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Performance of geotextile-reinforced shallow foundations used in Bangladesh

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ABSTRACT: This paper describes the field performance of geotextile-reinforced shallow foundation system constructed in a highly compressible soil deposits in the south-western region of Bangladesh to bear the buildings. The settlement in all the twenty eight constructed buildings were measured for the last three years starting from the completion of the foundation system. The measured settlements of the constructed buildings are more than that of the predicted values except the three buildings. The largest settlement, 600mm, was measured at a 75 square meters staff quarter while the lowest value was measured as 50mm at the Ladies hostel. The field measurement shows that uniform settlement occurred in all the buildings except two residential buildings. The results reveal that the geotextile-reinforced foundation system works perfectly in preventing the differential and total settlements of the buildings resting in a highly compressible soil provided the design is done properly based on the actual soil condition of the site and the material properties.

1 INTRODUCTION

Soil reinforcement has become a major part of geotechnical engineering practice over the last thirty five years and its use is growing rapidly as world wide development poses an increasing demand for land reclamation and the utilization of soft foundation soils. The modern form of soil reinforcement was introduced by Henry Vidal, a French architect and an engineer in the 1960s. Vidal's concept (Vidal 1969) was for a composite material formed flat reinforcing strips laid horizontally in a frictional soil, the interaction between the soil and the reinforcing members being solely by friction generated by gravity. The use of geosynthetic is a rapidly expanding area of geotechnical technology with numerous new products and applications being produced with any one year (Raymond & Giroud 1993). The geosynthetic-reinforced granular fill soft soil systems are now being used very frequently for shallow foundations (Shukla 1994). Experimental study on the use of geosynthetics in foundation bed was started as early as 1970 by Yamanouchi (Yamanouchi 1970). Such reinforced soil systems provide improved bearing capacity and reduced settlements by distributing the imposed loads over a wide area of weak sub-soil (Binquet & Lee 1975, Sakti & Das 1987, Ghosh & Madhav 1994, Otani et al. 1994). Soil reinforced provides numerous other indirect benefits such as speedy construction time, ease in construction etc. In Bangladesh, geotextile have been used in a shallow soil-reinforced foundation system to bear the buildings loads in a highly compressible organic soil at Khulna medical college campus as an alternative of conventional foundation. Twenty eight buildings of different categories were constructed and thus monitored for a long period to depict the performance of geotextile-reinforced foundation system (Haque 2000).

This paper describes the field performance of geotextile-reinforced shallow foundation system used to bear the buildings constructed in a highly compressible soil deposits in the south-western region of Bangladesh. Here the focus is mainly given on the measurement of total and differential settlements of the buildings occur under full design load. In the constructed twenty eight buildings, the settlement measured for 3 years, are more than that of the predicted values except the three buildings, namely, Academic building, Boys hostel and Ladies hostel. The largest settlement, 600mm, was measured at a 75 square meters staff quarter, which is four times higher than that of prediction. The lowest settlement was measured as 50mm at the ladies hostel. Almost uniform settlement occurred in all the buildings except two residential buildings. The sub-soil investigation reveals that the soil conditions around the residential buildings, where maximum settlement occurred, are different than that of general soil condition of the site, which was considered in the design. The results reveal that the geotextile-reinforced foundation system works perfectly in preventing the differential settlement and as well as the total settlement of the buildings resting in a highly compressible soil provided the design is done properly.

2 STATEMENT OF THE PROBLEM

The public works department (PWD) of Bangladesh undertaken the construction of Khulna medical college complex buildings at Sonadanga, Khulna in 1992. Sub-surface investigation was carried out at the project site. Based on the site condition, a shallow foundation system using geotextiles was employed in all constructed buildings at the campus.

2.1 *Location and soil condition of project site*

Khulna city is located about 332 km south-west of capital Dhaka as shown in Figure 1. The Khulna medical college complex is situated at Sonadanga of Khulna Metropolitan City and within the old 250 Bed Hospital Complex.

The sub-soil profile of Khulna city is characterized by brownish gray to gray. Soft to medium soft clay with silt and very few gray loose fine sand with organic contents which reveals that the sediments are sub-recent to recent in age. It also shows the regular sequence of lithological composition and consistency of the formation of same nature at least up to the 30m depth in all the explode bore holes. Sub-soil investigation (FCL 1984, CRTS 1995) shows, geologically the project site lies on a thick highly compressible fine-grained clay and organic soil deposits. The ground water table varies with the season. During the rainy season the water table lies at ground surface to 150mm depth while during dry season the water table goes down to 1.0 to 1.5m below the ground surface. The sub-surface soil is composed of pure clay and some where it is black organic clay. This layer extends to 2.50m depth and then starts organic clay, organic silt and clayey silt, which extends up to 15m.

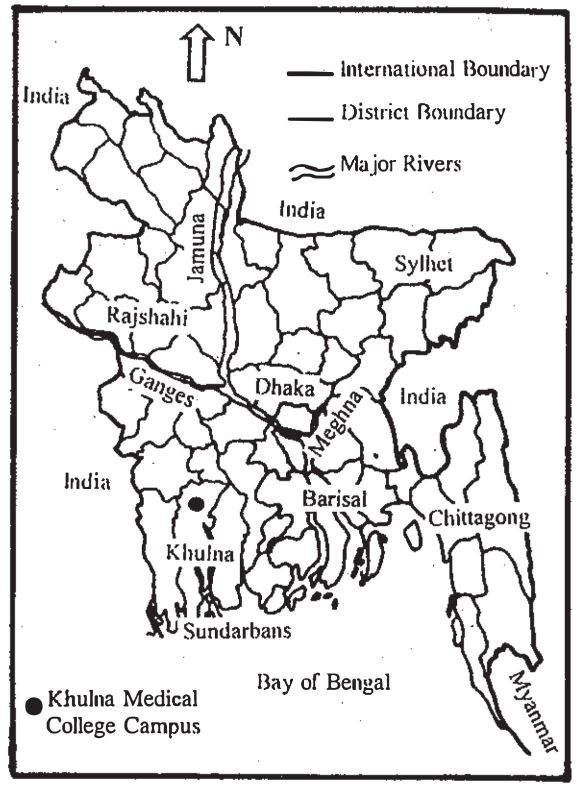

Figure 1. Project site shown in Bangladesh map.

2.2 *Foundation system*

Sub-soil investigation reveals that the soils are too weak to support a traditional economic spread foundation at shallow depth. Considering the soil type and its initial properties, materials availability, equipment, technical advantages, economy and finally with a hope and confidence, the authority came to a decision to introduce a new foundation system, geotextile-reinforced shallow foundation. By introducing geotextiles reinforcement, same traditional spread foundation was provided at shallow depth with improving sub-soil by sand mixed with khoa (brick aggregates) and sand compaction with geotextiles. The spread foundation rests on the compacted composite bed. The foundation system of two representative buildings are described below.

In the foundation system of Academic building having plinth area 3900 square meter, the total area covered by geotextiles is 7800 square meter. As per design provision, the geotextile is extended 4.5m beyond the plinth area of the buildings in all sides and the gaps between the front and mid block, mid block and gallery and galleries and blocks, were covered by geotextiles. After laying the geotextile on natural ground at a depth 3m from the existing ground level, a 600mm layer of densified brick aggregates and sands mixed were placed. Then 1.1m sand (FM≥1.0) and 0.8m sand (FM≥2.5) layers were placed. Both the layers were compacted by vibro-roller to obtain the designated degree of compaction. RCC footing having a cement concrete at the base was placed in the foundation. The plinth level raised to a vertical level at 1.20m above existing ground level (EGL). Typical cross section of the foundation in the Academic Building is shown in Figure 2.

In the foundation system of 75 square meter of staff quarter, the area covered by geotextiles is 520 square meter by extending geotextile 4.5m beyond the plinth area of the buildings in all sides. After laying the geotextile on natural ground at a depth 2.225m from the existing ground level, a 300mm layer of densified brick aggregates and sands mixed were placed. Then 1.1m sand (FM≥1.0) and 400mm sand (FM≥2.5) layers were placed. Both the layers were compacted by vibro-roller to obtain the designated degree of compaction. RCC continuous footing having was then placed in the foundation. The plinth level raised to a vertical level 1.5m above existing ground level (EGL). A typical cross section of the foundation system constructed in the 75 square meter staff quarter is shown in Figure 3.

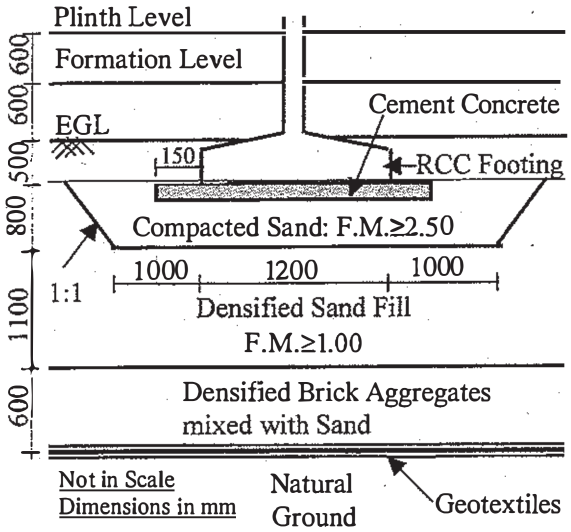

Figure 2. Foundation system at Academic Building.

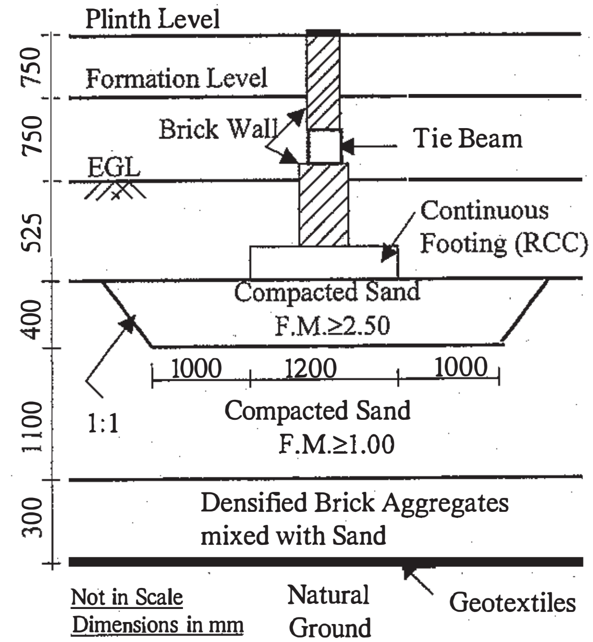

Figure 3. Typical cross of the foundation system used at 75 square meter staff quarter.

2.3 *Constructed buildings*

Total twenty nine buildings for different types are considered for the construction in Khulna medical college campus. As suggested from the sub-soil conditions, similar type foundation system were employed. Table 1 shows the list of already constructed 28 different types buildings. Out of these 28 buildings, the largest one is the Academic Building of 3900 square meter plinth area, constructed with reinforced cement concrete (RCC) frame. In addition of academic building, other 27 buildings, plinth areas vary from 1530 to 46 square meter were constructed.

3 FIELD INVESTIGATION

Field investigation was carried out to depict the in-situ performance of geotcxtile-reinforccd foundation system adopted in the constructed buildings. The performance is mainly evaluated based on the observed settlement response of the constructed buildings.

To observe the settlement from the beginning of the construction work, permanent Bench Mark pillars were established in front of each building. The settlement of all the buildings are measured at about every 6 months interval from July, 1997 to August, 2000, as shown in Table 2. The settlement measurements have been taken for total 19 constructed buildings. In general, from the table it can be seen that the settlement increases with time. The large amount of settlement occurs within the first one year. After that, although the settlement continues, the rate of settlement decreases.

Table 1. List of the buildings constructed with geotextile-reinforced foundation system.

Sl. No.	Name of the Building	No. of Building	Plinth Area (square meter)	No. of Stories	Unit in each Building
1	Academic Building	1	3900	4	----
2	Boys & Girls Hostel	2	1530	4	----
3	Prof. & Assoc. Prof. Quarter	6	140	4	4
4	Assistant Professor Quarter	3	116	4	4
5	Lecturer & Doctor's Quarter	5	93	4	8
6	Second Class Staff's Quarter	1	75	4	8
7	Third Class Staff's Quarter	3	56	4	8
8	Fourth Class Staff's Quarter	7	46	4	8

Table 2. Measured settlement of the constructed buildings.

Sl. No.	Name of the Building	Settlement (mm) Measured on the Following Seven Dates						
		15.9.97	15.3.98	15.9.98	26.11.98	30.6.99	30.12.99	30.8.2000
1	Academic Building	0	0	5	10	15	25	60
2	Ladies Hostel	0	0	5	10	20	30	50
3	Boys Hostel	30	30	37	37	40	75	126
4	Prof.'s Quarter No.1	155	216	244	262	275	285	300
5	Prof.'s Quarter No.2	180	235	259	271	282	291	300
6	Prof.'s Quarter No.3	165	223	262	298	298	298	300
7	Prof.'s Quarter No.4	155	213	253	296	305	316	327
8	Asstt. Prof.'s Qr. No.1	186	244	277	305	305	305	306
9	Asstt. Prof.'s Qr. No.2	265	329	363	381	387	392	400
10	Lecturer's Qr. No.1	271	302	323	344	354	364	372
11	Lecturer's Qr. No.2	219	298	354	378	398	426	440
12	Lecturer's Qr. No.3	332	366	408	436	442	449	453
13	Second Class Staff Qr.	296	408	524	600	600	600	600
14	3rd Class Staff Qr. No.1	256	326	393	413	416	420	426
15	3rd Class Staff Qr. No.2	158	213	283	329	357	390	414
16	4th Class Staff Qr. No.1	293	341	445	485	493	502	510
17	4th Class Staff Qr. No.2	268	372	445	521	526	532	537
18	4th Class Staff Qr. No.3	314	396	482	524	536	546	558
19	4th Class Staff Qr. No.4	302	357	415	427	442	466	483

4 RESULTS AND DISCUSSIONS

The performance of geotextile reinforced foundation system are studied based on the measured settlements. The foundation system shows the negligible settlement case and also four times larger settlement than that of predicted. The causes of settlement of these two extreme cases are identified here and hence discussed in the following sections.

4.1 *Settlement response of academic building*

The foundation of Academic building was constructed for five-story at front and north block, three-story for both galleries and cafeteria. In first phase construction was completed three stories at front block and partly four stories at north block. Full load has already been loaded at the gallery. But cafeteria stands up with one story load.

From the loading condition described above, it is clear that the two blocks of the original academic building was not yet been loaded fully as per the design consideration. Only two galleries was loaded as per the design. Even though the full load has not been imposed yet, 60% of the settlement would be expected to occur at this loading stage. But only 60mm settlement was recorded till August 30, 2000, which is much lower than that of predicted value. Sub-soil report shows that a relatively good soil condition exists in this particular site. Also the load intensity of all blocks are distributed over a larger area than the building area due to the extension of geotextiles by 4.5m in all the sides from the boundary of the building.

4.2 *Settlement response of residential buildings*

After 3 years of construction, the settlement of residential buildings were found as much higher than that of predicted. The time-settlement profiles of four types residential buildings are shown in Figures 4 to 7. Very soft dark gray and grayish brown clay exists up to 3m depth from existing ground surface. Next 6m is very dark gray organic clay and the further 9m is gray/dark gray silty clay with organic traces. The geotextile was laid just on the very dark gray organic clay, which is most compressible layer. Due to the self weight of the building and improved foundation layer on geotextile, the bottom layer compressed deadly. But the structure surrounding with geotextile (4.5m around the building) settles uniformly. As a result, no differential settlement occurred in any place and no cracks observed in any portion of the building.

4.3 *Causes of variation between the predicted and measured settlements*

If one endeavor to inquire about the cause of excessive settlement, then it is revealed that, in Academic building the existing imposed load is now below the assessed vertical load. In this building, the geotextile area is large, as a result the bearing area is also augmented, and the loading intensity is comparatively low, on the foundation. Since the improved soil bed on geotextiles acts as a mat, moreover the soil condition around the Academic building area is comparatively more eminent than the residential areas. Besides this almost all the buildings in the residential

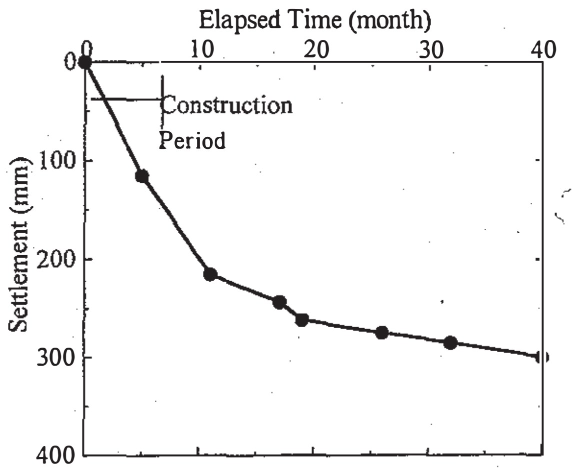

Figure 4. Settlement profiles of 140 square meter Professor's & Associate professor's quarter.

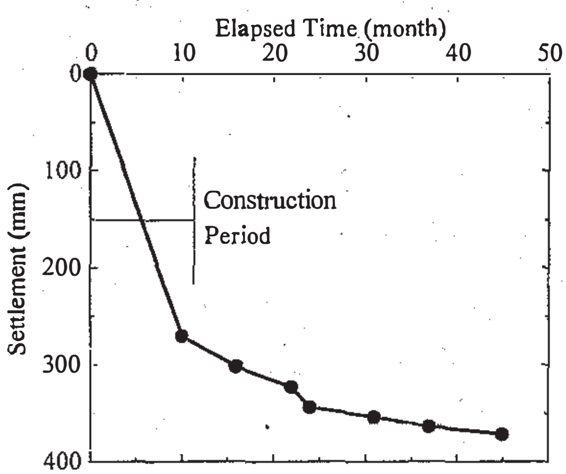

Figure 5. Settlement profiles of 93 square meter Lecturer's quarter No.1.

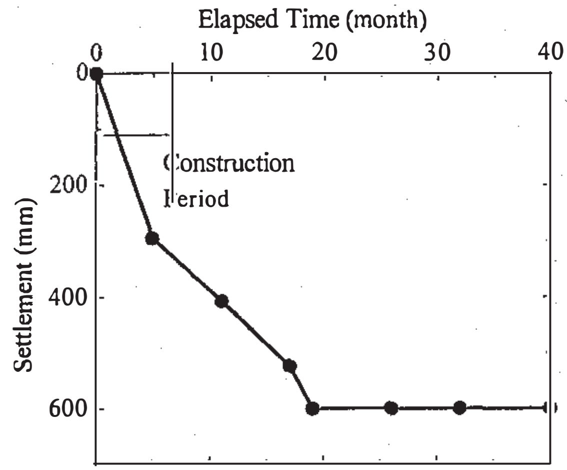

Figure 6. Settlement profiles of 75 square meter Second class staff quarter.

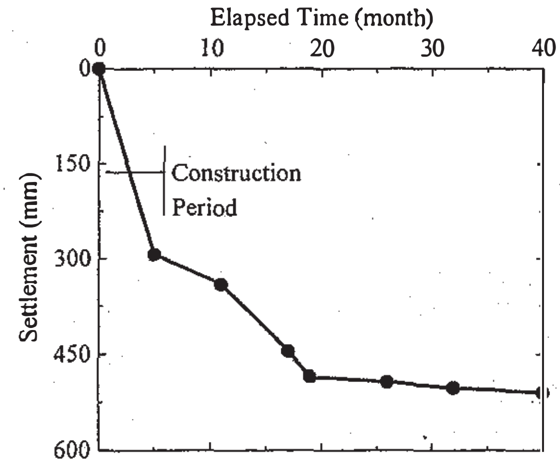

Figure 7. Settlement profiles of 46 square meter Fourth class staff quarter No.1.

area settles excessively. 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. Due to these two thick compressible layers, the structures fall into 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 buildings is small and also the buildings were constructed individually. In spite of that just now the load intensity is more in the residential area than the Academic building. Due to this over and above load and weak compressible soil foundation, the quarters settled more quickly but the settlement occurs at uniformly in every place of the buildings and cracks in the buildings do not visible.

4.4 *Performance of geotextiles*

The settlement behaviour depicts clearly that the geotextiles performed perfectly in the foundation system. If geotextile has not worked accordingly with pull up or expansion then differential settlement could be occurred. As a result cracking symptoms inevitably is to be shown. Any differential settlement except two residential quarters were observed. The differential settlement in those two buildings occurred for the different consistency in horizontal soil layer due to the presence of deep ditch, which was not encountered in the sub-soil report. However, no cracks were observed in any one of the constructed buildings.

5 CONCLUDING REMARKS

Based on the present study the following conclusion can be made:

1. Field investigation shows that the measured settlements are 2 to 4 times higher than that of predicted values in all the constructed buildings except three buildings.

2. Despite the large settlements, no differential settlements and cracks were observed, that reveals the good performance of geotextiles in preventing differential settlement even in very soft ground.

3. The field investigation depicted the fact that the exact sub-soil profile in every building site is to be determined individually to use in design.

4. In Bangladesh, geotextiles are almost new materials in shallow foundation. So in the contract provision to monitor the performance of the foundation should be included.

6 ACKNOWLEDGEMENT

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