COST EFFECTIVE FOUNDATION ON PROBLEMATIC SOIL OF RECLAIMED AREAS IN DHAKA CITY

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ABSTRACT
Dhaka city is expanding rapidly on reclaimed land. Most of these sites are developed by filling marshy lowlands (1.5~13.5 m) using dredged materials from nearby river bed. Almost all fills are basically silty sand. The SPT N-value of the filling varies from 1~13. Current practice of foundation design for buildings in reclaimed areas is generally deep foundation (piles). Long piles are essentially vulnerable to lateral loads and construction of such long piles is difficult. Moreover, for five to six storied buildings pile foundation is uneconomical. This study has been conducted to propose an alternative and cost effective foundation system for building in reclaimed areas of Dhaka city. The study site was in Mirpur Defence Officers' Housing Scheme (DOHS), Mirpur, Dhaka. A shallow foundation with reinforced base soil was constructed at the selected site for full scale load test. Bearing capacity of the foundation soil was found to be increased by 15-20% due to base soil reinforcement. This test result eliminates the requirement of a deep foundation for a five to six storied residential building on such problematic soil. The finding of this study thus reveals a cost effective foundation alternative for medium rise structures in reclaimed areas of Dhaka city.

Keywords: Reclaimed area, geotextile, fill materials, cost effective foundation.

INTRODUCTION
Dhaka city is experiencing a rapid growth of urban population and it will continue to do so in future due to several unavoidable reasons. As a result, different new areas are being reclaimed near Dhaka city. In most cases, the practice for developing such reclaimed areas is to fill low lands (1.5-1.5m) by dredged soil collected from nearby riverbed (Islam and Nasrin, 2009; Ahmed, 2010 and Islam et al., 2013). Hydraulic filling procedure is the most widely used method among many filling procedures to reclaim such lands. Fig. 1 gives a pictorial view of reclamation procedure of the present day in Dhaka city. Details of land reclamation procedure are described in Islam et al. (2013).

Some studies have been carried out to evaluate the characteristics of dredged fill layer of the reclaimed sites (Ahamed 2005;). In most cases, the dredged material is silty sand with high fines content (Islam and Hossain, 2010). The presence of fines in hydraulic fill means greater compressibility and reduced permeability and hence it is subjected to long term consolidation. Soft organic clay layer beneath the filling layer may also cause excessive settlement problem to the structures lying on top of such soil with a shallow foundation (Islam et al., 2013).

Current practices of foundation design for buildings in such reclaimed areas are mainly construction of piles. Long piles are essentially exposed to lateral loads and negative skin friction (Islam and Nasrin, 2009). Negative skin friction produces a drag load that can be of substantial amount for long piles. Quality control of cast-in-situ long piles is also questionable. Moreover, for five to six storied building, pile foundation becomes uneconomical. Hence, the need for a cost effective foundation on such problematic soil has emerged as a potential subject to be addressed. The ultimate capacity of a reinforced shallow foundation on problematic soil is always estimated with empirical assumptions. Due to lack of analysis, the option of adopting reinforced shallow foundation on such soil has been neglected until very recently.

(a)

(b)

(c)

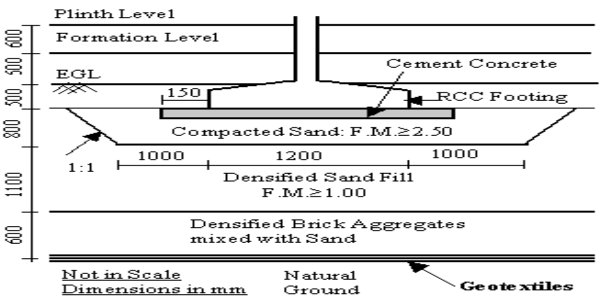
(d)

Fig. 1. Hydraulic filling procedure (a) dredged fill transported by barge (b) & (c) dredged fill transferred to the site in the form of slurry and (d) delivery of fill to the site.

CASE STUDY

In recent past use of geo-textile as reinforcement to improve the bearing capacity of foundation soil and settlement performance of shallow foundation has gained much attention in the geotechnical engineering field. However, this practice is yet to emerge as a popular solution. Geo-textile and other reinforcing materials at the base of a shallow foundation was used to construct a building structure at Khulna Medical College campus (Alamgir and Chowdhury, 2004). The performance of the adopted systems was found to be quite satisfactory. . Academic building of Khulna Medical College and its foundation system are shown in Fig. 2.

(a)



(b)

Fig. 2. (a) Academic building of Khulna Medical College and (b) foundation system (Alamgir and Chowdhury, 2004)

It is quite obvious that the dredged fill-soil of reclaimed areas demand special attention for designing foundation systems on it. There has to be a proper subsoil investigation, correct load-settlement pattern and proper numerical analysis for designing shallow foundation on these type of problematic soil. With this backdrop, the objective of this paper is to investigate the sub-soil characteristics of the selected reclaimed area and conduct full scale load tests on a reinforced shallow footing to investigate the feasibility of cost effective shallow foundation system on problematic soil of reclaimed areas in Dhaka city following numerical analysis.

METHODOLOGY

At first the sub-soil characteristics of selected reclaimed area (Mirpur DOHS) was determined for evaluating the bearing capacity of shallow foundation on it. Bearing capacity was estimated by analytical method. Then the bearing capacity of foundation soil and load-settlement behaviour of shallow foundation was evaluated by plate load test. A shallow foundation was constructed on reclaimed soil with base soil reinforcement by geo-textile for full scale load test. From the full scale load test, load-settlement behaviour of a shallow foundation was observed for 25 mm of settlement. From the load-settlement graph, the ultimate bearing capacity was determined for 25 mm

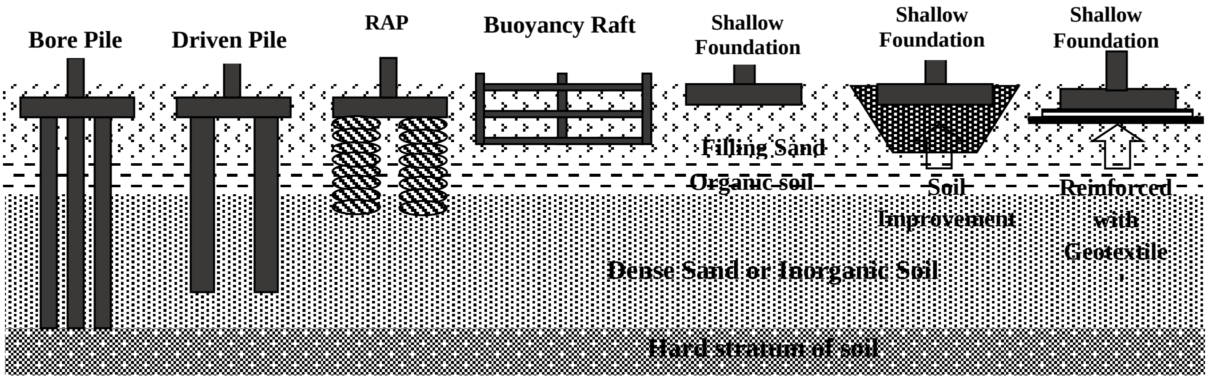


Fig. 3. Suitable foundation options for the study area (Fox and Cowell, 1998)

settlement. At the end, a comparative analysis of cost between reinforced shallow foundation and pile foundation was done to propose a cost effective shallow foundation on this type of problematic soil of Dhaka city.

FOUNDATION OPTIONS/ALTERNATIVES

At present, cast-in-situ pile foundations are generally used for building construction. Some other suitable foundation systems based on past studies (Fox and Cowell, 1998) that can be proposed for the study areas are shown in Fig. 3. These foundation systems can mitigate the problems that may occur to the structures in the reclaimed areas of Dhaka city. However, it is to be noted here that suitable foundation alternative is to be confirmed by field trials.

Shallow Foundation with Reinforced Footing

Traditional analysis usually discourages shallow foundation in reclaimed lands. However, bearing capacity calculation by appropriate soil characterization together with reinforced footing may lead us to adopt shallow foundation in many places of reclaimed land. Field load test verified by numerical analysis will clarify the effects of reinforcement used in the improved foundation system. The reinforcement option could be a geo-textile at the bottom over which there could be compacted sand and sand-aggregate layer. Details of the footing reinforcement is shown in Fig. 4.

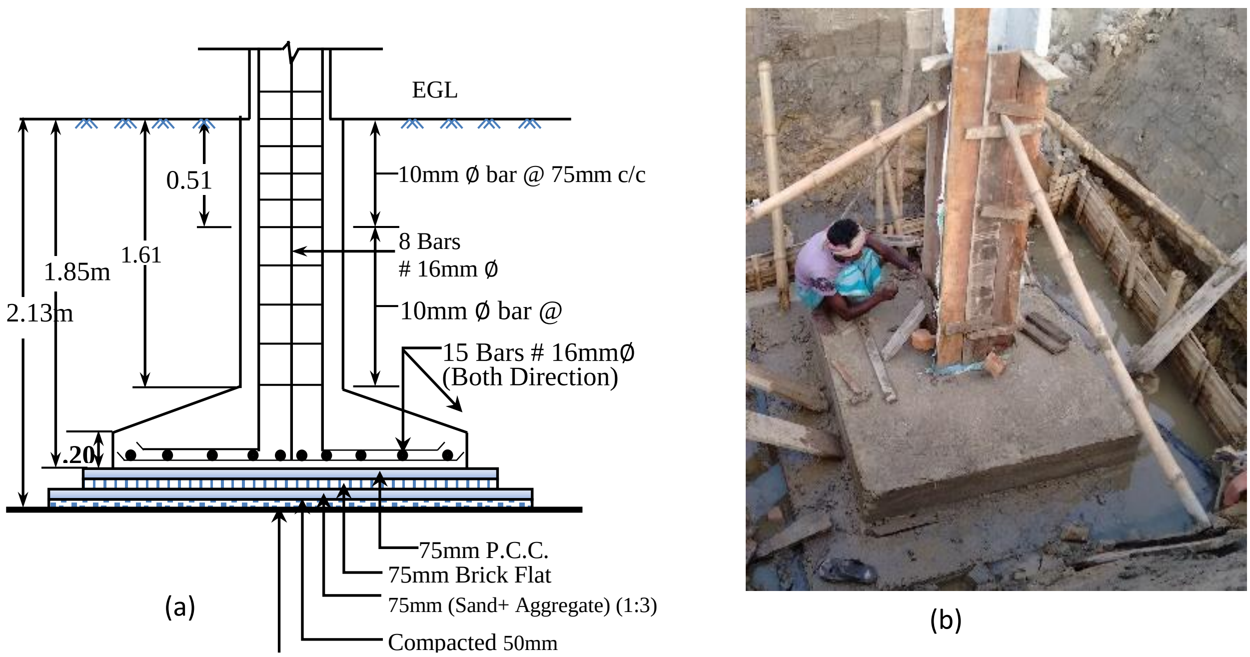


Fig. 4: (a) Section view- sallow foundation with reinforcement and (b) photograph of constructed shallow foundation with reinforcement in field

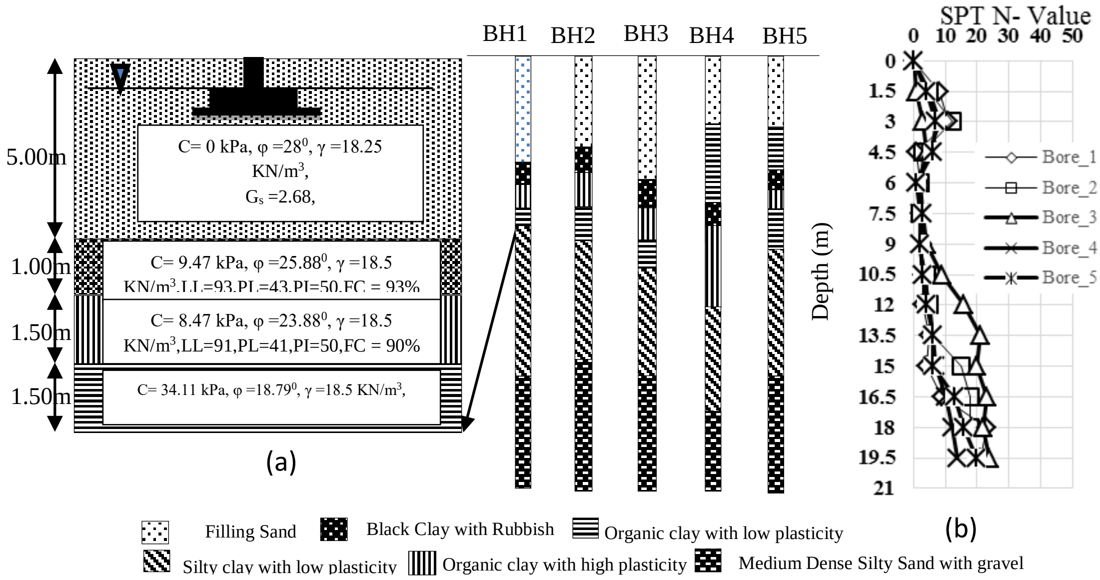


Fig. 5. (a) Sub-soil strata below footing and (b) Borelogs and SPT N-values of reclaimed

The study area is a typical reclaimed area of Dhaka city. It has a dredged fill layer of 3 to 6.5 m on top. Below the dredged fill soil there are black clay with rubbish, organic clay and silty clay. Beneath the clay layer from 16.5m below EGL, medium dense to dense silty sand layer exist having a higher SPT N-value. Details of sub-soil properties below footing and typical bore-logs of the study areas with field SPT N-value are presented in Fig. 5.

Sub-Soil Characteristics

In the reclaimed land generally it is found that the depth of filling sand layer varies from 4 to 6m from EGL. In most cases, the dredged material is silty sand with high fines content. The field SPT N-value of the filling layer varies from 1 to 11. It has been found that the value of specific gravity of the sand of the filling layer varies from 2.65 to 2.73. From the grain size analysis of dredged fill soil it is found that mean grain size (D_{50}) and fines content (F_c) of the sand of the filling layer vary from 0.12 to 0.15 mm and 17.4 to 30.7%, respectively. It is clear that the dredged fills are poorly graded sandy soil (SP). It has high void ratio and low density. The soil generally have low bearing capacity and is likely to experience local or punching shear failure ($C_u<6$, $C_c<1$). More details about the characteristics of organic soil are available in Islam and Nasrin (2009).

RESULTS AND DISCUSSIONS

Bearing Capacity Evaluation and Improvement

Various methods were adopted to evaluate the bearing capacity of foundation soil. Ultimate bearing capacity of foundation is shown in the graphical form in Fig. 6. At the very outset, empirical equation using SPT N-value was used to find out the bearing capacity of soil. The bearing capacity was found to vary between 304 kPa to 310 kPa. Based on various theoretical analyses, the bearing capacity was estimated to be within 257 to 350 kPa. Following plate load test, the bearing capacity of foundation soil was calculated to be 342 kPa. Foundation soil was also modelled with GEO5 software and estimated bearing capacity was found to be 267 kPa. Finally, a full scale load test was conducted on the shallow foundation constructed on reclaimed soil of Mirpur DOHS with the reinforced base layer. The reinforcement was done placing a geo-textile at the base of the footing. Full scale load test on the reinforced footing has raised ultimate bearing capacity of the foundation soil up to 400 kPa corresponding to a settlement of 25 mm. A comparitive analysis of load vs settlement curve of plate load test and full scale load test is shown in Fig. 7. At the end of the result analysis, it is found that the design bearing capacity of dredged fill soil is increased at least by 15%-30% due to foundation reinforcement.

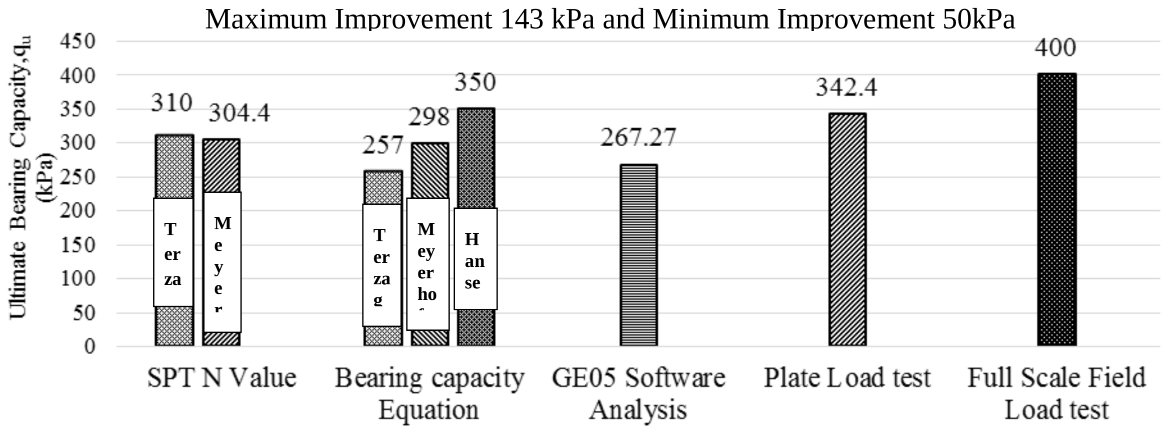


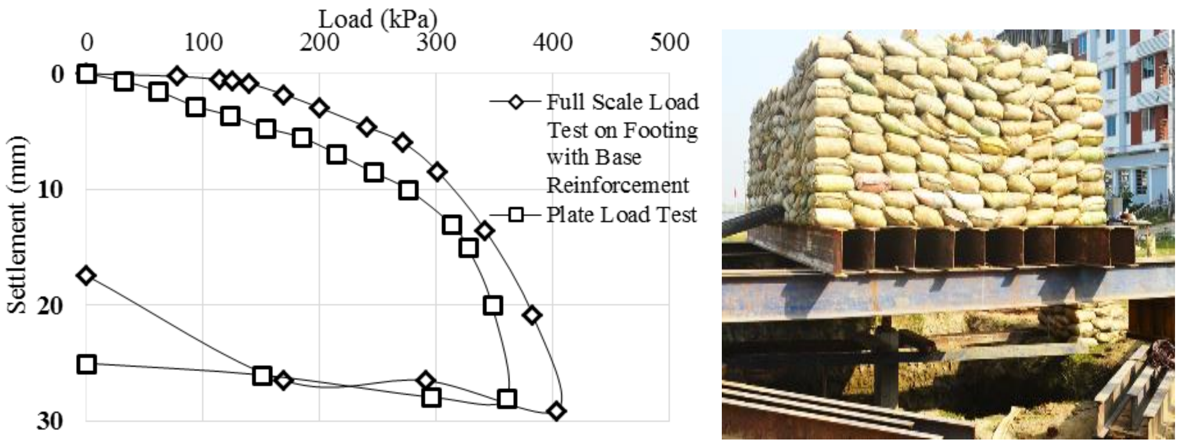
Fig. 6: Ultimate bearing capacity determined from different

Bearing Capacity and the Limit of Vertical Extension of Residential Building

ETABS software was used to analyse the maximum and minimum load that a G+6 storied building, having shallow foundation, exert on the foundation soil. The maximum and minimu base pressure was found to be 249.92 kPa and 90.98 kPa respectively. Average base pressure was noted to be 200 kPa. From the tests and analyses, it can be concluded that a medium rise building (up to six stories) can be constructed with reinforced shallow foundation on such reclaimed areas.

Settlement Analysis

Consolidation settlement of the shallow foundation on dredged fill soil was estimated considering design bearing capacity to be 300 kPa and due to the surcharge of the filling layer over the soft organic clay. It has been calculated that the total consolidation settlement of structure will be approximately 19mm. This total settlement is below the allowable limits and less likely to cause any structural damage.



(a) (b)

Fig. 7: (a) Load - settlement curve and (b) field load test arrangement

Cost Analysis

As per AASHTO design guideline; for 450kN load the dimensuions of pile for our site would be of 17m long having 0.508m dia (2X Piles together). Volume of concrete for two piles with pile cap is around 9.5m^3; whereas shallow foundation at 1.5m depth with base reinforcement requires around 1m^3 volume of concrete. In terms of cost, two piles with pile cap will cost around 140,000 BDT where reinforced shallow foundation will cost around 65,000 BDT. A comparative analysis of cost for pile foundation and shallow foundation is graphically presented in the Fig. 8.

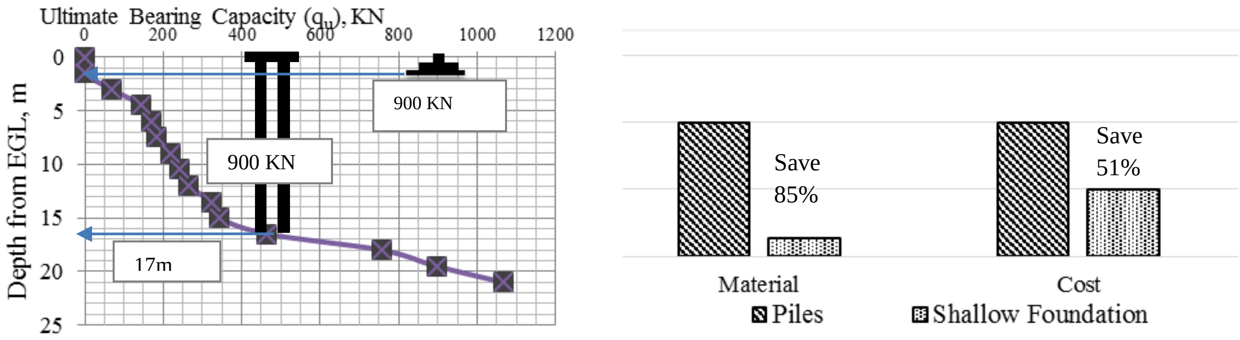


Fig. 8: Comparative analysis – shallow foundation vs. deep (pile) foundation
(a) Dimension (b) Material & Cost

CONCLUSIONS

Reclamation of Dhaka city without proper planning and design has made such lands problematic with respect to large settlement potential, negative skin friction and liquefaction. Current practice of foundation design for buildings in reclaimed areas is generally deep foundation (piles). Pile foundation may be used for high rise building to avoid liquefaction problem. RAPs and Buoyancy Raft foundation can also be used to avoid excessive settlement problem. However, special attention should be taken during foundation design in such soil conditions and field trials has to be done before implementation of such foundation system.

The proposed reinforced shallow foundation may be adopted for low rise buildings (especially up to G+6 stories) on reclaimed land where sub-soil characteristics are identical to that of studied site. Alternately this type of shallow foundation may also be used in conjunction with deep foundation specially for peripheral footing that experience comparatively low base reaction. From the field tests and analyses, it has also been revealed that the proposed shallow foundation is a cost effective foundation alternative for the reclaimed areas of Dhaka city.

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