Comparative Cost Analysis of Pile Foundation with Soil Improvemnet of a Reclaimed Area

***Syed Aaqib Javed*[1]*, *Anika Salsabiyl*[2], *Farhana Nasrin Jubaida*[3], *Md. Zahidul Islam*[4], *Shafiqul Islam*[5]**

[1]Lecturer, [2,3,4]Undergraduate Student, [5]Assistant Professor

Department of Civil Engineering, Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh.

****Corresponding Author***

***Email Id:**-aaqib.aust@gmail.com*

ABSTRACT

Soil liquefaction is the most hazardous phenomenon for buildings, highways, railways and other structures in recent past years. Liquefaction of soil followed by earthquakes has always been a source of danger for the people living in the highly vulnerable seismic zones of the world. Dhaka city is expanding rapidly on reclaimed land due to rapid increase of population. The behavior of piles in reclaimed areas is significantly affected if the soil liquefies. Therefore, soil improvement is necessary. This paper discusses the variation of cost of piles of a reclaimed area with and without considering soil improvement technique like sand compaction pile and stone column. Cost analysis of sand compaction pile and stone column with different properties, i.e. diameter of the pile, Fineness modulus (FM) is also estimated in the context of Bangladesh. Sand Compaction pile is only 1.3% to 2.1% of pile cost. On the other hand, stone column is more than 50% of RCC pile. Sand compaction pile is more cheaper than stone columns. The cost of sand compaction pile, for 1000 m2 area with FM 1.8 and fill volume 0.15 cum/m are 3.2 lac, 3.1 lac and 2.8 lac for diameter 200 mm, 250mm and 300 mm respectively.

***Keywords:**-Liquefaction, sand compaction piles, Stone columns, reinforced concrete pile, cost analysis of piles*

INTRODUCTION

Soil liquefaction occours when a saturated soil substantially losses strength and stiffness due to applied stress, usually earthquake or any other sudden change in stress and causing it to behave like a liquid. This ground shaking influences the increase of pore water pressure. The superimposed weight on the ground is transferred to the pore water as the soil losses its strength as it losses its gain to gain contact. This transfer increases the pore water pressure in the saturated zone and buoying up the already dislodged soil grains. Buoyancy is responsible for the total collapse of the soil structure which does not possess any shear strength or load carrying capacity [1-2]. Liquefaction problem has become significant when rapid urbanization by expanding the cities in reclaimed areas took place. The soil liquefaction depends on the different types of parameters which are magnitude of earthquake, the distance from the source of the earthquake, site-specific conditions, ground acceleration, type of soil, relative density, grain size distribution, fine content, plasticity of fines, fluctuation of groundwater table and reduction of effective stress. In the past several earthquakes like Niigata earthquake (1964), Alaska (1971), Loma Prieta earthquake (1989), Chūetsu earthquake (2004), Christchurch earthquake (2011) caused great destruction and damage. Liquefaction affects buildings, roads, bridges, buried pipelines and infrastructures etc. in many ways. In case of piles there is not only a loss of vertical bearing capacity within the liquefied soil but also enormous horizontal forces can be exerted on the pile foundations by the liquefaction. If piles are constructed in a loose liquefaction-endangered layer and embedded into a dense bearing layer, they can be over-stressed or buckle due to large bending moments. The liquefaction risk around the pile foundations can be minimized by modern ground improvement methods. Methods to mitigate the effects of soil liquefaction have been develop by earthquake engineers and include various soil compaction techniques such as Sand compaction piles, Stone columns, Jet grouting, Heavy weight compaction, Blending and Blast Densification.

Sand compaction piles are large diameter sand columns that have been used for rapid improvement of soft ground and near-shore regions for land reclamation works. These piles are installed by driving a closed-ended casing into the ground to a selected depth (usaually 3 to 15 m). Sand is then forcibly injected through the casing-tip. When the casing is withdrawn in stages, it is formed a sand column in contact with the displaced soil. The degree of compaction that Sand Compaction Piles are capable of being highly dependent on penetration spacing, soil type, vibrator type and size and compaction procedures. In Japan, significant application has been made to construct the Kansai International Airport [3]. Undrained shear strength increased about 50% as excess pore pressures in clays dissipated after the installation of sand compaction piles [3]. The increase in effective stress of the clay is found after Sand compaction piles installation by using finite element analysis [4]. This method is often used to prevent liquefaction and has been confirmed in past intense earthquakes, showing this to be one of the most reliable improvement methods. The post installation unconfined compressive strength of the clay was almost twice the pre-installation strength [5].

Stone columns are significant in soil stabilization and are ideally welcome for improvement of soft clays, silts and loose silty sands. One of the most effective soil improvement techniques to mitigate soil liquefaction and increase soil bearing capacity is stone columns. Crushed gravel is used for the backfill material. Stone Columns improve the ground by compaction of the soil adjacent to it, reinforcing and permit rapid dissipation of earthquake induced pore pressure development by virtue of their high permeability. Stone column can be installed by non-cohesive natural soil and the stone column solutions have been proved to be more cost effective than the trench fill [6]. In case of un-encased stone column load carrying capacity increases with the increasing diameter of stone column, but in un-encased and encased layered soil load carrying capacity decreases with the increasing the diameter of stone column [7]. Stone column has been installed in coastal area to improve the bearing capacity of soil [8]. In order to improve the load bearing capacity of weak soil reinforced stone column has investigated [9].

The main purpose of this paper is to estimate the cost of the conventional deep foundation, i.e. piles considering soil improvement of a reclaimed area with liquefiable potentiality. Cost analysis of sand compaction pile and stone column with different properties, i.e. diameter of the pile, Fineness modulus (FM) is also estimated in the context of Bangladesh.

METHODOLOGY

The liquefaction potential of Shapnodhara Housing in Bosila, Mohammadpur, Dhaka, Bangladesh has been determined by [10]. Six soil reports of six different points of the study area with 25 borehole data were collected. Figure 1 shows the site location in the Bangladesh and Dhaka city map and figure 2 shows the site location of the experimental area. The method used for determining the liquefaction potential was Seed and Idriss (1982) and Japanese Code of Bridge Design including Chinese Criterion. The analysis was conducted up to 60 ft depth soil of the selected area. The selected area had a liquefiable soil ranges from 37 ft to 45 ft from ground level.

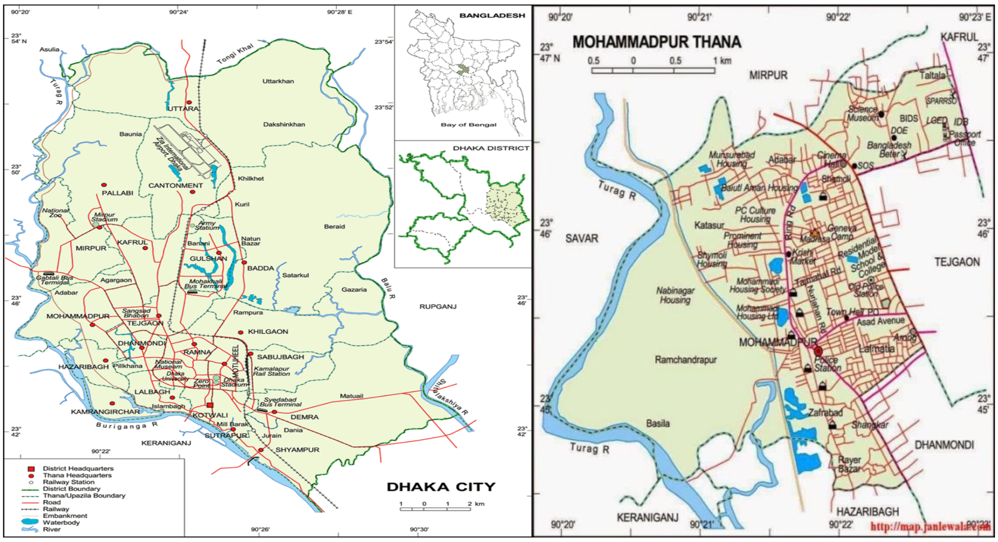

***Fig.1:**-Site Location in the Bangladesh and Dhaka City Map.[11]*

***Fig.2:**-Site Location of the Experimental Area.[11]*

Reinforced Concrete Pile

Reinforced Concrete pile is a well-recognized load transfer mechanism to transfer structural load in a strong soil layer by skipping comparatively weak upper layers. The average load bearing capacity and cost of RCC pile was estimated for a unit area of 1000 m^2. Unit costs used for analysis were based on Public Works Department (PWD) and Local Government Engineering Department (LGED) [12-13] schedule of rates (2018). Considering the plot sizes and already constructed buildings, 6 storied structures were considered for this study. According to BNBC (2006) [14] 300 psf (including self-weight of structure) was considered as typical floor load. Based on the above discussion, area load was 1800 psf (300x6). Pile capacity was calculated based on the collected soil reports considering a spacing of 3D with group efficiency of 90%-100%. The length of pile was selected to 60 ft as up to 45 ft the soil was liquefiable and required N value was found on that layer. The diameter of the pile was selected to 500 mm and 550 mm.

Soil Improvement Technique

Sand compaction pile

Sand compaction piles are usually 0.46 to 0.76 m in diameter and placed at about 1.5 to 3 m center to center [12]. Total cost for different diameter and different Fineness modulus (FM) has been estimated. The unit rate was collected from LGED schedule of rates (2018). The average depth of the pile was selected to 40 ft as liquefiable soil ranges from 37 ft to 45 ft from ground level.

Stone column

The gravel used for the stone column has a size range of 6 to 40 mm. Stone columns usually have diameters of 0.5 to 0.75 m and are spaced at about 1.5 to 3 m center to center [12]. The average depth of the pile was selected to 40 ft as liquefiable soil ranges from 37 ft to 45 ft from ground level. The diameter of the column was selected to 300 mm. Total cost for different Fineness modulus (FM) has been estimated. The unit rate was collected from LGED schedule of rates (2018) [15].

TEST RESULT AND DISCUSSION

Cost Analysis of Reinforced Concrete Pile

The summary of the total number of piles and cost is presented in Table 1. In case of, 500 mm diameter, total number of piles required for a total load of 19380 kip is 304 whereas for 550 mm diameter, the total number of pile is 300. Total cost for 500 mm diameter is 20951.9K and for 550 mm diameter is 24204.3K.

Table 1:-*Summary of Total Number of Piles and Cost*

Diameter (mm)	Total load (Kip)	Average pile capacity (kip)	Total number of piles	Total cost (1 in Tk 1K)
500	19380	63.67	304	209.5
550		64.32	300	242

Cost Analysis of Sand Compaction Pile

For a specific diameter and fill volume, total cost of sand compaction piles increased with the increase of FM. In case of 250 mm diameter and 0.15 cum/m fill material, there was a maximum increase of 42.85% in cost when the FM increase from 1.5 to 2.5. The total cost of sand compaction piles decreased with the increase of diameter for a fixed FM and a fixed fill material. The decrease in total cost was 10% when diameter changes from 200 mm to 300 mm for a specific FM 2.5 and a specific fill material 0.15 cum/m. For 1000 m^2 area the cost of sand compaction pile with FM 1.8 and fill volume 0.15 cum/m are 3.2 lac, 3.1 lac and 2.8 lac for diameter 200mm, 250mm and 300mm respectively. As per LGED schedule of rates (2018) cost of compaction pile with different specifications are shown in Figure 3 to 5. Total cost for average fill volume with varying FM and diameter is presented in Table 2.

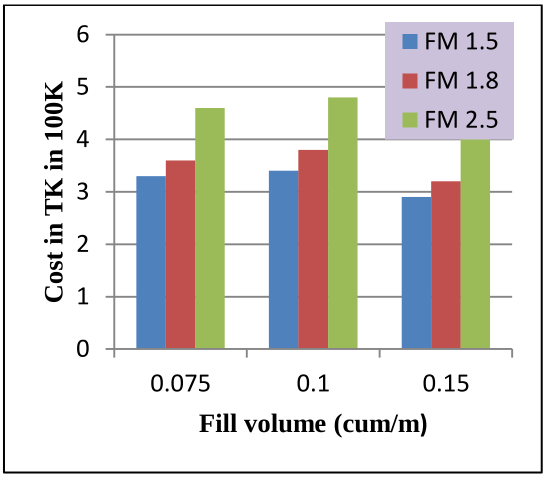

Fig.3:-*Cost Comparison of Sand Compaction Pile of 200 mm Diameter*

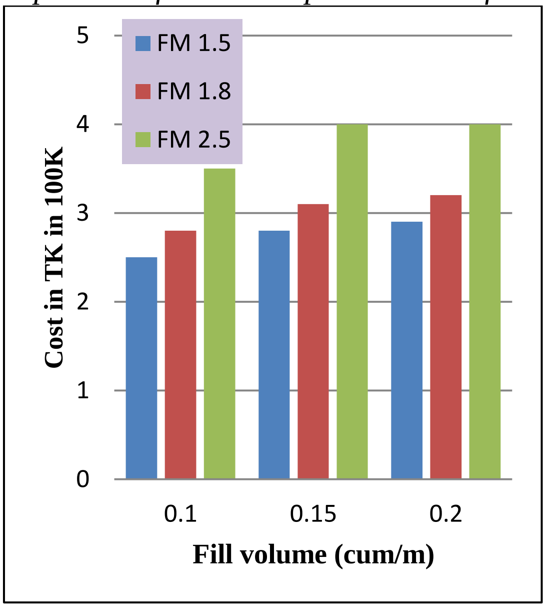

Fig.4:-*Cost Comparison of Sand Compaction Pile of 250 mm Diameter*

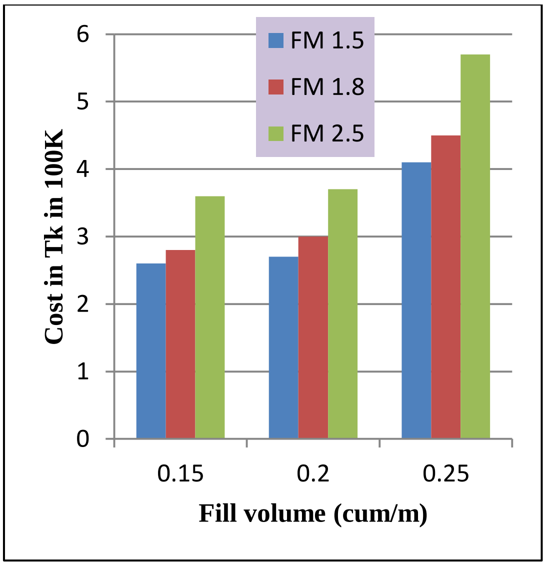

Fig.5:-*Cost Comparison of Sand Compaction Pile of 300 mm Diameter*

Table 2:*-Total cost for Average Fill Volume (Tk in 100k)*

FM	200 mm diameter	250 mm diameter	300 mm diameter
1.5	3.2	2.73	3.13
1.8	3.53	3.03	3.43
2.5	4.47	3.83	4.33

Cost Analysis of RCC Pile in Improved Soil

The selected area for this research has liquefiable soil up to a depth of 45ft. The water table is high specially in rainy season due to adjacent water bodies. Considering the geology of Dhaka and the presence of water in soil pores the area is very vulnerable in the context of strong earthquakes. In that case only providing pile to skip liquefiable soil will not be sufficient. Soil improvement is required before/along pile construction. Considering the FM, diameter of sand compaction pile and RCC pile 18 cases have been designated as described in Table 3.

Table 3:*-Summary of Combined Cost of Sand Compaction Pile and RCC Pile*

Case	Diameter of sand compaction pile (mm) with FM	Diameter of RCC pile (mm)	Average cost of sand compaction pile (in Tk 100K)	Cost of RCC pile (in Tk 100K)	Total cost (in Tk 100k)
Case 1	200 (1.5)	500	3.2	209.5	241.5
Case 2	200 (1.8)		3.53		244.8
Case 3	200 (2.5)		4.47		254.2
Case 4	250 (1.5)		2.73		236.8
Case 5	250 (1.8)		3.03		239.8
Case 6	250 (2.5)		3.83		247.8
Case 7	300 (1.5)		3.13		240.8
Case 8	300 (1.8)		3.43		243.8
Case 9	300 (2.5)		4.33		252.8
Case 10	200 (1.5)	550	3.2	242	274
Case 11	200 (1.8)		3.53		277.3
Case 12	200 (2.5)		4.47		286.7
Case 13	250 (1.5)		2.73		269.3
Case 14	250 (1.8)		3.03		272.3
Case 15	250 (2.5)		3.83		280.3
Case 16	300 (1.5)		3.13		273.3
Case 17	300 (1.8)		3.43		276.3
Case 18	300 (2.5)		4.33		285.3

The Combined cost of sand compaction pile and RCC pile for defined cases is shown in Figure 6 and Figure 7. The variation in combined total cost is not significant compared to RCC cost only. The soil improvement cost (i.e. sand compaction pile) is varying 1.3% to 2.1% with respect to pile cost. Therefore, the soil improvement cost is insignificant (1.15% to 1.75%) with respect to total construction cost.

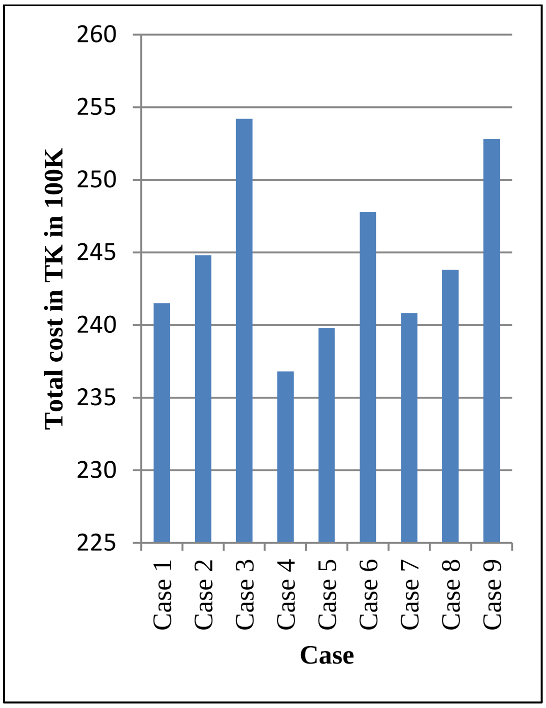

Fig.6:-*The Combined Cost of Sand Compaction Pile and RCC Pile for Defined Cases*

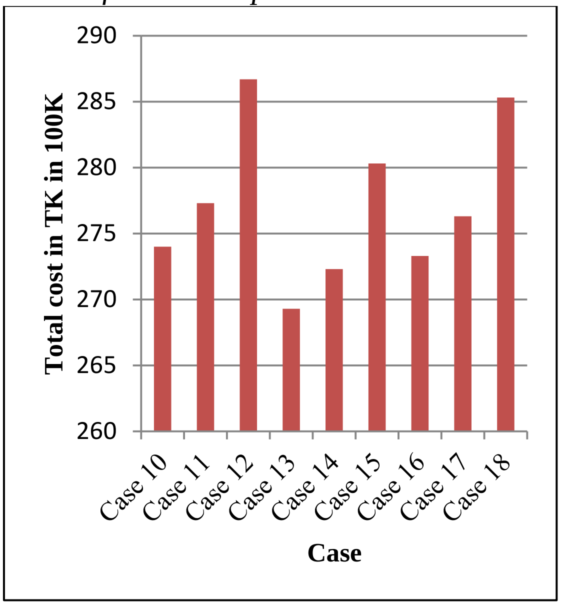

Fig.7:-*The Combined Cost of Sand Compaction Pile and RCC Pile for Defined Cases*

Cost Analysis for Stone Column

As a soil improvement and load transfer mechanism stone column is a good option. But in case of load transfer it will not be as effective as RCC pile. The cost of stone column is more than 50% of RCC pile. The analysis result indicates that stone column is a better option for comparatively small structure where stone column will perform for both soil improvement and load transfer purpose. Figure 8 represents the cost of stone column for different FM. FM 0.2 and 0.3 is for 300 mm diameter and FM 0.6 and 0.8 is for 500 mm diameter.

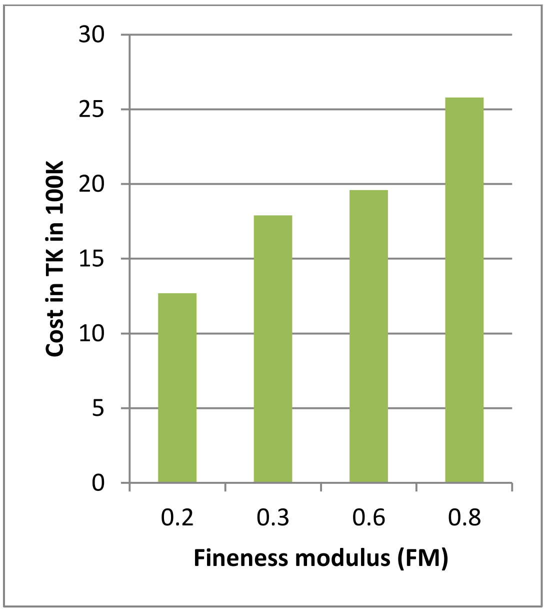

Fig.8:*-Cost Comparison of Stone Column*

CONCLUSION

Total cost of sand compaction piles increased with the increase of FM, for a specific diameter and fill volume. The total cost sand compaction piles decreased with the increase of diameter for a fixed FM and a fixed fill material. The cost of sand compaction pile, for 1000 m2 area with FM 1.8 and fill volume 0.15 cum/m are 3.2 lac, 3.1 lac and 2.8 lac for diameter 200mm, 250mm and 300mm respectively. The area is very vulnerable in case of strong earthquakes as the there is a presence of water in the soil pores. In that case only providing RCC pile to skip liquefiable soil will not be sufficient. Soil improvement is required before/along pile construction. The soil improvement cost (i.e. sand compaction pile) is only 1.3% to 2.1% pile cost. Therefore, the soil improvement cost is insignificant (1.15% to 1.75%) with respect to total construction cost. The cost of stone column is more than 50% of RCC pile. Therefore, the total cost will make the project uneconomical. Stone column can be used where it can perform for both soil improvement and load transfer purpose. The analysis result indicates that it can perform duel when the structure is comparatively small.

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