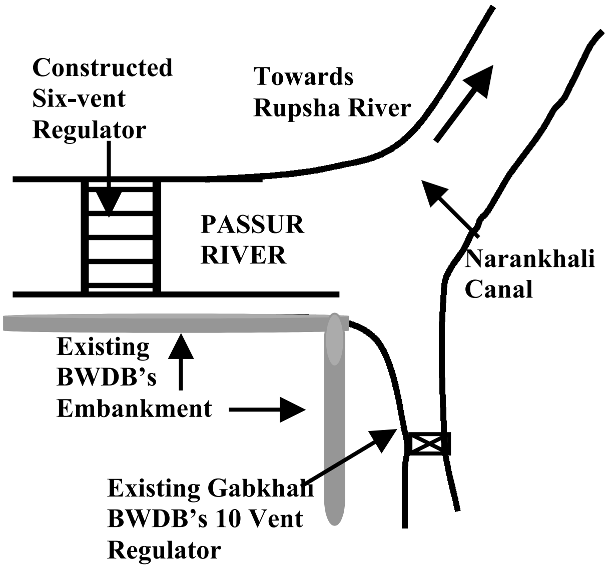


Fig. 10. Location of the six-vent regulator at Fakirhat.

BIT campus. The sub-soil at BIT campus consists of fine-grained soil till the great depth. Sub-soil profiles are given in Table 1. In this project, granular piles were installed using both the wet-replacement and dry-displacement methods. Granular piles are made of sand and crushed stone compacted in a cylindrical hole into the soft ground. Sylhet sand, Local sand and stone chips as shown in Fig. 13 were used. A combined sand by mixing Sylhet sand and local sand at a ratio1:2 was also used.

In this project, sand pile (using combined sand) and stone columns with a diameter of 200mm and a length of 6m were installed by dry-displacement method (Zaher 2000, Alamgir and Zaher 2001 and Alamgir et al. 2001). Granular piles were installed in single and group pattern with triangular arrangement at 750mm spacing as shown in Fig. 14.

The effectiveness was measured by the plate load test at natural and improved ground. The field measurement as shown in Figure 15 reveals that the load carrying capacity of soft ground is increased significantly due to the installation of granular piles irrespective of the type of granular materials. The result reveals that the stone columns can carry around 2.5 times more load than that of sand piles. The investigation shows that the piles/columns spacing ratio is to be less than 2.5 to get the group effect. The change of soil strength along the depth was also examined by conducting standard penetration test (SPT) after ten months of granular piles installation. SPT result shows that the soil strength measured as N-Value, increases along the depth by 2 to 3 times due to the installation of granular piles.

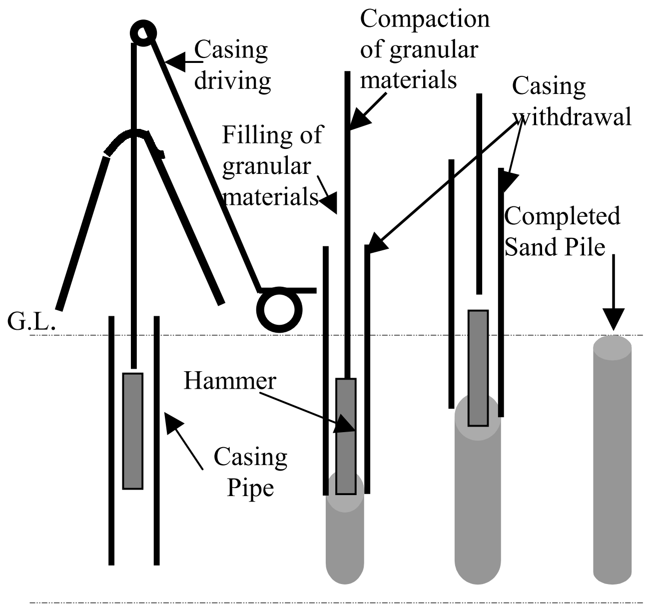
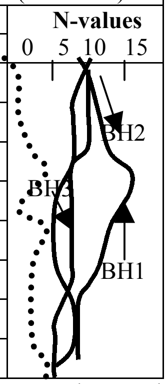


Fig. 11. Installation sequence of granular piles.

Depth of Soil (m)	Standard Penetration Test Results (N-Values)			
	NG	*Improved Ground*		
		BH1	BH2	BH3
0-1.5	2	7	9	9
1.5-3	3	9	9	8
3- 4.5	4	10	7	7
4.5- 6	2	13	8	7
6- 7.5	4	11	8	7
7.5-9	3	9	7	8
9-10.5	3	7	6	8
10.5-12	4	6	7	7



Natural Ground (NG) — Improved Ground
BH1, BH2 & BH3 are Borehole 1, 2 & 3

Fig. 12. Improvement of ground measured by SPT.

In the same site, wet-replacement method was used to install sand piles and stone columns, 200mm diameter and 6m long, in a single pattern (Sobhan 2001 and Alamgir et al. 2001). The equipment was fabricated locally and wash boring method used to create the hole. Three types of granular materials, namely, a combined sand prepared as Sylhet sand : Local sand =1:2, Sylhet sand and 10mm well down graded stone chips were used. Effectiveness was measured by the plate load test as shown in Fig. 16. The result reveals that the bearing capacity of the improved ground was increased by 144% for combined sand, 166% for Sylhet sand and 177% for stone chips comparing natural ground. In the wet-replacement method caving was created along the hole especially in the upper region of the granular piles due to the overburden pressure. As a result materials consumption increased and the

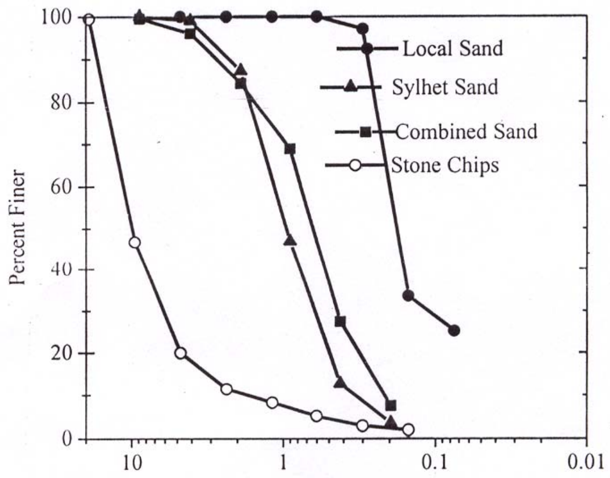
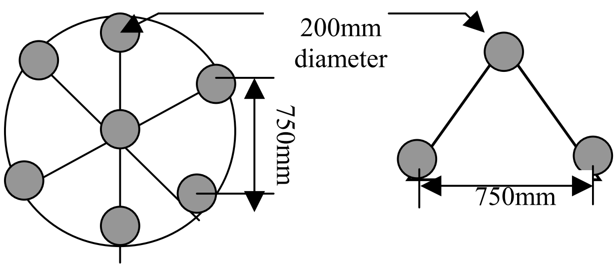


Fig. 13. Grain size distribution curves of granular materials.



(a) Sand Piles (b) Stone Columns

Fig. 14. Layout plan of granular piles.

the adjacent fine-grained soils infiltrated into the voids of granular materials. The experience reveals that the installation of granular piles were carried out smoothly for the case of dry-displacement method but special measures were required to in case of wet-replacement method.

STUDENT DORMITORY AT BIT KHULNA

BIT Khulna is situated on the Khulna-Jessore highway about 11.0km from the center of Khulna city. The sub-soil investigation (UBEL 2002) reveals that the top layer consists of 3m thick fine filling sand. After that a soft fine-grained soil layer with decomposed wood extends up to the depth of 8m. This layer is followed by a thick layer (8m to 26m) of clayey silt with high organic contents at a depth 22 to 23m. Beyond this layer fine sand of dense to very dense relative density exists up to the end of boring ranged from 33 to 36m depth from the existing ground surface. The consultant (UBEL 2002) suggested friction pile of diameter 500mm and length 22.5m to carry 30 tons per pile in compression.

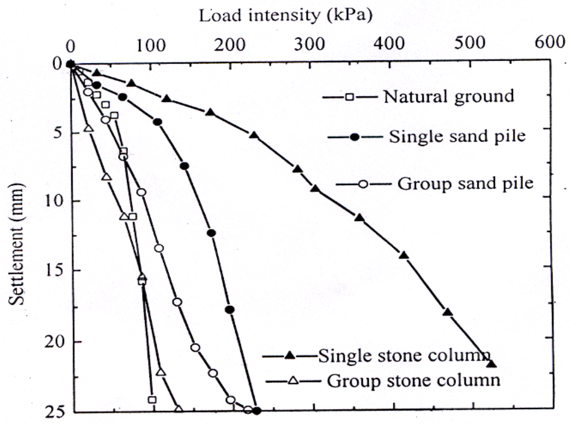


Fig. 15. Load-settlement response for dry-displacement method.

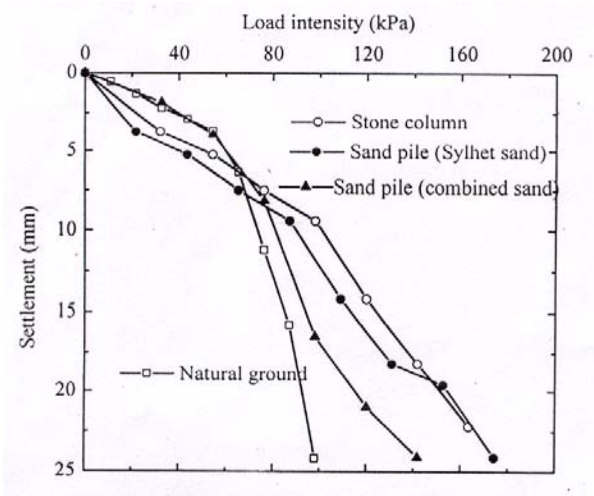


Fig. 16. Load-settlement response for wet-replacement method.

But the Engineering section of the Institute was decided a foundation system replacing the 3.4m thick soft fine-grained soil from the existing ground surface. This excavated area was refilled by compacted sand cushion and than the building was rested on individual footing. The excavation of 2.1m measured from the bottom was filled by sand having Fineness Modulus of 1.20 and compacted properly by sheepsfoot roller. Optimum moisture content and the thickness of sand layer were maintained properly to ensure 90 to 95% degree of compaction in the field. Rectangular isolated footing of average dimension of 4800x3800 mm of thickness 150 to 200 mm inches was than prepared over the compacted sand filling. Typical cross section of the foundation system adopted in the student dormitory is shown in Fig. 17.

Table 3. Soil profile at Student dormitory site in BIT Khulna

Depth of Soil (m)	Average of Four Bore Holes	
	N-value	Stratification
0-3	5-10	Firm silt, trace clay, fine sand
3-6	2-3	Soft clayey silt
6-8	2-7	Soft decomposed wood
8-10	3-7	Firm clayey silt
10-22	3-8	Soft to firm clayey silt
22-23	6-7	Firm clayey silt, trace organic
23-26	6-7	Firm clayey silt
26-31	6-11	Compact silt, trace clay, fine sand
31-33	26-49	Dense silt & fine sand

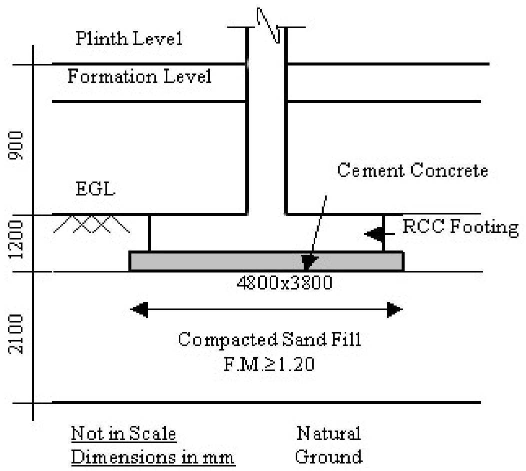


Fig. 17. Foundation system of Student Dormitory at BIT, Khulna.

CONCLUDING REMARKS

This paper discussed the field performance of some ground improvement techniques practiced to construct the structures in Khulna region of Bangladesh. The considered ground improvement techniques are granular piles, sand replacement and the use of geotextiles in shallow foundation. In most of the cases soft compressible ground was improved successfully by the adopted improvement techniques and the constructed structures are found in safe conditions considering both the technical and utility aspects. However in some of the cases the effectiveness of the above adopted ground improvement techniques is questionable due to very large total and differential settlements. The adopted foundation systems have proved their success and open the future prospects as an alternative of the conventional pile foundation in such big projects. From these field investigations it can also be concluded that the success of any adopted ground improvement techniques in such soft compressible soil depends on the close monitoring system and the quality control in all the steps involved in the engineering works such as sub-soil investigation, design and construction.

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