COST EFFICIENT SOFT SOIL IMPROVEMENT TECHNIQUE FOR A SPECIFIC PROJECT AT NAMAPARA, KHILKHET, DHAKA.

By

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A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

Department of Civil Engineering

Sonargaon University

147/I, Green Road, Dhaka-1215, Bangladesh

Section: (13A)

Semester -Year (Spring-2022)

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The thesis titled “cost efficient soft soil improvement techniques for a specific project at Namapara, Khilkhet, Dhaka” submitted by S. M. Karim (BCE1801013003), Md. Mahadi Hasan (BCE1801013091), Md. Bahar Uddin BCE1801013176, Md. Feroz Mia (BCE1801013094), Md. Bakir Ahamad (BCE1801013030) Session 13A, Spring-2022 , has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Civil Engineering on 19-05-2022.

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DECLARATION

It is hereby declared that this thesis/project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Dedicated

to

"This thesis has been dedicated our parents and teachers"

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ABSTRACT

This paper contains the cost efficient soft soil improvement techniques for a specific project at Namapara, Khilkhet, Dhaka. The objective of this research is to analyze the different soil improvement techniques and the comparable model of these soil improvement techniques. The verification of the soil improvement techniques is more important than the implementation of the soil improvement techniques. A cost comparison has been made between four soft soil improvement techniques. There are Sand compaction pile (SCP), Soil replacement compaction, prefabricated vertical drain (PVD) & Dynamic compaction (DC). Analysis of the effectiveness of soft soil improvement technique before and after improvement techniques. Application of those most common improvement techniques with cost estimating. After estimate we have find out that, SCP improvement technique is the most cost efficient (216.6 tk per sq ft) and easier technique to increase bearing capacity of soil. This is a significant finding of this research.

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CHAPTER - 1
INTRODUCTION

1.1 Background and Motivations

Soft soil problems are often associated with sediment and stability where it represents a major challenge in Geotechnical Engineering. Research on a soft soil was carried out to determine the level of sediment resulting from the applied load and thus compare the most ideal form of arrangement by the results obtained from bearing capacity.

Soft soil ground improvement plays a significant role in the embankment preparation and construction. The soft soil improvement techniques like Sand Compaction Pile (SCP), Dynamic Compaction (DC) and Prefabricated Vertical Drain (PVD) are most commonly used recently. Many construction firms used different soil improvement techniques, but they did not emphasize the verification of the soil improvement techniques. The verification of soil is necessary before and after the soil improvement. In most cases, ground improvement has been needed. In a broad sense, ground improvement refers to the incorporation of different techniques employed for modifying the properties of a soil to improve its engineering performance. In this project, four types of soft soil improvement techniques named DC ,SCP, PVD & soil replacement (compaction) have been used.

The selection of Soft soil improvement techniques is a big challenge in our country. Soft soil improvement techniques like the sand drain are low-cost improvement techniques, but it took a huge time to consolidate the clay soil in Bagerhat (Chakraborty et al., 2017). So, selection of soft soil improvement techniques is very important to consider the following factors: i) cost, ii) consolidation time and iii) site conditions etc. sometimes a combination of soft soil improvement techniques is very effective.

All these researches described the specific cost efficient soft soil improvement technique in a specific project. In this project. four soil improvement techniques in one specific site. In this site, soil condition is such that under a clay soil layer, a soft clay soil layer exists where SPT value is around 5. To reduce susceptible to liquefaction in the sandy layer DC has been chosen and the soft clay soil layer is for SCP.

1.2 Specific Objectives

i. Identify soft soil improvement techniques using method of civil engineering sector of Bangladesh.’

ii. Analyze the cost and benefit of soft soil improvement techniques.

iii. Recommend the cost efficient soft soil improvement techniques for specificside.

1.3 Problem Statement

Properties and characteristics of soft clays are first presented. Because several problems are faced when projects construction is intended on soft clays several improvement techniques can be adopted. Preloading with or without moisture test, vacuum consolidation and reinforcement by columns are currently used to enhance properties of soft clays. Also, rigid inclusions may be used. The principles and basic criteria for the test of all these techniques are explained. Comparison between advantages of improvement techniques is carried out by four test report of typical case histories.

1.4 Organization of the thesis

Chapter 1: Introduction Primary chapter deals with background of the study, significance of the research, focused on objective and limitation etc.

Chapter 2: Literature Review. The chapter discussed previous study on the related topics, concept and defined outlook written in Bangladesh context.

Chapter 3: Methodology. Project related materials and measurement noted in this chapter and finally, focused on the research outline.

Chapter 4: Results and Discussion. Analytical parts deal with laboratory test reports based on samples such as, data interpretation, data visualization and findings.

Chapter 5: Conclusions and Future Work. Last chapter overall research summary discussed in the chapter and further research notes for investigation.

CHAPTER- 2
Literature Review

2.1 Introduction

Soft clays belong to the well-known category of problematic soils. Such soils are mainly encountered under layered deposits in coastal areas. The lack of bearing capacity, high compressibility and very long time of consolidation are three typical properties of soft clays. Several problems related to soft clays exist from field investigation to their modeling behavior. Coring undisturbed samples in soft clays is a challenge because of disturbance during drilling.

Ansary and Rashid (2000) have presented to analysis the alleviation of the disaster due to future shocks which is an indispensable consideration for proper land use and effective town-planning. Silty-sands and loose sands induce flow slides, settlements, and loss of life and damage/destroy to property due to liquefaction potential. The susceptibility of liquefaction within a zone of probability two hundred square kilometers in the Greater Dhaka City zone, Bangladesh has been assessed based on SPT data from one hundred ninety boreholes. Liquefaction of saturated loose sands and silty-sands induce flow slides, settlements, loss of life and damage to property. The susceptibility of liquefaction within an area of approximately 200 square km in the Greater Dhaka Metropolitan area, Bangladesh has been assessed based on Standard Penetration Test data from 190 bore holes. The analytical results have been classified into two groups according to the extent of liquefaction observed, namely, as to whether the site is liquefiable or non-liquefiable. Hossain et al. (2003) has described liquefaction potential index and sub-soil characteristics of Mirpur area. To characterized/identified soil deposit 8 boreholes were drilled at the proposed site. In the laboratory, Specific gravity, Grain size distribution, Moisture content, Atterberg limits, unconfined compressive strength, density and Shear strength parameters of the samples have been analyzed. It was observed that geotechnical properties of the soil in the study area varied with depth and location. It was observed that loose soil exists from 4.7 m to 14.0 m depth below the existing ground level (EGL). From the study, the possibility of the liquefaction had been found to be zero. Rahman (2004) updated the seismic micro-zonation maps for liquefaction as well as site amplification due to an earthquake. Alam and Islam (2009) have evaluated the understanding of the geological setting of Bangladesh which is important for foundation design as well as to estimate the Earthquake Hazards. Soil formation below the foundation need to be identified for proper selection and design of foundation. A process of deltaic sedimentation into a slowly and continuously subsiding tectonic basin has developed the geology of Bangladesh. Above the papers evaluated the sub-soil characteristic at the different location of Bangladesh. In fact, liquefaction micro-zonation or seismic map has been proposed. In this research, an attempt was conducted to create a proposed zonation map based on soft soil regarding clay using GIS interface which is useful for identifying proper soft soil improvement techniques.

2.2 Content

2.2.1 Geological Conditions Of Bangladesh:

Bangladesh is the largest delta in the world. Huge alluvium is opened on the surface. The oldest deposits are the Plio-Plesitocene Barend clay, Madhupur clay and Lamaic region clay. Sediment deposited is not evenly distributed through the country. At the northern part it is about 128 m thick where granite is extracted for construction purposes. But the thickness gradually increased towards the south. At the center is the capital city Dhaka of Bangladesh where sediment is covering more than 22+ km. About 250 large and small rivers are flowing through the country. River born sediment was deposited from these river systems. From north to south Bangladesh was classified into 3 tectonic zone namely; a) Stable platform or Indian platform (consisting of Himalayan for deep, Rangpur Saddle, Dinajpur Shield, Bangura platform and Hinge zone); b) Bengal Basin (consisting of Faridpur Trough, Hatiya Trough, Barisal Trough, Surma Basin); and c) the Chittagong Hill tract. Sedimentary covers are not uniform throughout the country. Massive drilling, geophysical survey viz. electromagnetic survey, seismic survey, resistivity survey etc. are revealing the depositional and basin history of the country. Various deposit such as, Natural hydrocarbon deposit such as Coal deposit at the Northern part of Dinajpur district; gas at south and eastern part, Bijoypur clay of Netrokona district, Heavy minerals of Cox’s Bazar Inani beach with radiometric element, glass sand, limestone etc. are major resources of the country. A geological map is shown in Figure 1. Three types of soil a) Alluvial Clay and Silt b) Alluvial Silt and c) Madhupur Clay residuum] have been described in this map.

Figure 3.1: Geological map of Bangladesh

Zonation based on soft soil is very much significant for the proper identification of soft soil improvement techniques on the specific/defined location of Bangladesh.

Three Geographic Information system (GIS) maps have been proposed by ArcView-GIS-2010 software as follows: a) Soil parameters information map b) SPT (N) value-based map (SPT 1-5) and c) Soft clay layer thickness maps. Bangladesh is on the delta formed by the three main rivers the Meghna, the Ganges, and the Brahmaputra. These rivers originate outside the country's national boundary and make up the MeghnaGanges -Brahmaputra river system. Therefore, availability of soft clay is higher in the southern part of the country and the riverside areas.

2.2.2 SUB-SOIL INVESTIGATIONS:

The execution of one thousand borings has been performed for sub- surface investigation works. The stiffness and density characteristics of the soil layers were analyzed by conducting the SPT. The information of eight representatives bore logs has been shown in Figure. The sub-soil investigation has been performed by a consulting firm named Soil and Foundation Consultants. The thickness of layers (soft clay) varies from 1 to 17 meters. The Reduced Level (RL) has been varied from 0 to 0.91 meters and Groundwater Level (GWL) has been varied from 0.15 m to 3.05 meters. The SPT consists of driving a sampler named thick-walled into the granular soil deposit. The depth of the split-barrel sampler (standard)is 460 millimeters into the soil below the bottom of the bore and counting the number of blows to drive the sampler into the last 305 mm. The driving mass is 63.5 kg. The falling height is 760 mm.

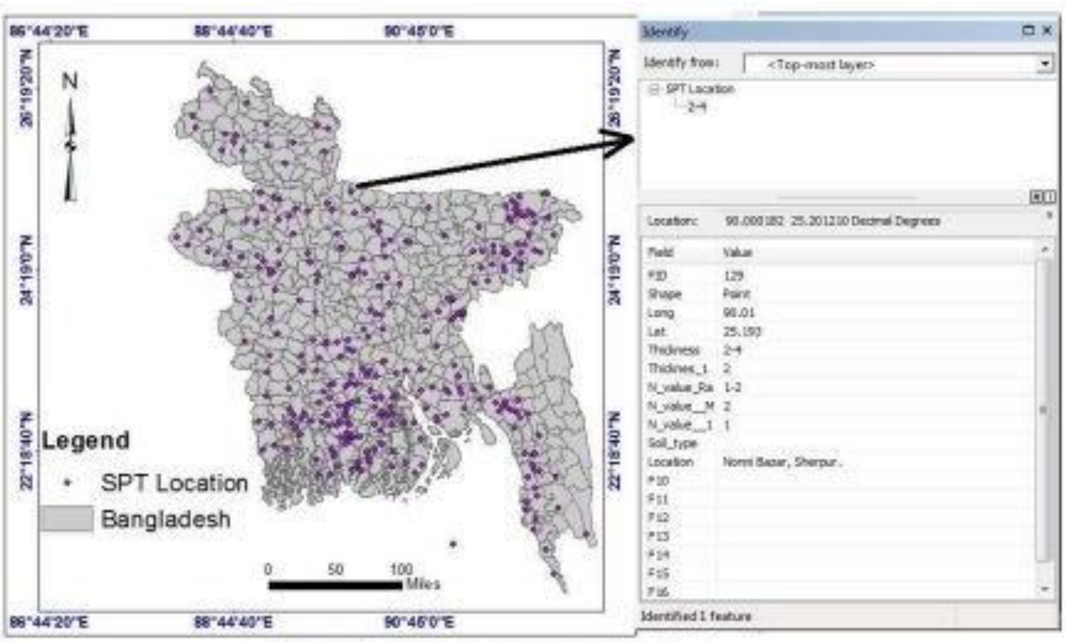

Figure 3.2: Soil parameters information

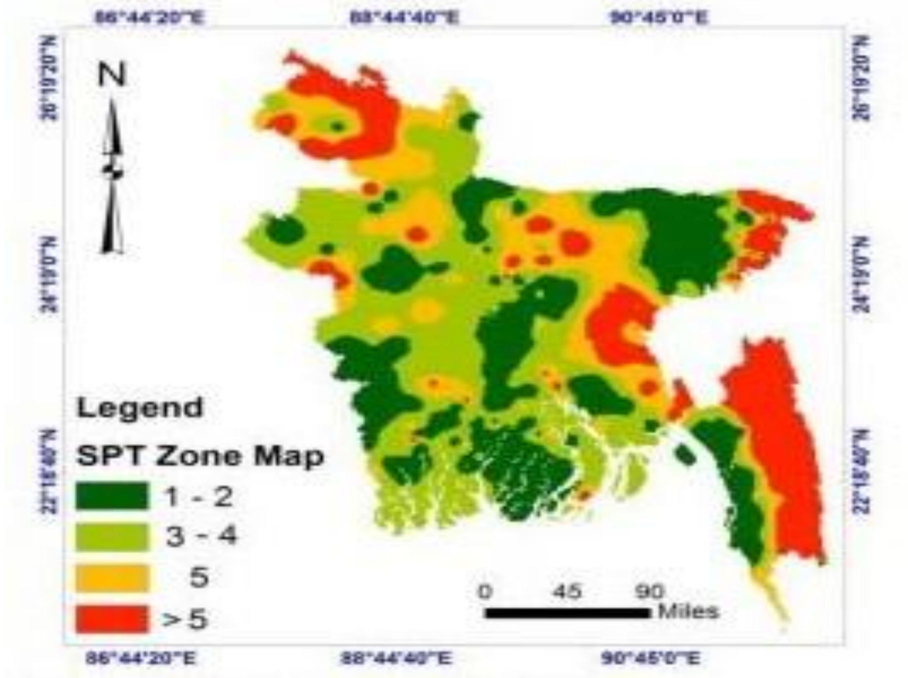

Figure 3.3: Zonation map using N value

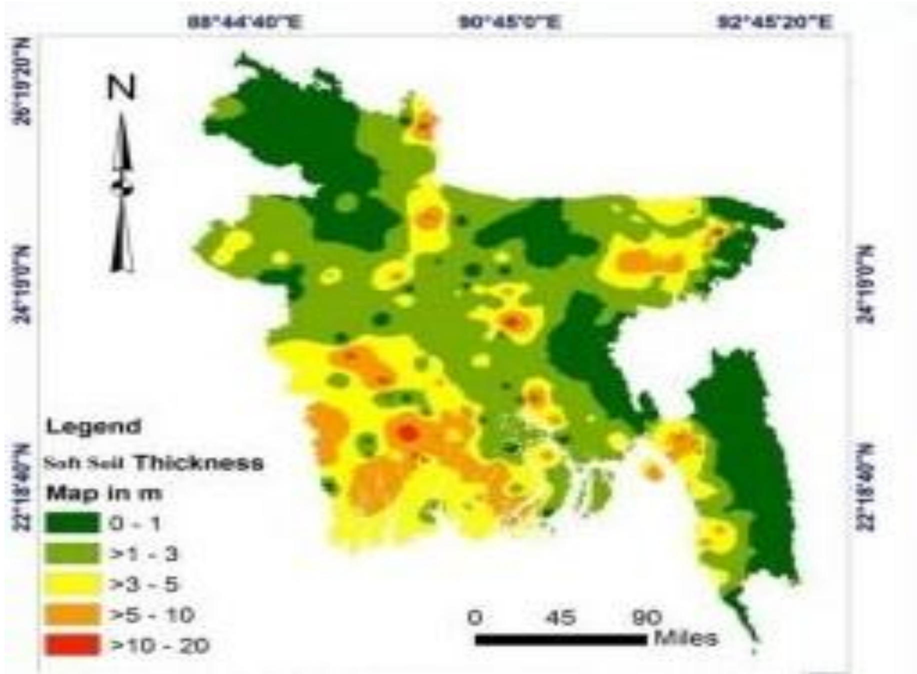

Figure 3.4: Thickness map for soft soil

Three (3) GIS maps were proposed in this paper, using ArcView GIS. First is the soil parameters information map, second is the zonation map using N value and third is the thickness map for the soft clay layer. Accessibility of soft clay is higher in the southern part of Bangladesh, mainly along the riverside. The clay layer (soft) thickness varies from 1 to 17 meters. This paper has proposed three GIS-based maps which might be useful for identifying soil improvement techniques/procedures in the different locations of Bangladesh. [1]

2.2.3 Geological Conditions Of Dhaka City:

Over the past 45 years, Dhaka city has experienced a rapid growth of urban population and it will continue in the future due to several unavoidable reasons. Hence, most of the areas of Dhaka city have already been occupied. As a result, different new areas are being reclaimed inside and near Dhaka city by both government and private agencies. General practice for reclaiming such areas is to fill low lands (ditches, lakes etc.). In most cases, the practice for developing new areas is just to fill low land by dredge fill materials. Different filling procedures are in practice to develop such land. One of them is to carry soil by vehicles from remote sources and manually dumped at the filling site. Due to huge traffic congestion, the most widely used method is the hydraulic filling procedure. In most cases, the dredged material is almost silty sand with high fines content. The presence of fines in hydraulic fill means greater compressibility and greater difficulty in compaction of the fill. Fines also reduce permeability and hence the rate of drainage is slow. Therefore consolidation rate is also slow. Since Dhaka city exists in seismic Zone 2 of Bangladesh. This silty sand layer may liquefy if an earthquake of sufficient magnitude occurs in future. Filling material is dumped directly upon the marshy lowland. After a certain time, the organic content beneath the previous surface water is decomposed and produces a soft organic clay layer. This very soft organic clay layer may cause excessive settlement problems to the structures having shallow foundation on the top filling layer.

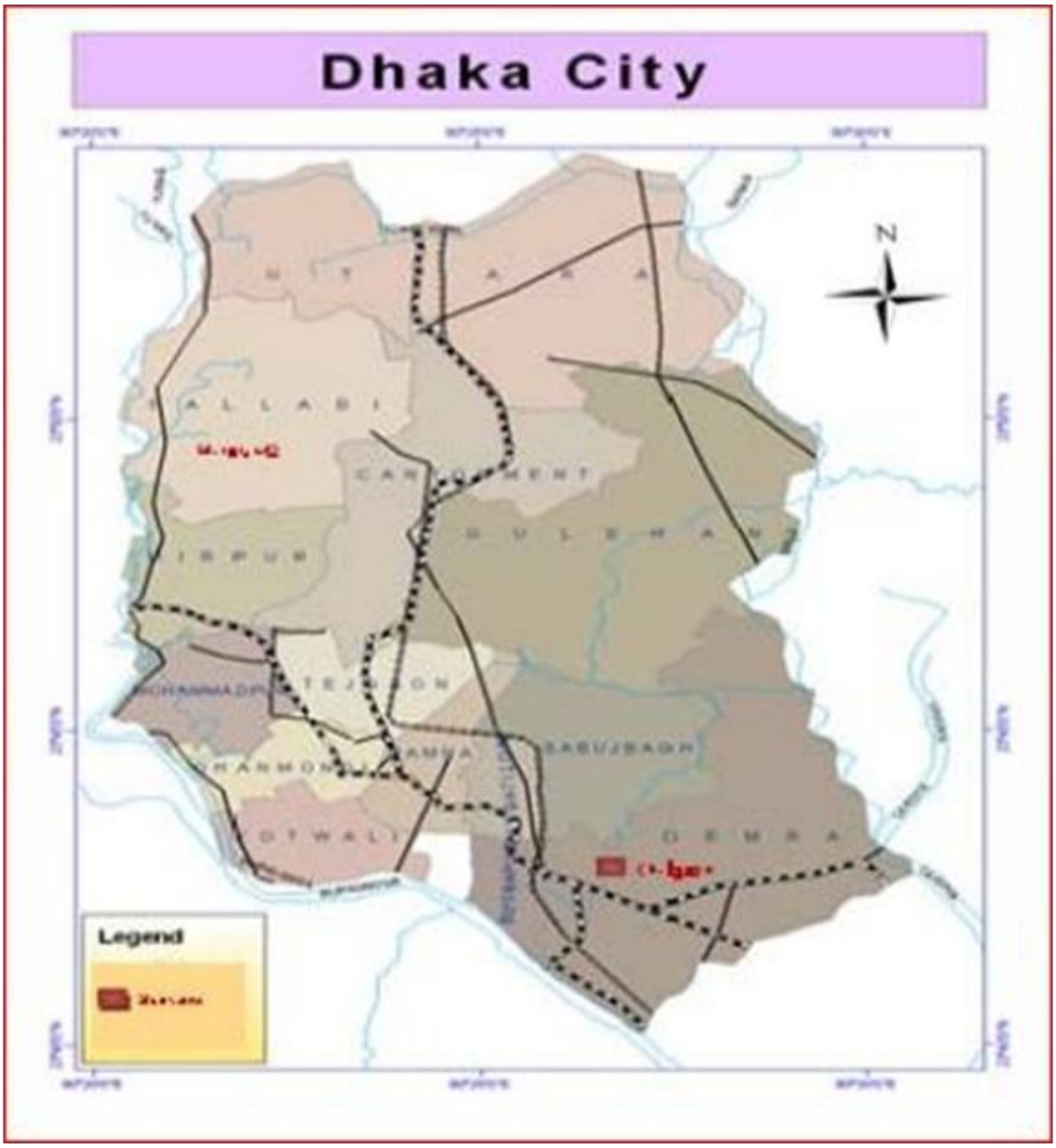

Figure 3.5: Soft soil map of Dhaka city

As well as, it may cause geotechnical problems such as negative skin friction to the pile foundation. Negative skin friction produces a drag load which can be very large for long piles. reported measurements of drag loads that exceed the allowable loads that ordinarily would have been applied to the piles in case of marine clay. Some studies have been carried out to understand the characteristics of dredge fill layers of Dhaka city [1]. Those studies mainly focused on the liquefaction problem/potential of such areas. Khan and Ferdous (2004) [5] investigated the properties of similar soil of Khulna city and proposed foundation alternatives for that area. Similar investigations may be conducted for the reclaimed area of Dhaka city. It is clear that this very soft clay layer, in reclaimed areas, demands special attention for designing foundation systems on or through it. So, it is felt necessary to carry out research to know the characteristics of the soft organic clay layer of such reclaimed areas and propose suitable alternatives for foundation systems on such soil.

Properties of Filling Soil In most cases, the dredged material is almost silty sand with high fines content. It is seen that the depth of the filling layer varies 1.5 to 5.5 m from Existing Ground Level (EGL). Physical and Index Properties It has been found that the value of specific gravity of the sand of the filling layer varies from 2.61 to 2.69. The physical and index properties of filling sand are summarized. It has been found that mean grain size (D50) and fine content (Fc) of the sand of the filling layer vary from 0.150 to 0.180 mm and 17.4 to 27.6%, respectively. B. Properties of Organic Soil: Just below the filling sandy layer, a very soft layer of thickness varies from 0.5 to 7.0 m. This soft soil is dark black in color with organic content. Uncorrected SPT N Value of this layer varies from 1 to 2. Physical and Index Properties It has been found that specific gravity of the organic layer varies from 2.25 to 2.55. Mean grain size (D50) and fine content (Fc) of organic layer shows constant value 0.010 mm and 100%, respectively. The physical and index properties of organic clay are summarized in Table 2. It has been found that natural moisture content and dry unit weight of the soft organic layer varies from 28 to 72% and 4.7 to 9.6 kN/m3 , respectively. This result indicates that moisture content is very high and varies in a large range. As well as, the dry unit weight of this soft organic soil is also very low. It has been found that Organic content (OC) of the soft organic clay at Mirpur-12 and Khilgaon areas vary from 4.7 to 9.4%, and 6.7 to 9.6%, respectively. Atterberg's Limits test has been performed on organic soil samples at Mirpur-12 and Khilgaon to determine liquid limit, plastic limit and liquidity index. It has been presented in Table 2. It has been found that the top filling layer is non-plastic sand. Liquid limit, plastic limit and plasticity index of organic layer vary from 45 to 192%, 20 to 129% and 18 to 63%, respectively which are highly plastic. Soft organic layer has been classified by the Unified Soil Classification System (USCS). Figure 4 presents the position of the soft organic clay samples on Casagrande plasticity chart. It is seen that soils are varying from OL (medium compressibility and organic silt) to OH (highly compressibility and organic clay). Strength Properties Unconfined compression tests have been conducted on undisturbed samples collected from these selected areas. Table 3 shows the summary of unconfined compression test results. It is found that natural moisture content of the study areas varies from 28 to 72%.Unconfined compressive strength and failure strain of organic clay layer of Mirpur-12 varies from 16 to 50 kPa and 13 to15 %, respectively. Whereas unconfined compressive strength and failure strain of the organic layer of Khilgaon varies from 6 to 58 kPa and 9 to15%, respectively. Compressibility and Swelling Properties One-dimensional consolidation tests have also been conducted on undisturbed soil samples collected from these selected areas. Typical e-logP curves have been presented in Fig. 5. It is seen that the elastic rebound is very low. Table 4 presents the one-dimensional consolidation test results. It has been found that initial void ratio (eo), compression index (Cc) and Recompression index (Cr) of soft clay layer vary from 1.50 to 3.88, 0.44 to 1.25 and 0.05 to 0.44, respectively. The coefficient of consolidation (cv) varies from 0.20 to 10.89 m2 /yr. It is also seen that eo and Cc is very high, which is similar to the properties of organic soil. It indicates that excessive settlement may occur to the structures having on it.

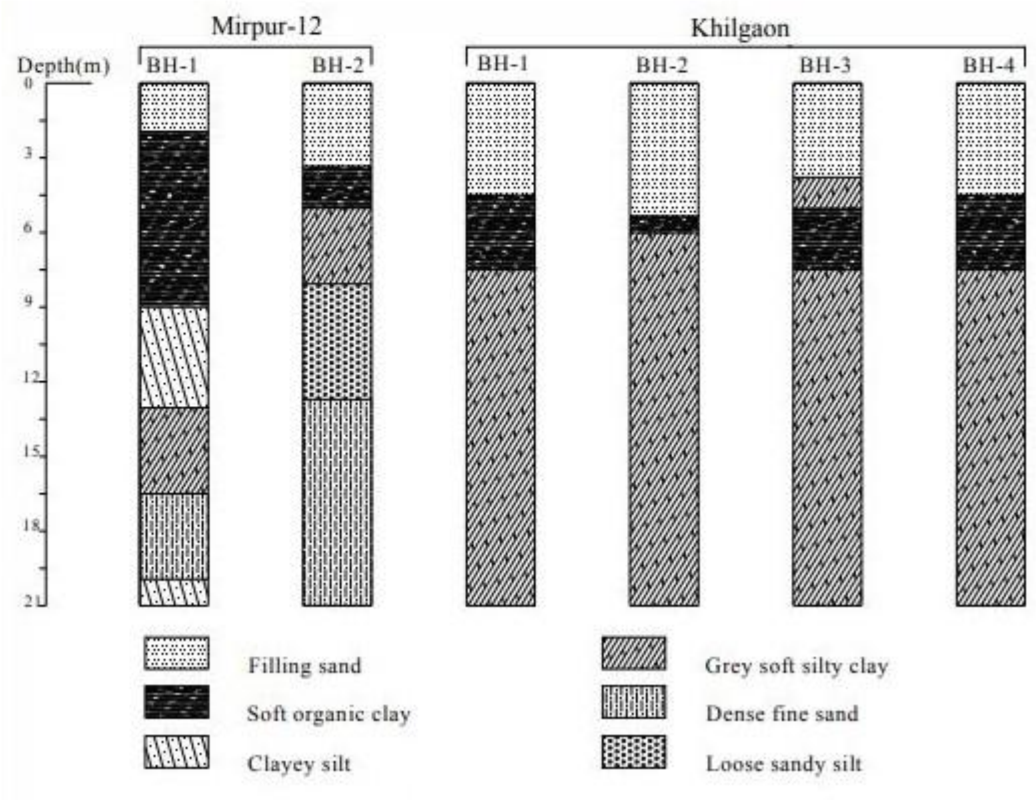

Figure 3.6: Typical borelogs of different study areas.

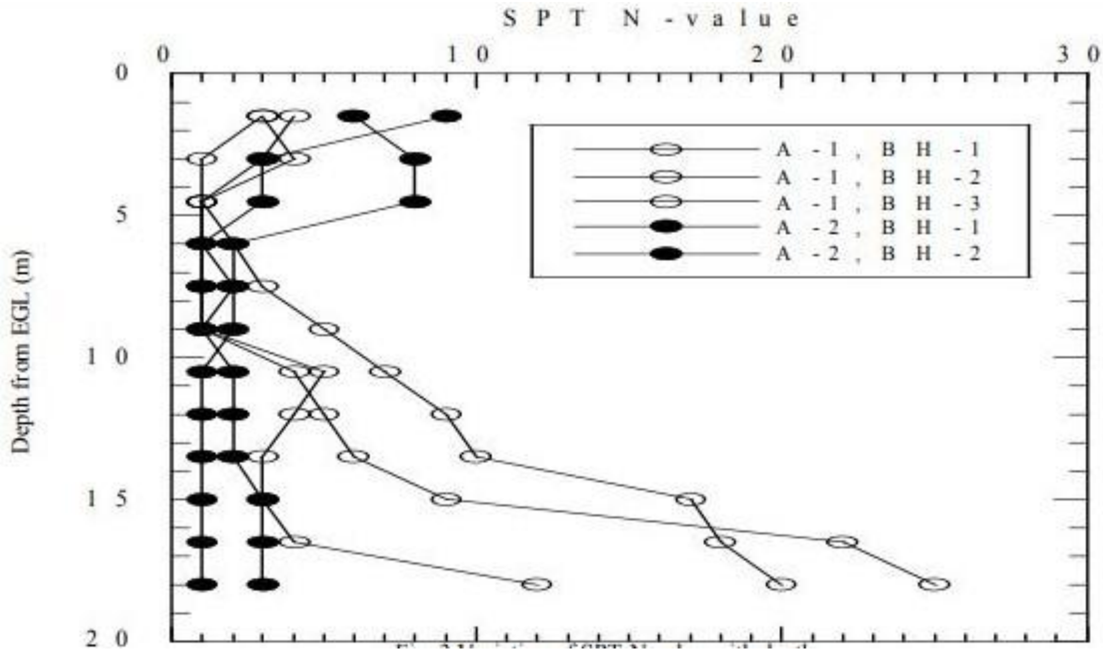

Figure 3.7: Variation of SPT-N value with depth

2.3 Summary

Dhaka city has experienced a rapid growth of urban population and it will continue in the future due to peoples demand and several unavoidable reasons. Unfortunately, most parts of Dhaka city having competent subsoil for building construction are already exhausted. As a result, different new areas are being developed by filling low land. In most cases, the practice for developing such areas is just to fill lowlands (2 to 5 m) by dredged soils collected from nearby river banks and river bed. It is found that the dredged soil is almost silty sand. This invites earthquake induced liquefaction susceptibility for thus developed reclaimed areas [1]. Mean grain size and fine content of the fill materials for developing such areas varies from 0.15 to 0.18 mm and 17.4 to 27.6%, respectively. The SPT N-value of the filling depth varies from 1 to 9. Filling soil is directly dumped on the marshy lowland just upon the vegetation and other organic materials. After a certain time, these organic materials beneath the filling soil are decomposed and produce a soft organic layer. It is found that the thickness of the soft layer varies in the range of 0.5 to 7.5 m. The SPT N-value of this soft organic layer varies from 1 to 2. Liquid limit, plastic limit, plasticity index varies from 41 to 192, 20 to 129 and 15 to 63, respectively. Organic content of the soft clay soil varies from 4.3 to 28.5%. Unconfined compressive strength and failure strain of the soft clay varies between 6.0 to 58.0 kPa and 9 to 15%, respectively. Initial void ratio, compression index, recompression index and coefficient of consolidation of these soft clay layers varies from 1.50 to 3.90, 0.44 to 1.25, 0.05 to 0.44

and 0.20 to 10.89 m2 /yr, respectively. From the characteristics of the soil it is seen that the filling soil is liquefiable in some places. The properties of the soft organic layer indicates that this soft layer is highly plastic and highly compressible. These soft layers will undergo large settlement due to the weight of the filling layer and the load that will come from the super structures. Further research is being conducted to correlate compressibility properties and ground improvement techniques/alternative foundation systems for such sub-soil conditions. [2]

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CHAPTER-3
Methodology

3.1 Introduction

This chapter gives an overview of techniques that are commonly used to improve the performance of saturated clayey soil in situ, its functions, methods of installation and test materials, the applicable soil types and cost of those techniques. Then, this study concluded that there is an urgent need to study the technique of removal and replacement for improving soil behavior taking into consideration geotechnical requirements (i.e. bearing capacity and settlement) the most suitable material corresponding to minimum total cost of soft soil improvement works.

3.2 Methodology Overview

The social, economic, cultural and industrial growth of any country depends heavily on its transportation system. The only mode which could give maximum service to one and all is transportation by highways and railways. As a result of development of infrastructures like buildings, highways, railways and other structures in recent past years has resulted in scarcity of good quality of land for construction projects. Therefore the engineers are bound to adopt inferior and weak soil for construction. In the present scenario the role of ground improvement techniques has become an important and crucial task for various construction projects. By ground improvement techniques the strength of the soil increases, its compressibility reduces and the performance under applied loading enhances. The expansive and collapsible soils are challenges to engineers due to their peculiar behavior of high swelling and shrinkage action. The construction of foundation on sanitary landfills, soft soils, organic soils and karst deposits are troublesome. It is better to replace or bypass such type of soil strata by adopting suitable design of foundation and if not possible the ground improvement is the best solution for such a construction project site. This paper presents thorough study on various available modern ground improvement techniques and their applications in civil engineering in the present scenario. [3]

3.3 List of Soft Ground Treatment Methods

1. Consolidation and drainage methods:

This method maintains trafficability and reduces the amount of residual settlement occurring during road service period by promoting drainage or consolidation of the ground so as to increase ground strength. It is divided into the following seven subtypes.

1.1. Surface drainage: A trench is constructed in the surface part to maintain trafficability for execution machines.

1.2. Sand mat: Sand is spread over the ground surface to maintain surface drainage for consolidation of a soft soil layer. This method is also used to maintain trafficability for execution machines.

1.3. Slow banking: An embankment is constructed at a slower-than-usual speed to prevent fracturing of the ground and to increase the strength of the ground due to consolidation of a cohesive soil layer

1.4. Surcharge: A load is applied to soft ground prior to the execution of a structure to promote consolidation of the clay layer so as to reduce residual settlement and increase ground strength. One preloading method is applied to locations where structures like culverts are to be constructed, and another method, extra-banking, is applied to general embankment areas.

1.5. Vertical drains: Drains are vertically installed in the ground to shorten the horizontal distance for drainage of pore water so as to promote consolidation settlement in a cohesive soil layer or increase ground strength. This method is further divided into two subtypes.

1.5.1. Sand drain: Sand drains made up of highly water-permeable sand are installed vertically in the ground.

1.5.2. Prefabricated vertical drain Artificial drains made of paper (cardboard), plastic, or natural fibers are vertically installed in the ground.

1.6. Vacuum consolidation The pressure inside the soft ground is made negative by means of a vacuum pump or vertical drains so that the atmospheric pressure works as an excess burden load. In addition, pore water in the ground is forcibly discharged to promote consolidation settlement and ground strength enhancement.

1.7. Groundwater lowering: The groundwater level is lowered so as to apply a load, equivalent to the buoyancy that the ground had received before groundwater level lowering, to a lower soft layer so as to promote consolidation settlement and ground strength enhancement.

2. **Compaction methods: In this method:** sand is press-fed into the ground or a dynamic load is applied to the ground to promote ground compaction so as to prevent liquefaction, increase ground strength, and reduce settlement. This method is further divided into the following two subtypes.

2.1. Vibratory compactions: This method, in which ground is compacted by means of dynamic loading, is subdivided into the following five processes.

2.1.1. Sand compaction pile: In this method, sand is pressure-fed into the ground by means of impact loading or vibration loading so as to form sand piles in the ground. Compaction of sandy soil ground by means of this method prevents the occurrence of liquefaction, and for cohesive soil ground it ensures ground strength enhancement and settlement reduction.

2.1.2. Rod compaction: A vibrating rod is driven into the ground to compact sandy soil ground so as to control the occurrence of liquefaction.

2.1.3. Vibro-flotation: A bar-shaped vibrator jets water into the ground while being vibrated in order to compact sandy soil ground, thereby preventing the occurrence of liquefaction.

2.1.4. Vibro-tamper: Vibro-tamping is used to compact sandy soil ground from the ground surface downward so as to prevent liquefaction.

2.1.5. Falling weight compaction: A heavy bob is dropped onto the ground to compact loose sandy soil ground or gravelly soil ground, thereby reducing compression settlement or preventing liquefaction. This method is suited to compacting ground mixed with waste matter and having large voids.

2.2. Static compactions: Sand piles are formed in the ground or fillers are fed into the ground by means of static pressure feeding, rather than the use of dynamic energy such as vibration or tamping, to compact the ground. This static method is further divided into the following two processes.

2.2.1. Static compacted sand pile: Sand is force-fed into the ground by static means to form sand piles for compaction of sandy soil ground, thereby preventing damage due to liquefaction or ensuring strength enhancement of cohesive soil ground and reduction in the amount of settlement.

2.2.2. Static pressure fit compaction: Low-fluidity filler is force-fed into the ground to compact sandy soil ground, thereby preventing the occurrence of liquefaction.

3. **Induration methods: In this method**: an additive, such as cement, is mixed into the soil, and ground consolidation occurs by means of a chemical reaction. This method is further divided into the following five subtypes.

3.1. Shallow soil stabilization: An additive, such as cement or lime, is mixed into the subsurface part of soft ground and agitated, in order to reinforce the shear strength of the ground so as to enhance stability, control deformation, and maintain trafficability.

3.2. Deep mixings: A binder material, mainly cementitious material, is injected into the ground so as to conduct in-situ mixing and agitation of the binder and the soft soil, and strong columnar, block-shaped, or wall-shaped stabilized masses are formed deep in the ground to ensure ground stability enhancement, deformation control, reduction in settlement, and prevention of liquefaction-induced damage. This type is divided into deep mixing (mechanical agitation), high-pressure jetting agitation, and a combination of these methods.

3.2.1. Deep mixing: A weak soil is consolidated in columnar shapes by forcibly mixing a cementitious binder with the soil in the ground with agitation blades.

3.2.2. High pressure jetting mixing: Solidified masses are formed by cutting the ground with a cementitious binder jetted at high pressure into the ground and mixing the cut soft soil in-situ with the binder.

3.3. Lime pile stabilization: A soil-improving material mainly composed of quicklime is injected into soft ground in a columnar shape, and the ground strength is enhanced by the actions of water absorption and expansion and chemical reaction so as to ensure ground stability enhancement, settlement reduction, or liquefaction prevention.

3.4. Chemical grouting: A filler is injected into voids in sandy ground so as to enhance ground stability, control seepage, or prevent liquefaction.

3.5. Freezing: The ground is temporarily frozen in order to stabilize the excavated surface or prevent water from welling up.

4. **Excavation replacement method**: In this method, a soft soil located relatively closer to the surface is replaced with good quality soil to ensure ground stability or reduce settlement.

5. **Pore water pressure dissipation method**: Drains with water permeability higher than crushed stone are installed in sandy soil ground to quickly dissipate excess pore water pressure that would occur in the sandy soil layer in an earthquake, thereby preventing the occurrence of liquefaction.

6. **Burden pressure reduction methods:** An embankment is constructed with a material lighter in weight than ordinary soil in order to reduce the stress increase in the ground, thereby reducing settlement or slip sliding force in the cohesive soil layer. This method is subdivided into the following two methods.

6.1. Lightweight banking: In this method, an embankment is constructed with a material lighter in weight than ordinary soil. Representative methods using the same principle include the Styrofoam block method, foamed mixture lightweight soil method, and foamed bead mixture lightweight soil method.

6.1.1. Styrofoam block: Styrofoam blocks are piled up and tightly bound with each other with binding fixtures to build up an embankment.

6.1.2. Bubble mixed lightweight soil: A lightweight soil mixture made up of soil or fine aggregate mixed with water, cement, and air bubbles is used to build an embankment.

6.1.3. Formable beads mixed lightweight soil: A lightweight banking material made up of a soil mixed with foamed beads (plus a binder and water added in some cases) is used to build an embankment.

6.2. Culvert: Part of an embankment is formed by arranging a series of culverts.

7. **Reinforced banking method**: This method ensures the stability of an embankment by means of installing a reinforcing material on the surface of the foundation ground or at a lower part of the embankment and integrating the material with the embankment. It is effective in preventing liquefaction of the banking material by mitigating loosening of the banking material due to consolidation settlement and is expected to reduce deformation of the embankment even if the banking material or the foundation ground is liquefied due to an earthquake. It is different from the reinforced embankment method in which reinforcing materials are installed on the embankment slope at a constant height.

8. **Structural methods:** Structural methods are methods in which structures or materials higher in shear strength or rigidity than soils are constructed in or on the ground to reduce the total settlement of a cohesive soil layer, ensure the stability of the embankment, and reduce stress in the ground. There are four major methods, as follows.

8.1. Counterweight filling: The stability of an embankment is maintained by backing up the side of the embankment proper with a smaller embankment.

8.2. Contiguous wall: An embankment is surrounded by cast-in-site reinforced concrete (a continuous underground wall), and, in addition, continuous underground walls are constructed at appropriate intervals in a grid pattern inside the surrounding array of reinforced concrete so as to control shear deformation in an earthquake and prevent liquefaction-induced damage.

8.3. Sheet pile: Sheet piles are installed in the ground in the lateral direction of the embankment so as to form a continuous wall in order to ensure embankment stability, control lateral deformation of the ground, or prevent liquefaction-induced damage.

8.4. Pile: Piles are driven into the ground to transfer the loads of the embankment to the foundation ground, thereby reducing total settlement, ensuring ground stability, controlling deformation due to stress reduction, and preventing liquefaction-induced damage

9. **Laying reinforced material method**: In this method, reinforcing materials are laid under sand mats as temporary work to maintain trafficability. This compacts the sand mats and controls loosening of the soil due to consolidation settlement, thereby mitigating damage due to liquefaction of the banking materials during an earthquake. [1]

3.4 Applicability of Each Method:

The main conditions to take into account in selecting soft ground treatment work methods are the theory and effects of the method, road conditions, ground conditions, work conditions, and economic efficiency.

(1) **Principles and Effects of Treatment** Works The major treatment work methods are classified according to their theory and intended effects as summarized.

Function	Typical methods		Effects – Settlement: Reduction in settlement during service with acceleration of consolidation settlement	Effects – Settlement: Reduction in total settlement	Effects – Stability: Increase in strength gain due to consolidation	Effects – Stability: Increase in resistance force	Effects – Stability: Reduction of sliding force	Effects – Deformation: Isolation of stress	Effects – Deformation: Reduction of stress	Effects – Liquefaction – Preventing liquefaction – Improvement of sand properties: Densification	Effects – Liquefaction – Preventing liquefaction – Improvement of sand properties: Consolidation	Effects – Liquefaction – Preventing liquefaction – Improvement of sand properties: Grading treatment	Effects – Liquefaction – Preventing liquefaction – Improvement of sand properties: Reduction of saturation	Effects – Liquefaction – Preventing liquefaction: Increase in effective stress	Effects – Liquefaction – Preventing liquefaction: Dispersion of excess pore water pressure	Effects – Liquefaction – Preventing liquefaction: Control of shear deformation	Effects – Liquefaction: Measures to mitigate facility damage while tolerating liquefaction	Effects: Securing trafficability
Consolidation and drainage	Surface water drainage																	+
	Sand mat		+															+
	Slow banking method				+													
	Surcharge		+		+													
	Vertical drain	Sand drain	+		+													
		Vertical drain	+		+													
	Vacuum consolidation		+		+													
	Groundwater level reduction		+		+								+	+				
Compaction	Vibratory compaction	Sand compaction pile	+	+	+	+			+	+								
		Rod compaction		+*						+								
		Vibro-floatation		+*						+								
		Vibro-tamper		+*						+								
		Falling weight compaction		+*						+								
	Static compaction	Static compacted sand pile	+	+	+	+			+	+								
		Static pressure-fit compaction								+								
Induration	Shallow soil stabilization			+		+		+			+							+
	Deep mixed	Mechanical mixed		+		+		+	+		+					+	+	
		Jet grouting		+		+		+	+		+					+	+	
	Lime pile			+		+				+	+							
	Chemical injection			+		+					+							
	Freezing					+												
Excavation replacement	Excavation replacement			+		+		+				+						
Lowering Pore water pressure	Pore-pressure dispersing														+			
Load reduction	Lightweight embankment	Styrofoam block		+			+		+									
		Bubble-mixed lightweight soil		+			+		+									
		Formable bead-mixed lightweight soil		+			+		+									
	Culvert			+			+		+									
Embankment reinforcement	Embankment reinforcement					+											+	
Structural measure	Counterweight filling					+											+	
	Contiguous wall															+		
	Sheet pile					+		+							+**		+	
	Pile			+		+			+								+	
Laying materials	Laying reinforced materials					+												+

+; Effective for sand ground, +**; Cases with drainage function*

Table 4.1: Theory & effects of each method. [3]

Even if the same work method is selected, if it is applied for a different purpose and use, the design method will be different. Each method has its own intended effects, and in many cases, a method has major effects, which are its primary purpose, as well as associated secondary effects. For instance, when the sand compaction method is applied to cohesive soil ground, the expected major effects include a reduction in total settlement due to stress distribution with sand piles and, as a safety measure, an increase in slip resistance. A number of secondary effects can also be expected including acceleration of consolidation and reduction of stress as a solution for preventing lateral deformation.

(2) **Road Conditions Methods** applicable to a specific project vary depending on the road conditions (e.g., the shape or location of the road embankment) and ground conditions (e.g., the geological composition or soil properties). Road condition items to take into account in selecting treatment methods include (a) the shape (structure) of the longitudinal or transverse cross-section of the road embankment, and (b) the location of the road embankment (whether or not it is at an approach section).

(3) Ground Conditions

i) Soil properties

Sandy soil ground: Sand or sandy soil has larger particles than cohesive soil, but the void ratio is smaller. Sandy soil also has good water permeability, and there are few problems with sandy soil ground regarding ordinary actions. However, since there is a fear of liquefaction occurring in a loose sandy soil layer due to the actions of seismic motion, it is necessary to conduct checking as specified by "3-2-7 Stability against Seismic Ground Motion" and study measures according to the results. Cohesive soil ground Because of the soil properties of cohesive soil ground, soft ground treatment work is often necessary. Some cohesive soils have a high sensitivity ratio and suffer a drastic decline in strength once they are disturbed. Therefore, the treatment requires selecting methods that disturb the ground as little as possible. Caution is also necessary as methods based on the same principles show different patterns of ground disturbance depending on the implementation procedure.

Peaty ground: Peat layers often have high compressibility, water content exceeding 300%, and extremely small initial strength. Their permeability, however, is often very high, and settlement due to primary consolidation rapidly progresses even without the use of consolidation accelerating methods (e.g., the vertical drain method). Because strength reinforcement can be expected with the progress of consolidation, the slow banking method is an effective method for these soils. Muck has low permeability and often has water content of less than about 300%. There is a severe drop in strength once its structure is disturbed, and so an increase in strength due to consolidation cannot be expected. Therefore, the surcharge method, which causes a minor degree of ground disturbance, can be used to cope with settlement, while the overweight fill method can be used to secure stability. However, these methods tend to become very large in scale.

ii) Geological composition

Shallow and thin soft layer: When a soft layer is shallow and thin, its consolidation settlement is small and ends in a short time. In general, it is also less subject to slip failure. Therefore, the treatment of these layers is often conducted with a simple subsurface water drainage method. When constructing a very important structure, it is relatively easy to excavate and remove the problem soft layer. Thus, the excavation replacement method is also often used.

Thick soft layer: When a soft layer is thick, the subsurface water drainage method is used in combination with other methods according to the purpose of application. However, for extremely thick soft layers, it is not only difficult but also uneconomical to apply the vertical drain method or sand compaction pile method to every layer. Therefore, the standard procedure in this case would be to use the above methods to a certain depth and leave the remaining part untreated or jointly use the surcharge method. With long vertical drains, the seepage resistance of the draining material is large if the material has a small cross-section, and due to consolidation delay it will not show the effect expected by the theory.

This soft layer (less than 3-4m) sandwiched between draining layers:

In many cases, settlement due to consolidation rapidly progresses because of a short consolidation drainage distance, and it can be expected that the increase in strength will be sufficient. Therefore, treatment of these layers is often conducted with the subsurface water drainage method, slow banking method, or surcharge method. In some cases, if sand layers are continuous, even those that are only about 5 cm in thickness, they can be effective as draining layers. If the sand layers are not continuous, they will not serve as effective draining layers, and this requires attention. Thick soft layer

lacks draining layer (sand layer): Since the distance for consolidation drainage is long, it takes a long time to accelerate consolidation settlement, and no rapid increase in strength is expected. Settlement measures are thus often conducted with the vertical drain method, which accelerates consolidation. Stability acceleration is then often realized by using the counterweight filling method, slow banking method, sand compaction pile method, induration method, or lightweight embankment method, either singly or in combination.

Thick sand layer (4 m or more) at shallow depth underlain by soft cohesive layer: When the embankment is low, in general there will be no stability-related problems, and only settlement will cause problems. Settlement measures are generally conducted with the vertical drain method or surcharge method. Although the vacuum loading method or groundwater lowering method work to increase consolidation loads, caution is necessary regarding the maintenance of vacuum pressure or the impact of groundwater lowering on the surrounding area during execution. When sand layers have accumulated in a loose condition, caution is required regarding the occurrence of liquefaction in a major earthquake.

(4) Work Conditions:

In selecting treatment work methods, items to be considered regarding work conditions include work period, materials, trafficability for construction machinery, the execution depth, and impacts on the surrounding area.

Work period : This is an extremely important item in the selection of treatment work methods. There are many cases in which a relatively economical method will be sufficient if the work period is long enough. In other words, when the work period is long, it is often possible to construct an embankment while maintaining stability with the slow banking method, and residual settlement will be minimized by leaving the work site for a long time. When vertical drains or sand compaction piles are installed, long installation spacing can be maintained, or the driving length can be reduced. Thus, a long work period produces various advantages. Therefore, when deciding the work period for soft ground treatment in a road project, the basic rule is to first secure a sufficient period for the treatment, and to select appropriate treatment work methods according to the available work period.

Materials: Since it has recently become difficult to obtain highly permeable sea sand or river sand, points to consider in selecting appropriate treatment work methods should include the easiness or economic efficiency of acquiring materials for each method. [4]

Trafficability for construction machinery:

It is necessary to guarantee sufficient trafficability for construction machinery when soft ground is improved. Therefore, a combined use of the sand mat method and shallow soil stabilization method is often adopted. In order to secure trafficability, the sand mat thickness is generally decided by considering the weight of the construction machines, Table 4-3 shows guideline values for contact pressure for machines used in the prefabricated vertical drain method, sand compaction pile method, and deep mixed method.

For the prefabricated vertical drain method, “Center driving type” means that the casing is set at the center of the construction machine, while “Edge driving type” means that the casing is set on either side of the construction machine. [4]

Method	Installation depth (m)	Contact pressure (kN/m^2) Center driving type	Edge driving type
Prefabricated vertical drain	10～20	35～40	40～45
	20～30	40～45	45～65
	30～40	45～50	Not applicable
Sand compaction pile	10 or less	80～90	
	10～20	90～110	
	20～30	110～130	
Deep mixed (Mechanical mixed)	10 or less	70～80	
	10～20	80～110	
	20～30	110～130	

Table 4.2: Guidelines for contact pressure of construction machines [3]

5) Execution depth:

The maximum execution depth greatly varies depending on the type of treatment work method, the type of machines to use, the ground conditions, and other factors. It is necessary to check each particular method by using specialized books, brochures, and other literature. For example, it is generally understood that the excavation replacement method can reach to a depth of about 2 to 3 m. When improving to a greater depth, it is necessary to study other methods, including the economic efficiency. The maximum execution depth with the vertical drain method or sand compaction pile method is about 45 m. Caution is necessary when there is a gravelly layer with a high N-value at an intermediate depth in the ground, as there are cases where soft layers beneath it may not be improved, depending on the method used.

Impact on the surrounding area:

If the ground is extremely weak or the embankment is high, there are often serious impacts on the surrounding area, including large settlement or swelling of the surrounding ground. Therefore, if residential houses or important structures are located near the slope toe of the embankment, it is necessary to focus on methods that can reduce total settlement and control shear deformation. If it is impossible to use these methods or to protect structures against impacts, it may be necessary to study the idea of using an elevated structure instead of an embankment. When selecting treatment methods, it is necessary to fully study: - noise or vibration during execution; - the impacts on structures in the surrounding area; - changes in the groundwater level; - the impacts of discharged water or muddy water, and of additives or chemicals used, on the water quality of the groundwater; and - other impacts on the surrounding environment.

Particularly problematic matters in terms of influence on the surrounding area are described below.

a. Vibration and noise: During the works Figures 4-2 and 4-3 show the relationships between vibration and noise and their attenuation for various construction machines. The sand compaction pile Soft Ground Treatment Manual 4 - 19 (SCP) method, sand drain (SD) method, and falling weight compaction method produce greater noise during execution than the other methods. Therefore, if there are structures or residential houses nearby, work control will include measuring vibration and noise, and necessary actions are taken as required. The deep mixed method and static compacted sand pile method are relatively low-vibration and low-noise.

b. Ground displacement: During the works Ground displacement occurring during ground treatment varies depending on topography, original ground, type of treatment work, treatment specifications, and type of construction machines used. In particular, the compaction method tends to cause large deformation in the surrounding ground during use, and thus requires caution. The deep mixed method is known to cause relatively little deformation, but this does not mean that no displacement will occur. There are reports that some deformation occurs in the surrounding ground depending on the topography or ground conditions. Therefore, when work is conducted near structures, the most suitable treatment work and construction machinery are selected, and experimental construction is carried out. In addition, it is necessary to pay sufficient attention to displacement of existing structures during the treatment work.

c. Impact on groundwater: The groundwater lowering method or vacuum compaction method will reduce the groundwater level in the surrounding ground. Therefore, it is necessary to take appropriate measures (e.g., installing water cut-off sheet piles) at locations likely to suffer ground settlement or groundwater level reduction. The induration method and contiguous wall method require full attention, because they may affect groundwater flows or groundwater quality. The following cases require the careful attention,; - when using the methods that cause noise and vibration, or that cause ground displacement - methods that draw up or shut off groundwater - when a road is constructed near an urban area, a densely populated area, residential houses, or other existing structures.

3.5 Selection of the Method:

The followings are necessary to consider for selecting soil treatment methods. - performance required of the structure - purpose of treatment - characteristics of the soil - land use restrictions - impacts on the work period and the surrounding area - effectiveness and economic efficiency.

In the selection flow, the top priority of study is placed on the sand mat and similar methods to secure trafficability. If any problems arise regarding settlement or stability, then methods that involve slowly building up the embankment and that are relatively inexpensive (e.g., surcharge or the slow banking method), are preferably studied. Suitable methods are studied based on the theory and effects of each method as shown in Table 4-2. If the use of only the surcharge method might not solve a settlement-related problem because of strict time constraints, the use of the only the slow banking method will not be able to maintain sufficient stability, or the filling works could cause deformation or other damage to facilities in the vicinity. In selecting appropriate treatment methods, a number of promising methods are selected based on the study of the road conditions, ground conditions, work conditions, and records of past application on similar types of ground, as described in "(3) Conditions to consider in selecting soft ground treatment work methods". An initial design is then carried out for these methods to calculate the rough cost, and the most suitable method is selected based on a comprehensive point of view. If the cost of the soft ground treatment work is expected to be very high, it is necessary to conduct an extensive study, including changing the road structure or route, taking into account economic efficiency, road standards, etc.

Treatment methods are not only implemented individually, but also jointly with other methods. For example, the sand mat method, in which the surface of a soft layer is covered with sand, facilitates the operation of construction machines and also serves as a draining layer. Therefore, it is ordinarily used jointly with the vertical drain method or similar methods. Examples of methods often used in combination with others are shown in Table 4-4. Since this table only gives some of the combinations and many other combinations are possible, it is therefore necessary to study the most effective and economical combination that fits the local conditions when selecting treatment methods. However, caution is necessary because the assumed effect will not always be realized from a combination of methods. For instance, with the combination of the high-rigidity deep mixed method and low-rigidity reinforcing material as a method to prevent slip failure, as shown in Figure 4-4, the amount of deformation at which the peak strength is realized is different between these materials, and the tensile strength of the reinforcing material is not expected to show much of its intended effect for small deformations. Therefore, this embankment reinforcement method may not be effective in reducing the load of the deep mixed method. [3]

3.6 Primary Case Study :

Location: The construction project of the proposed multistoried residential building of Imparo Ventures Limited situates at Namapara, Khilkhet, Dhaka.

Area of research: Mainly our studies on cost efficient soft soil improvement techniques on above mentioned project.

Correction of the field SPT values: The overall field SPT values (Nf) have been corrected due to the effect of the Overburden pressure at the different layers of investigation in the case of each Borehole. The above corrections have been done according to the following equations as suggested by Bazaraa (1967) (Ref: Table No: 3-2, Page No-99, Foundation analysis & Design by J.E. Bowles, 3rd edition). 75 k Pa (1.5 ksf), = … … … … … For Po N = … … … … … For PoN > 75 kPa, Where, N = field SPT value. N' = Corrected value of the field SPT due to overburden pressure. = 0.04 for SI units; = 2.0 for Fps units 2 = 0.01 for SI units; = 0.5 for Fps units Po = Effective overburden pressure, (in kPa or ksf) The field SPT values has been corrected due to overburden pressure (according to the above equation) and the corrected values of the field SPT as obtained therefore are provided in the following table.

TECHNOSOIL INTERNATIONAL

Client : Imparo Ventures Ltd.
Project : Multistoried Residential Building
Location : Namapara, Khilkhet, Dhaka.

Borehole No.	:	1 (One)
Boring Depth	:	100'-0"
E.G.L.	:	
G.W.L.	:	1.00 m down
Date	:	2/11/2021

Depth (ft)	Sample Type & No.	Sample Depth (Thick)	Description of materials	Depth (ft)	Standard Penetration Test Values 6"	6"	6"	12"
5.0	D-1	(18.00)	Yellow ash spotted medium plastic very soft Silty CLAY, CL.	5.0	1	0	1	**1**
10.0	D-2			10.0	1	0	1	**1**
15.0	D-3	18.00		15.0	1	0	1	**1**
20.0	D-4		Yellow ash spotted low plastic Clayey SILT, ML.	20.0	3	4	4	**8**
25.0	D-5	(20.00)		25.0	3	4	5	**9**
30.0	D-6			30.0	3	4	5	**9**
35.0	D-7	38.00		35.0	3	4	5	**9**
40.0	D-8		Reddish yellow medium dense SILT & fine SAND, ML.	40.0	6	10	14	**24**
45.0	D-9	(10.00) 48.00		45.0	7	12	15	**27**
50.0	D-10	(5.00) 53.00	Yellowish Brown dense Silty fine SAND, SM.	50.0	10	16	22	**38**
55.0	D-11		Yellowish Brown to reddish yellow dense to very dense very fine SAND, little/trace silt, SM.	55.0	11	18	25	**43**
60.0	D-12			60.0	11	19	28	**47**
65.0	D-13			65.0	9	15	21	**36**
70.0	D-14			70.0	10	14	20	**34**
75.0	D-15	(48.00)		75.0	9	13	20	**33**
80.0	D-16			80.0	14	21	27	**48**
85.0	D-17			85.0	16	22	28	**50**
90.0	D-18			90.0	19	25	25	**50** (11")
95.0	D-19			95.0	18	27	23	**50** (10")
100.0	D-20	101.00		100.0	19	26	24	**50** (10")

S.P.T

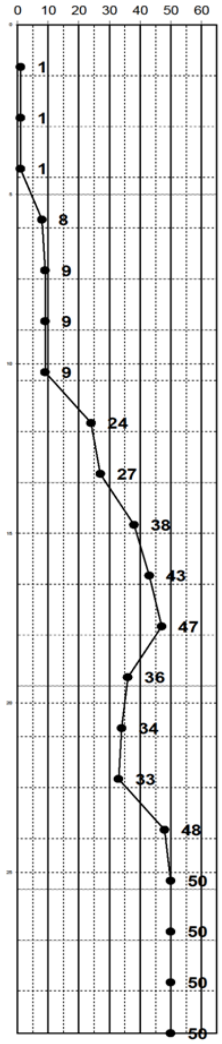
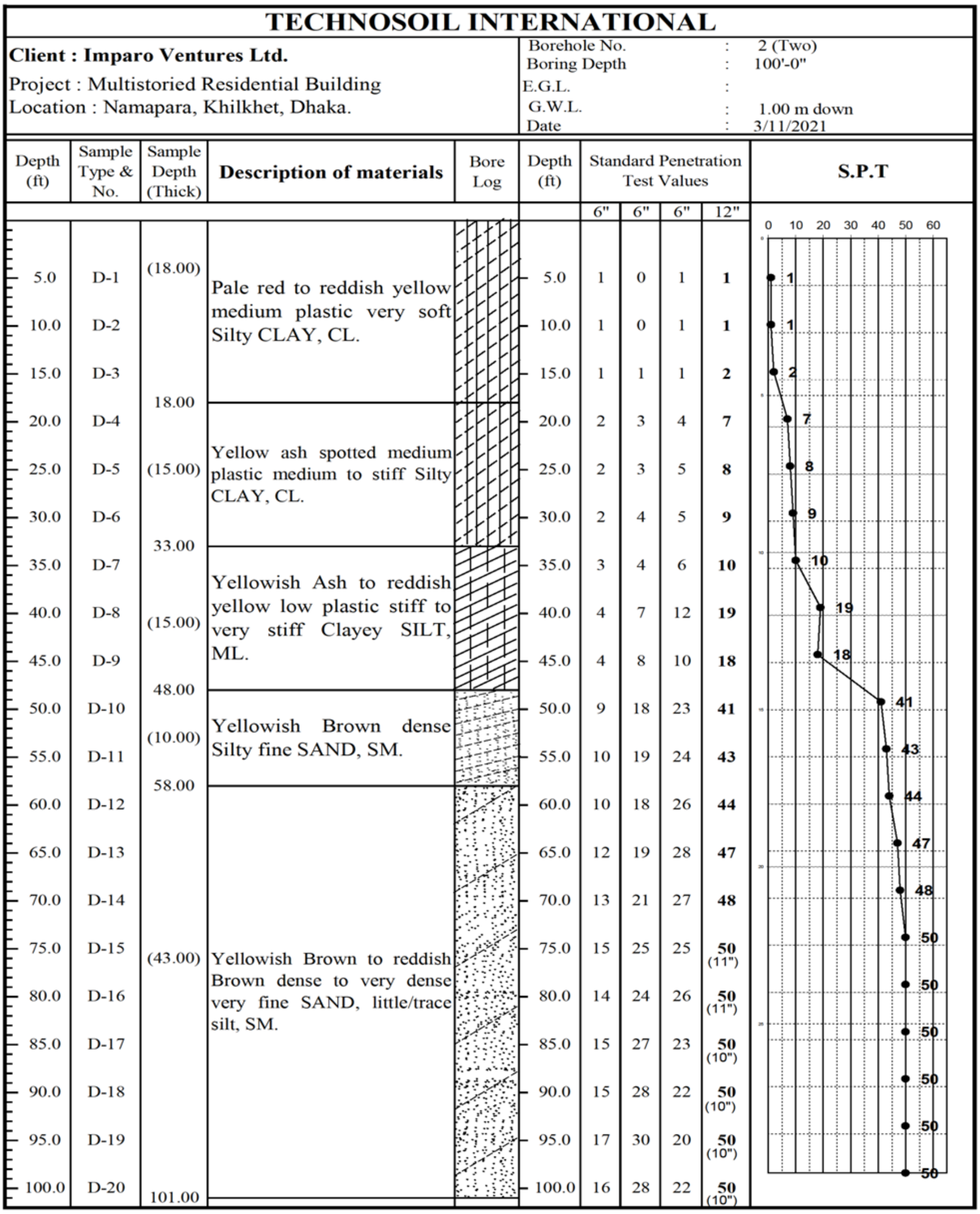


Figure 3.16: SPT Diagram 1



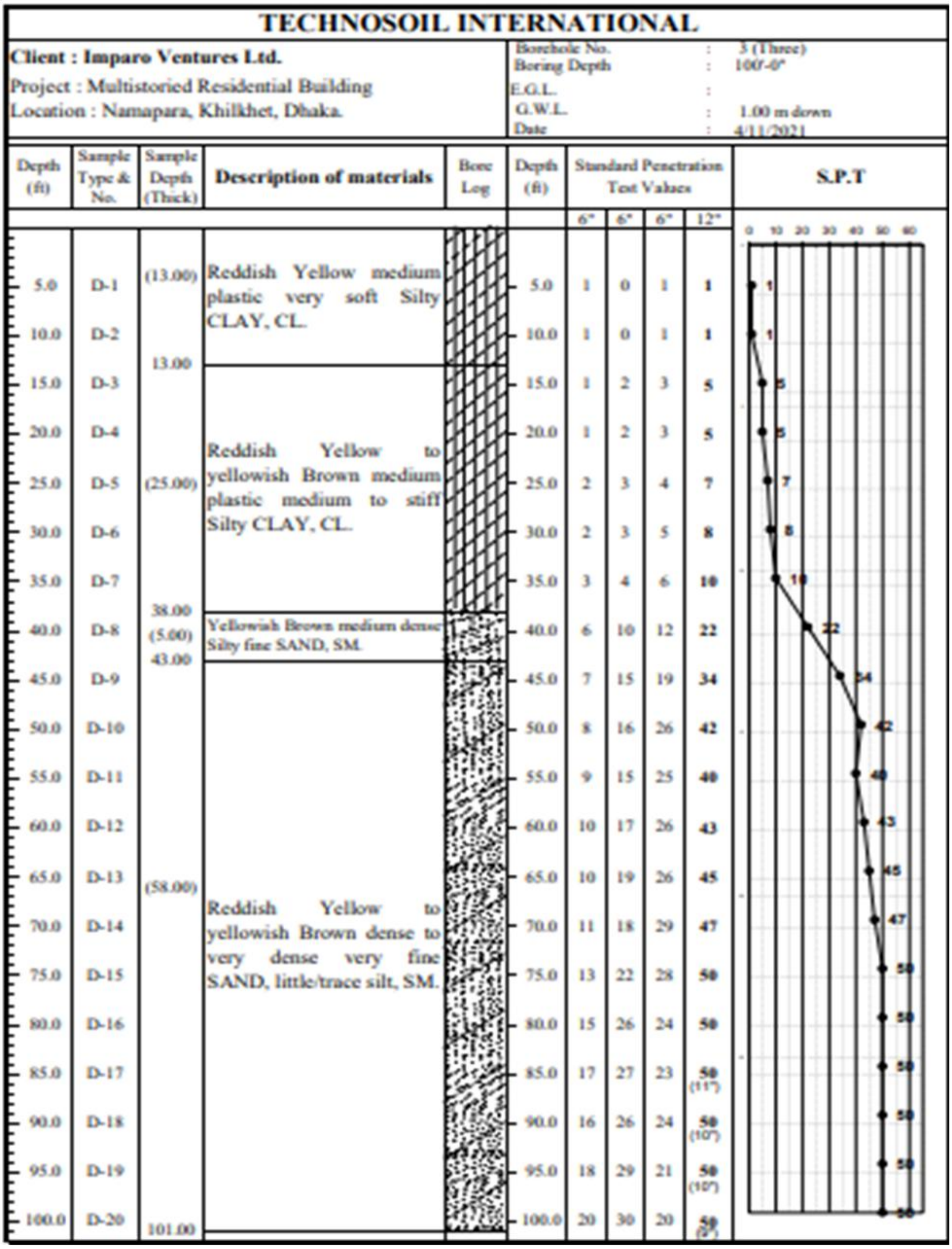
TECHNOSOIL INTERNATIONAL

Client : Imparo Ventures Ltd.
Project : Multistoried Residential Building
Location : Namapara, Khilkhet, Dhaka.

Borehole No. : 2 (Two)
Boring Depth : 100'-0"
E.G.L. :
G.W.L. : 1.00 m down
Date : 3/11/2021

Depth (ft)	Sample Type & No.	Sample Depth (Thick)	Description of materials	Depth (ft)	6"	6"	6"	12"
5.0	D-1	(18.00)	Pale red to reddish yellow medium plastic very soft Silty CLAY, CL.	5.0	1	0	1	1
10.0	D-2			10.0	1	0	1	1
15.0	D-3			15.0	1	1	1	2
20.0	D-4	18.00	Yellow ash spotted medium plastic medium to stiff Silty CLAY, CL.	20.0	2	3	4	7
25.0	D-5	(15.00)		25.0	2	3	5	8
30.0	D-6			30.0	2	4	5	9
35.0	D-7	33.00	Yellowish Ash to reddish yellow low plastic stiff to very stiff Clayey SILT, ML.	35.0	3	4	6	10
40.0	D-8	(15.00)		40.0	4	7	12	19
45.0	D-9			45.0	4	8	10	18
50.0	D-10	48.00	Yellowish Brown dense Silty fine SAND, SM.	50.0	9	18	23	41
55.0	D-11	(10.00)		55.0	10	19	24	43
60.0	D-12	58.00	Yellowish Brown to reddish Brown dense to very dense very fine SAND, little/trace silt, SM.	60.0	10	18	26	44
65.0	D-13			65.0	12	19	28	47
70.0	D-14			70.0	13	21	27	48
75.0	D-15	(43.00)		75.0	15	25	25	50 (11")
80.0	D-16			80.0	14	24	26	50 (11")
85.0	D-17			85.0	15	27	23	50 (10")
90.0	D-18			90.0	15	28	22	50 (10")
95.0	D-19			95.0	17	30	20	50 (10")
100.0	D-20	101.00		100.0	16	28	22	50 (10")

Figure 3.17: SPT Diagram 2



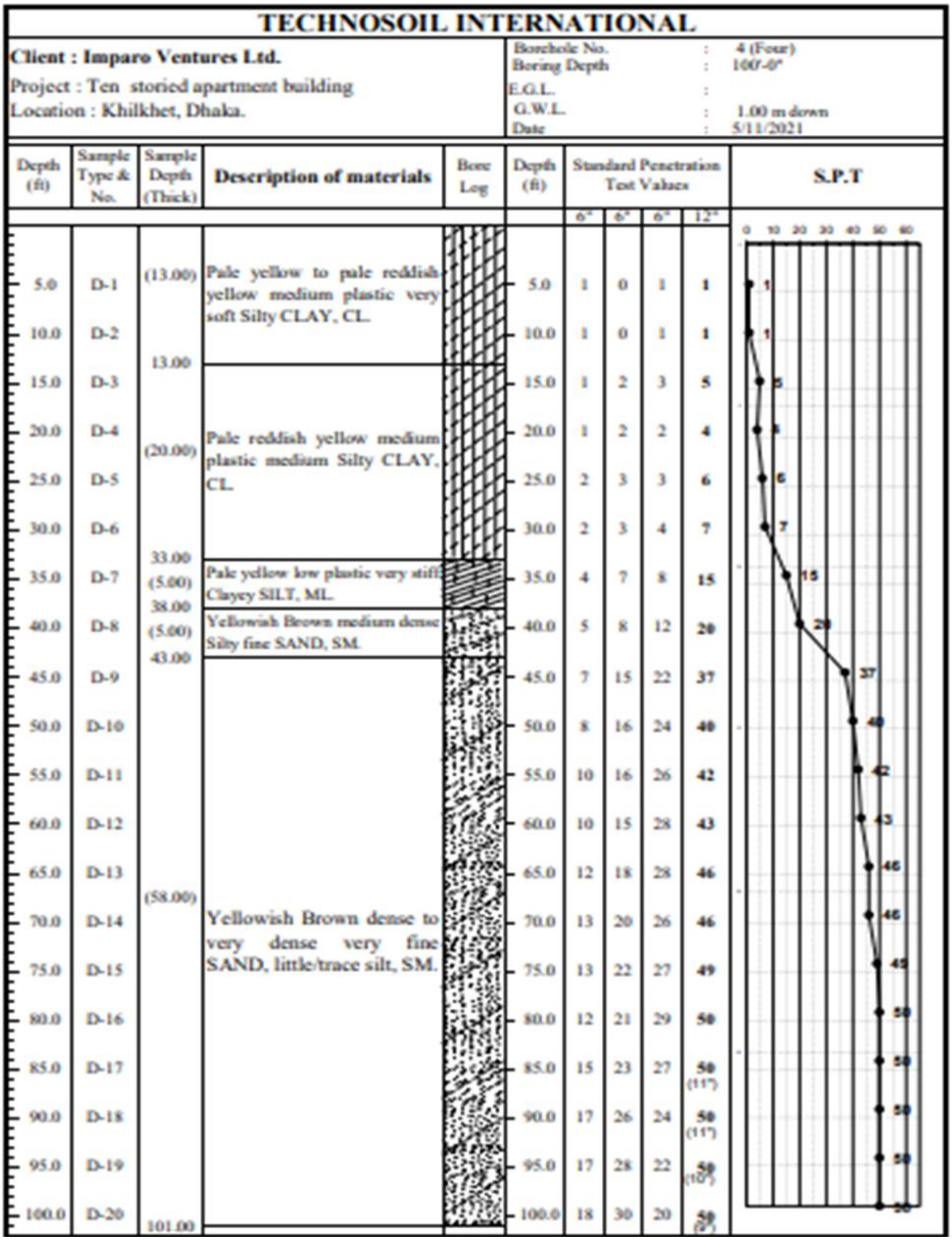
TECHNOSOIL INTERNATIONAL

Client : Imparo Ventures Ltd.
Project : Multistoried Residential Building
Location : Namapara, Khilkhet, Dhaka.

Borehole No. : 3 (Three)
Boring Depth : 100'-0"
E.G.L. :
G.W.L. : 1.00 m down
Date : 4/11/2021

Depth (ft)	Sample Type & No.	Sample Depth (Thick)	Description of materials	Bore Log	Depth (ft)	6"	6"	6"	12"
5.0	D-1	(13.00)	Reddish Yellow medium plastic very soft Silty CLAY, CL.		5.0	1	0	1	1
10.0	D-2				10.0	1	0	1	1
15.0	D-3	13.00	Reddish Yellow to yellowish Brown medium plastic medium to stiff Silty CLAY, CL.		15.0	1	2	3	5
20.0	D-4				20.0	1	2	3	5
25.0	D-5	(25.00)			25.0	2	3	4	7
30.0	D-6				30.0	2	3	5	8
35.0	D-7				35.0	3	4	6	10
40.0	D-8	38.00 (5.00) 43.00	Yellowish Brown medium dense Silty fine SAND, SM.		40.0	6	10	12	22
45.0	D-9		Reddish Yellow to yellowish Brown dense to very dense very fine SAND, little/trace silt, SM.		45.0	7	15	19	34
50.0	D-10				50.0	8	16	26	42
55.0	D-11				55.0	9	15	25	40
60.0	D-12				60.0	10	17	26	43
65.0	D-13	(58.00)			65.0	10	19	26	45
70.0	D-14				70.0	11	18	29	47
75.0	D-15				75.0	13	22	28	50
80.0	D-16				80.0	15	26	24	50
85.0	D-17				85.0	17	27	23	50 (11")
90.0	D-18				90.0	16	26	24	50 (10")
95.0	D-19				95.0	18	29	21	50 (10")
100.0	D-20	101.00			100.0	20	30	20	50 (8")

Figure 3.18: SPT Diagram 3



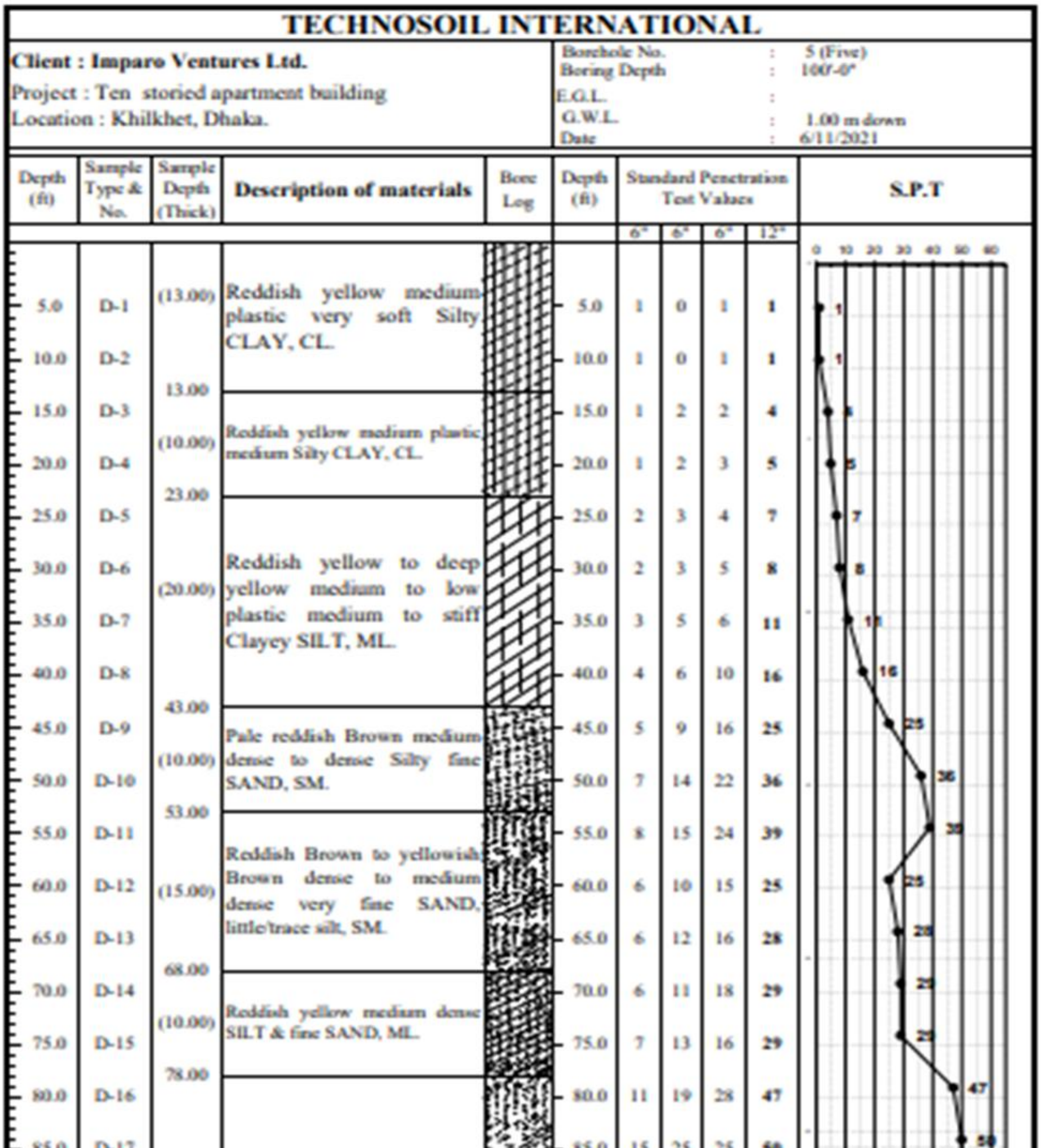
TECHNOSOIL INTERNATIONAL

Client : Imparo Ventures Ltd.
Project : Ten storied apartment building
Location : Khilkhet, Dhaka.

Borehole No. : 4 (Four)
Boring Depth : 100'-0"
E.G.L. :
G.W.L. : 1.00 m down
Date : 5/11/2021

Depth (ft)	Sample Type & No.	Sample Depth (Thick)	Description of materials	Bore Log	Depth (ft)	Standard Penetration Test Values 6"	6"	6"	12"
5.0	D-1	(13.00)	Pale yellow to pale reddish yellow medium plastic very soft Silty CLAY, CL.		5.0	1	0	1	1
10.0	D-2				10.0	1	0	1	1
15.0	D-3	13.00	Pale reddish yellow medium plastic medium Silty CLAY, CL.		15.0	1	2	3	5
20.0	D-4	(20.00)			20.0	1	2	2	4
25.0	D-5				25.0	2	3	3	6
30.0	D-6	33.00			30.0	2	3	4	7
35.0	D-7	(5.00) 38.00	Pale yellow low plastic very stiff Clayey SILT, ML.		35.0	4	7	8	15
40.0	D-8	(5.00) 43.00	Yellowish Brown medium dense Silty fine SAND, SM.		40.0	5	8	12	20
45.0	D-9		Yellowish Brown dense to very dense very fine SAND, little/trace silt, SM.		45.0	7	15	22	37
50.0	D-10				50.0	8	16	24	40
55.0	D-11				55.0	10	16	26	42
60.0	D-12				60.0	10	15	28	43
65.0	D-13	(58.00)			65.0	12	18	28	46
70.0	D-14				70.0	13	20	26	46
75.0	D-15				75.0	13	22	27	49
80.0	D-16				80.0	12	21	29	50
85.0	D-17				85.0	15	23	27	50 (11")
90.0	D-18				90.0	17	26	24	50 (11")
95.0	D-19				95.0	17	28	22	50 (10")
100.0	D-20	101.00			100.0	18	30	20	50 (8")

Figure 3.19: SPT Diagram 4



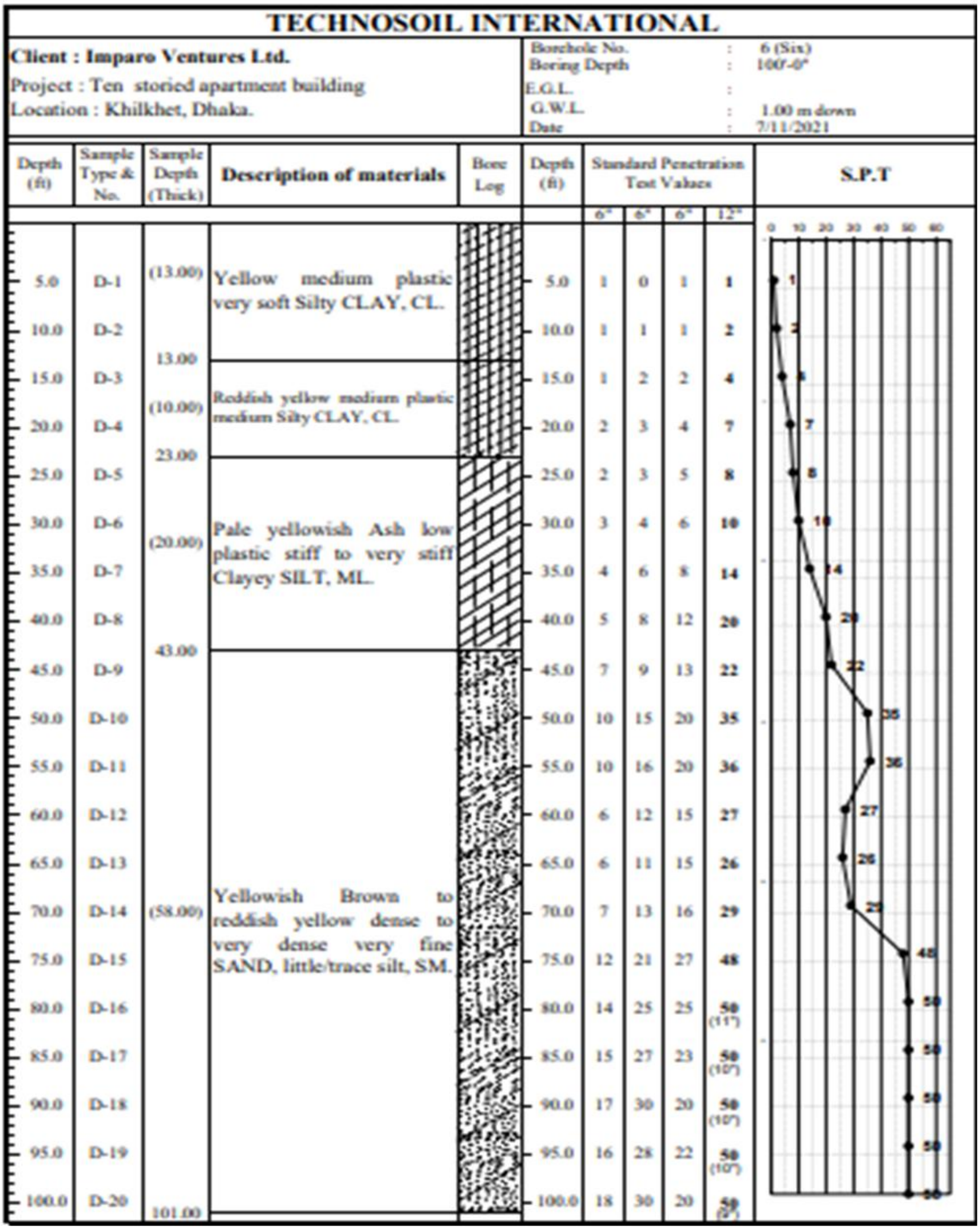
TECHNOSOIL INTERNATIONAL

Client : Imparo Ventures Ltd.
Project : Ten storied apartment building
Location : Khilkhet, Dhaka.

Borehole No. : 5 (Five)
Boring Depth : 100'-0"
E.G.L. :
G.W.L. : 1.00 m down
Date : 6/11/2021

Depth (ft)	Sample Type & No.	Sample Depth (Thick)	Description of materials	Depth (ft)	6"	6"	6"	12"
5.0	D-1	(13.00)	Reddish yellow medium plastic very soft Silty CLAY, CL.	5.0	1	0	1	1
10.0	D-2	13.00		10.0	1	0	1	1
15.0	D-3	(10.00)	Reddish yellow medium plastic medium Silty CLAY, CL.	15.0	1	2	2	4
20.0	D-4	23.00		20.0	1	2	3	5
25.0	D-5		Reddish yellow to deep yellow medium to low plastic medium to stiff Clayey SILT, ML.	25.0	2	3	4	7
30.0	D-6	(20.00)		30.0	2	3	5	8
35.0	D-7			35.0	3	5	6	11
40.0	D-8	43.00		40.0	4	6	10	16
45.0	D-9	(10.00)	Pale reddish Brown medium dense to dense Silty fine SAND, SM.	45.0	5	9	16	25
50.0	D-10	53.00		50.0	7	14	22	36
55.0	D-11		Reddish Brown to yellowish Brown dense to medium dense very fine SAND, little/trace silt, SM.	55.0	8	15	24	39
60.0	D-12	(15.00)		60.0	6	10	15	25
65.0	D-13	68.00		65.0	6	12	16	28
70.0	D-14	(10.00)	Reddish yellow medium dense SILT & fine SAND, ML.	70.0	6	11	18	29
75.0	D-15	78.00		75.0	7	13	16	29
80.0	D-16		Yellowish Brown dense to very dense very fine SAND, little/trace silt, SM.	80.0	11	19	28	47
85.0	D-17	(23.00)		85.0	15	25	25	50 (11")
90.0	D-18			90.0	17	28	22	50 (10")
95.0	D-19			95.0	17	30	20	50 (10")
100.0	D-20	101.00		100.0	19	31	19	50 (9")

Figure 3.20: SPT Diagram 5



TECHNOSOIL INTERNATIONAL

Client : Imparo Ventures Ltd.
Project : Ten storied apartment building
Location : Khilkhet, Dhaka.

Borehole No. : 6 (Six)
Boring Depth : 100'-0"
E.G.L. :
G.W.L. : 1.00 m down
Date : 7/11/2021

Depth (ft)	Sample Type & No.	Sample Depth (Thick)	Description of materials	Depth (ft)	6"	6"	6"	12"
5.0	D-1	(13.00)	Yellow medium plastic very soft Silty CLAY, CL.	5.0	1	0	1	1
10.0	D-2			10.0	1	1	1	2
		13.00						
15.0	D-3	(10.00)	Reddish yellow medium plastic medium Silty CLAY, CL.	15.0	1	2	2	4
20.0	D-4			20.0	2	3	4	7
		23.00						
25.0	D-5	(20.00)	Pale yellowish Ash low plastic stiff to very stiff Clayey SILT, ML.	25.0	2	3	5	8
30.0	D-6			30.0	3	4	6	10
35.0	D-7			35.0	4	6	8	14
40.0	D-8			40.0	5	8	12	20
		43.00						
45.0	D-9	(58.00)	Yellowish Brown to reddish yellow dense to very dense very fine SAND, little/trace silt, SM.	45.0	7	9	13	22
50.0	D-10			50.0	10	15	20	35
55.0	D-11			55.0	10	16	20	36
60.0	D-12			60.0	6	12	15	27
65.0	D-13			65.0	6	11	15	26
70.0	D-14			70.0	7	13	16	29
75.0	D-15			75.0	12	21	27	48
80.0	D-16			80.0	14	25	25	50 (11")
85.0	D-17			85.0	15	27	23	50 (10")
90.0	D-18			90.0	17	30	20	50 (10")
95.0	D-19			95.0	16	28	22	50 (10")
100.0	D-20	101.00		100.0	18	30	20	50 (8")

Figure 3.21: SPT Diagram 6

Applicable Soft soil improvement Techniques for above project

Usually many types of technique used to develop the soft soil strength in the world which are already discussed. For this project we are applying following Four most commonly technique in Bangladesh only for soft soil improvement.

1. Sand compaction pile (SCP)
2. Soil replacement.
3. Prefabricated vertical drain (PVD)
4. Dynamic compaction (DC)

3.6.1 Sand compaction pile (SCP)

Procedure:

The sand compaction pile (SCP) method is a technique of placing granular material (usually sand) into a ground through a casing pipe, and the sand is compacted by vibration, dynamic impact, or static excitation to construct a compacted sand pile in soils. A casing pipe with a plug of sand at its tip was driven to the bottom of improved ground by a vibrator method.

for soft clay deposits which are typically encountered in offshore works, thicker sand piles are installed into the clay at the sea bottom, as shown in. “Forced replacement” is the major principle for the improvement of offshore works, rather than the formation of “composite ground” where the sand piles replace the cohesive soils. In such cases, the objectives of the improvement are to increase the bearing capacity, to reduce the consolidation settlement, and to increase the horizontal resistance. [4]

Equipment and implementation process:

An on-land type equipment for the vibratory SCP and its installation procedure in a soft ground are illustrated respectively. The procedure is as follows.

(1) Excavation: excavate 5 feet from top to down on total area.

(2) Positioning: Set the casing pipe at the predetermined place.

(3) Penetration of a casing pipe: By operating the rig & copycall , penetrate the casing pipe into the ground (Dia-12 inch).

(4) Feeding sands: After the casing pipe has reached the required depth, feed sand into the casing.

(5) Drawing up the casing pipe: By drawing up the casing pipe, the sand in the pipe is forced out through the void by hammering (hammer weight= 950kg) .

(6) Re-driving the casing pipe: Re-drive the casing while compacting the sand pile pressed out by the hammer.

(7) Re-Positioning: Again Set the casing pipe at the predetermined place(distance 2 feet from each borehole.)

(8) Completion: Form each compacted sand pile to reach the ground surface by repeating the above procedure.

3.6.2 Soil Replacement

Procedure:

Soil replacement is one of the oldest and simplest methods which improve the bearing soil conditions. The foundation condition can be improved by replacing poor soil (eg. organic soils and soft clay) with more competent materials such as sand, gravel or crushed stone as well, nearly any soil can be used in fills. However, some soils are more difficult to compact than others when used as a replacement layer. The use of replacement soil under shallow foundation can reduce consolidation settlement and increase soil bearing capacity. It has some advantages over other techniques and deep foundation as it is more economical and requires less delay to construction. [5]

Below mentioned procedure we have to follow this improvement:

1.Excavate the total area up-to depth of 15 feet (considering as soft soil where N= 0-4) by excavator.

2.Dispose the soft soil away by drum truck.

3.Due to having medium soil after first 15 feet, we have to fill the area by sand mixing with ¾ bricks khoa. (ratio =8:1)

4.After filling every 6 inch we have to compact it perfectly by roller equipment.

5.Then again fill upto 6 inch as same ratio of sand and khoa & compact as it is.

6.By following the same procedure fill upto 10 feet of the depth.

7.No need to fill rest of 5 feet for structural construction purpose.

3.6.3 Prefabricated Vertical Drain (PVD)

Procedure:

This method statement has been prepared to describe the installation of PVD. The objective of this method statement is to provide the Engineer with the methodology of how the works performed and ensure a good degree of control during the execution of the works. The actual work method may differ depending on the Engineer requirement and site conditions. To expedite the consolidation of slow draining compressible soils, PVD has been installed into the soil to shorten the travel distance of pore water from the soil. After PVD installation has been completed, normally, pre-loading is applied to increase the pore water pressure and force the water to flow to the nearest drain. Alternatively, a vacuum technique can be used to simulate a pre-load. [6]

1) Excavate the very soft soil (N value 0-2) from the top of total area.
2) Fill the area by sand till 1 meter.
3) Install the geotextile filter jacket by boom tip equipment. (distance 2 m)
4) Place the woven pp geotex on hole area.
5) Again fill with sand on geotex. (0.66 ft depth)
6) Compact the sand and again fill with sand & compaction upto RL.

3.6.4 Dynamic compaction (DC)

Procedure:

In the framework of Dhaka Mass Rapid Transit Development Project, TOKYU has been nominated as the Contractor for ground improvement works of the depot site. Dynamic compaction technique shall be followed as a part of ground improvement works aiming to improve the loose sandy soil and provide a safe platform satisfying the project requirements. DC is to stabilize and density granular soils deposited both above and below the groundwater table. It has been aimed to improve soil bearing capacity and decrease the potential of liquefaction. The process consists essentially of dropping a large weight, into the ground to be compacted. DC techniques require the use of pounders weighing ranging from 10 to 23 tons released in free fall from a height ranging from 6 to 20 meters. The arrangement of the impact points and the other parameters of the treatment (energies, phasing, leaving periods) depend on the characteristics of the soil to be treated. Figure 4 & 5 shows the execution of Dynamic Compaction Work. [7]

1) First of all excavate the very soft soil from the top of the area.

2) Then fill the area by sand up to RL.

3) Start hammering by a heavy hammer from the height of 6-20 m. (hammer weight = 25-40 tons)

4) Hammer the area by maintain a fixed distance from each to other position (distance between one to another 2-3 meter)

5) After completing first round hammering, level the top surface by equipment.

6) Then again start hammering between those 2-3 meter gaps.

7) And again level the surface soil by equipment.

3.7 Secondary Case Study:

Introduction:

Soft soil ground improvement plays a significant role in the embankment preparation and construction. The soft soil improvement techniques like Sand Compaction Pile (SCP), Dynamic Compaction (DC) and Prefabricated Vertical Drain (PVD) are most commonly used recently. Many construction firms used to different soil improvement techniques, but they did not give emphasize the verification of the soil improvement techniques. The verification of soil is necessary before and after the soil improvement. In most cases, ground improvement has been needed. In a broad sense, ground improvement refers to the incorporation of different techniques employed for modifying the properties of a soil to improve its engineering performance. In this project, two types of soft soil improvement techniques named DC and SCP have been used. This research paper has been analyzed the two soft soil improvement methods. Shen et al. (2005) has presented a case history of the performance of two full-scale test embankments constructed on soft clay deposit in the eastern coastal region of China. The vacuum-PVD system has been applied for soft Bangkok clay combining capped PVD with vacuum pressure and embankment loading whereby the PVD has been connected by HDPE tubes to a vacuum pipe (Saowapakpiboon et al., 2008). The Ballina Bypass route in Ballina (New South Wales, Australia) has been built to reduce local traffic jams (Indraratna et al., 2012). Reddy et al. (2013) has proposed finite element modeling (FEM) for a portion of the new road at Kakkanad, Thankalam new road, India, where ground improvement (1000m and road width is expected to be 1.2m) has been made by preloading with PVD. Sari and Lastiasih (2014) have conducted an analysis to determine the stability of the embankment by height variation of highway embankment on soft soil. Bo et al. (2015) have described the selection of PVDs against the comprehensive specification and the selection of the PVD installation rig and accessories based on the in-situ ground conditions. Staged construction techniques with PVD of embankment has been considered as a common technique to reduce full consolidation and the excess pore water pressure (Al-Soud, 2016; Hore et al., 2020). The selection of Soft soil improvement techniques is a big challenge in our country. Soft soil improvement technique like the sand drain is low-cost improvement techniques, but it took a huge time to consolidate the clay soil in Bagerhat (Chakraborty et al., 2017). So, selection of soft soil improvement technique is very important to consider the following factors: i) cost, ii) consolidation time and iii) site conditions etc. some time combination of soft soil improvement technique is very effective. All these researches described the specific soft soil improvement technique in a specific project. In this project three soil improvement techniques in one specific sites. In this site, soil condition is such that under a sandy soil layer, a soft clay soil layer exists where SPT value is around 5. To reduce susceptible to liquefaction in the sandy layer DC has been chosen and the soft clay soil layer is for SCP.

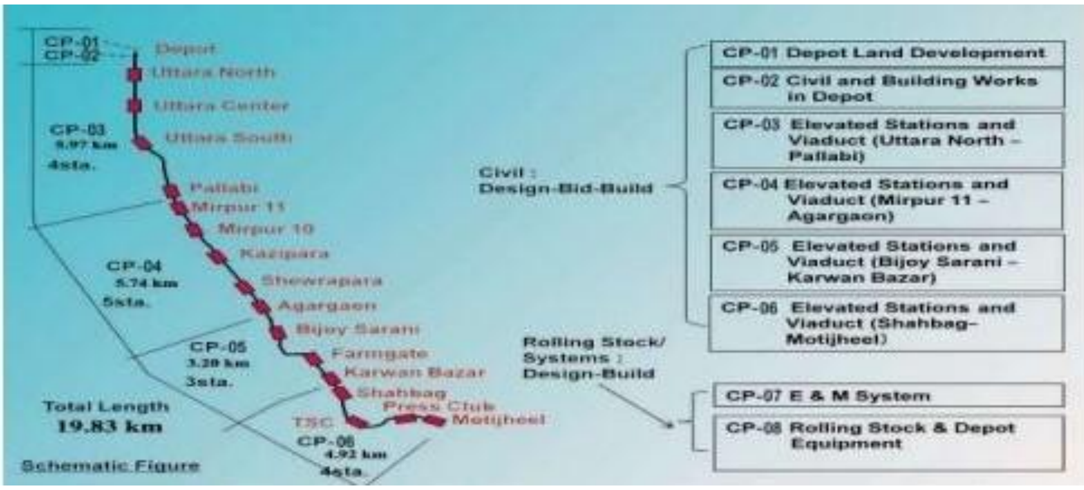


Figure 3.8: Location of MRT project [7]

3.7.1 Geotechnical Soil Properties:

The subsurface investigation work includes execution of 50 borings extending to the depth of 15.0 to 19.5 m, the performance of the required field and laboratory tests, evaluation of the bearing capacity and finally recommending for the safe and appropriate type of foundation suited to the subsoil conditions. Boreholes have been drilled vertically using a boring wash technique. Several laboratory tests have been conducted at the Geotechnical Engineering Laboratory of BUET on disturbed and undisturbed samples of sub-soils of contract package CP 01 section on samples collected from 50 numbers of exploratory boreholes. The density and stiffness characteristics of the subsoil layers in the boreholes have been measured by performing SPT. The thickness of soft compressible layers (silty clay, clayey silt and fine silty sand) varies from 4.5 to 12.0 m, as can be seen. Figure 2 shows the different soil layers.

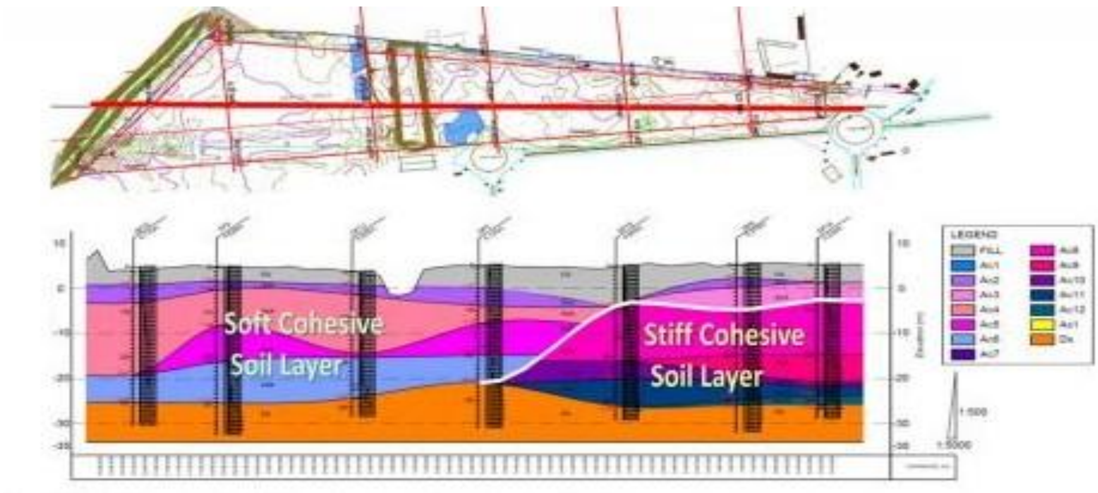


Figure 3.9: Soil profile of MRT line 6 depth before ground improvement [7]

A detailed laboratory investigation has been carried out on disturbed and undisturbed tube samples collected from the 52 boreholes. Liquid limit (LL), Plastic limit (PL) and Plasticity index (PI) of 25 samples retrieved from various boreholes have been determined. Besides, a Shrinkage limit (SL) of 12 samples and Linear shrinkage (LS) of 20 samples have been done. The values of liquid LL of the samples varied between 29 and 90, with PI varying from 9 to 61. SL and LS of the samples have been varied from 12 to 20% and 4 to 18%, respectively. The specific gravity values of the solid constituents of 20 samples have been determined. The values of specific gravity of the solid constituents of sub-soil have been found to vary between 2.60 and 2.66. Organic matter content of 4 selected samples of sub-soil has been determined. Organic matter content of the samples varied between 3.5 and 42.7%. Unconfined compressive strength tests have been carried out on seven undisturbed samples obtained from different depths of various boreholes. On the basis of the value of undrained Journal of Engineering Science 11(2), 2020, 37-44 39 shear strength, which is half of the unconfined compressive strength, three of the samples tested have been found to be very soft inconsistency. The values of qu of these samples varied between 12 and 38 kN/m2 while the values of axial strain at failure (Ɛf) of these samples have been found to vary between 2 and 6%. Three of the rest four samples were found to be soft to firm in consistency and values of qu of these samples varied between 45 and 99 kN/m2 .

Soil Improvement Techniques:

Three methods have been described in this research paper. These are SCP, DC and PVD.

Method Statement for soil Improvement (SCP):

Sand Compaction Method is the method to stabilize soft soil ground, in which sand is fed into the ground through a casing pile and has been compacted by vibration, dynamic impact, or static excitation to construct a compacted sand pile in the soft ground soil. This method has been applied in order to increase the density of loose sand ground, to improve its stability or compressibility and/or to prevent liquefaction failure. To soft clay ground, it assures stability and/or reduces ground settlement. Figure 3 shows the Outline of SCP Work

Figure 3.10: Outline of SCP work [7]

The casing pipe has been located in the design position. The casing pipe has been driven into the ground with the help of vertical vibratory excitation by the Vibro-hammer on the top of the casing pipe. During the penetration, the casing pile has been filled with SCP material is supplied through the hopper at the upper end of the casing pile by the lifting bucket. After reaching the prescribed depth, the casing pipe has been retrieved to feed the sand in the casing pipe into the ground with the help of compressed air. The sand fed into the ground has been compacted to expand the diameter by the vibratory excitation of the casing pile in the vertical direction. The degree of compaction has been controlled so that the diameter of the sand pile becomes the designed value (φ700mm). After compacting the sand to the designed degree, the casing pile has been retrieved again and the sand is fed into the ground. The sand has been compacted again by the vibratory excitation. The retrieving and penetrating length has been determined to construct 1.0m of SCP in each cycle.

Method Statement for soil Improvement (DC):

In the framework of Dhaka Mass Rapid Transit Development Project, TOKYU has been nominated as the Contractor for ground improvement works of the depot site. Dynamic compaction technique shall be followed as a part of ground improvement works aiming to improve the loose sandy soil and provide a safe platform satisfying the project requirements. DC is to stabilize and density granular soils deposited both above and below the groundwater table. It has been aimed to improve soil bearing capacity and decrease the potential of liquefaction. The process consists essentially of dropping a large weight, into the ground to be compacted. DC techniques require the use of pounders weighing ranging from 10 to 23 tons released in free fall from a height ranging from 6 to 20 meters. The arrangement of the impact points and the other parameters of the treatment (energies, phasing, leaving periods) depend on the characteristics of the soil to be treated. Figure 4 & 5 shows the execution of Dynamic Compaction Work.

Figure 3.11: Execution of Dynamic compaction work. [7]

Nos.	SCP	DC
1.	The SCP method improves soft ground by using vibration to install sand or any other similar material into the soft ground via a casing pipe and forms sand piles in the ground.	DC is a method that is used to increase the density of the soil by dropping a heavyweight repeatedly on the ground at regularly spaced intervals.
2.	The method to stabilize soft soil ground, in which sand is fed into ground through a casing pile and is compacted by vibration, dynamic impact or static excitation to construct a compacted sand pile in soft ground soil.	It is required the use of pounders weighing ranging from 10 to 23 tons released in free fall from a height ranging from 6 to 20 meters. The arrangement of the impact points and the other parameters of the treatment (energies, phasing, leaving periods) depend on the characteristics of the soil to be treated.
3.	This method is applied in order to increase the density of loose sand ground, to improve its stability or compressibility and to prevent liquefaction failure. To soft clay ground, it assures stability and reduces ground settlement.	It is aimed to improve soil bearing capacity and decrease the potential of liquefaction.
4.	This method is used for soft soil.	This method was mostly used for loose sandy soil to reduced liquefaction.

Table 4.3: Comparison of improvement between two techniques SCP & DC [7]

Method Statement for soil Improvement (PVD): This method statement has been prepared to describe the installation of PVD. The objective of this method statement is to provide the Engineer with the methodology of how the works performed and ensure a good degree of control during the execution of the works. The actual work method may differ depending on the Engineer requirement and site conditions. To expedite the consolidation of slow draining compressible soils, PVD has been installed into the soil to shorten the travel distance of pore water from the soil. After PVD installation has been completed, normally, pre-loading is applied to increase the pore water pressure and force the water to flow to the nearest drain. Alternatively, a vacuum technique can be used to simulate a pre-load.

Area of Soil Improvement		PVD Length	PVD Quantity	Total Length
No.	Area (sqm)	(m)	(Nos)	(m)
1	12235.753	10.5	6256	65688.0
2	10027.375	15.0	5125	76875.0
3	10579.281	13.5	5397	72859.5
4	4851.876	9.0	2481	22329.0
7	10941.244	23.5	5573	130965.5
8	12919.238	20.5	6585	134992.5
9	11139.223	19.5	5646	110097.0
10	6347.315	19.5	3176	61932.0
11	4381.268	14.5	2196	31842.0
13	6912.400	19.5	3520	68640.0
15	2793.347	13.5	1432	19332.0
16	10202.520	18.5	5263	97365.5
17	3881.759	11.5	2001	23011.5
Total	107212.599		54651	915929.5
Total PVD Area (sqm)		107212.599		
Total Number of PVD (Nos)		54651		
Total Length of PVD (m)		915929.5		

Table 4.4: Summary of PVD [7]

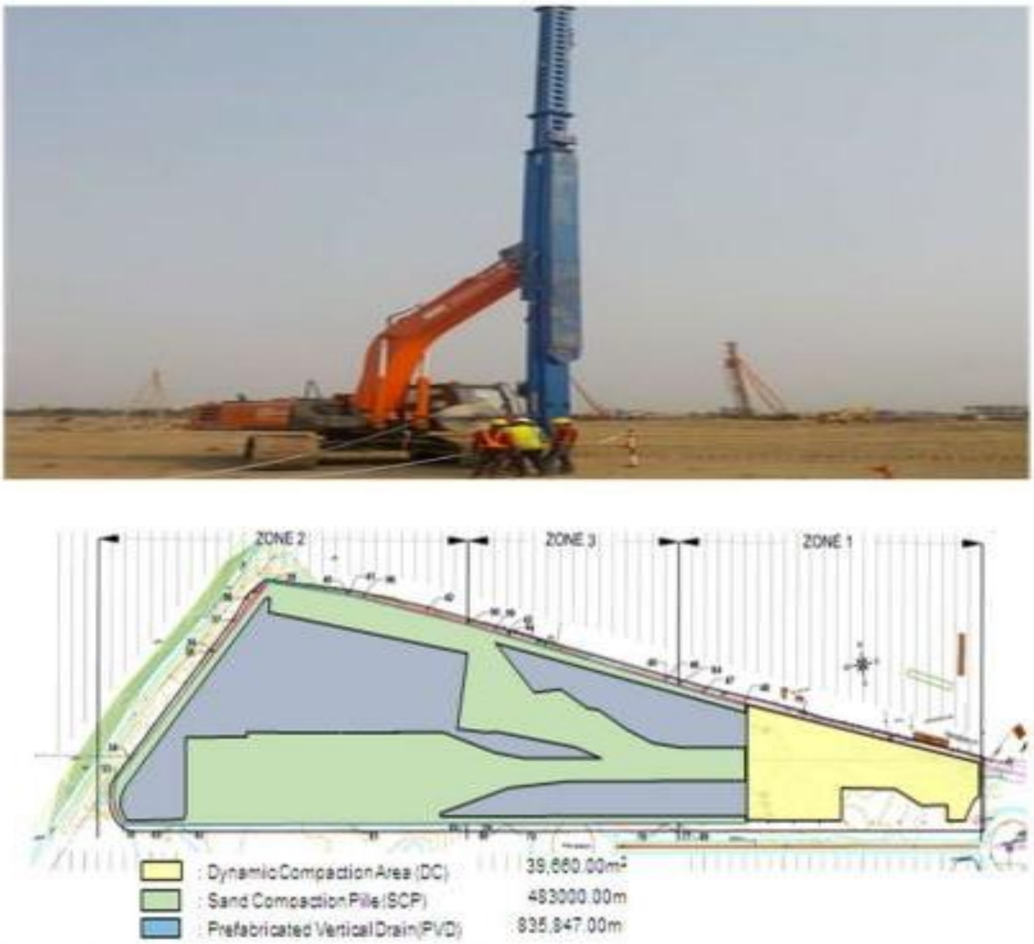


Figure 3.12: Area distribution of three methods [7]

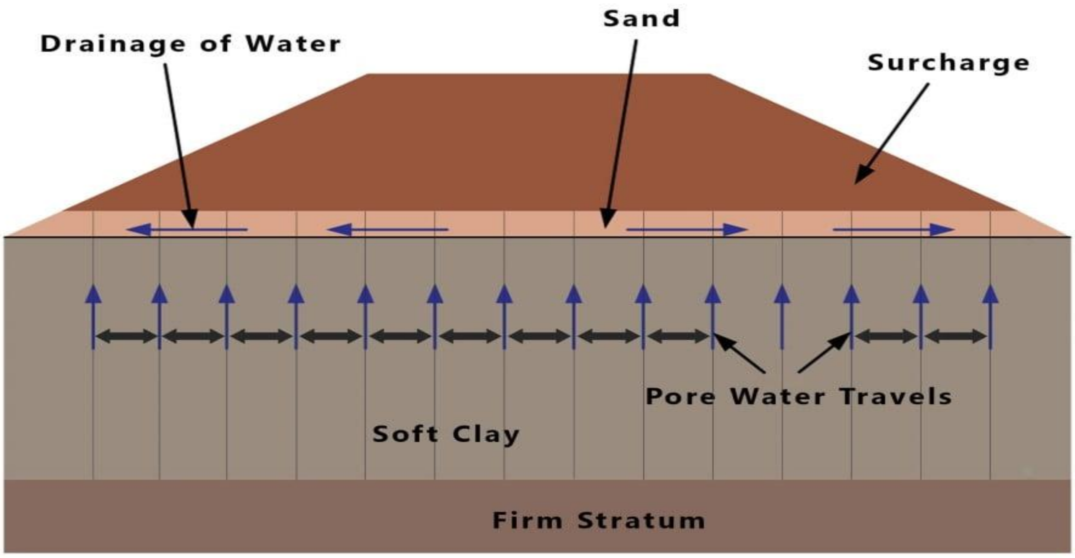


Figure 3.13: Pre-loading of PVD

The properties of the PVD material used on the project shall be as per the specifications. The width of PVD shall be 100 mm (approx.). Installation shall be in triangular patterns. The installation distance between points is 1.5 m. Installation depth depends mainly on the thickness of the soft soil layer that requires consolidation. The installation depth may vary during installation due to irregularities in the sub-soil, which has to be taken into account by the Engineer. Table 1 shows a summary of PVD.

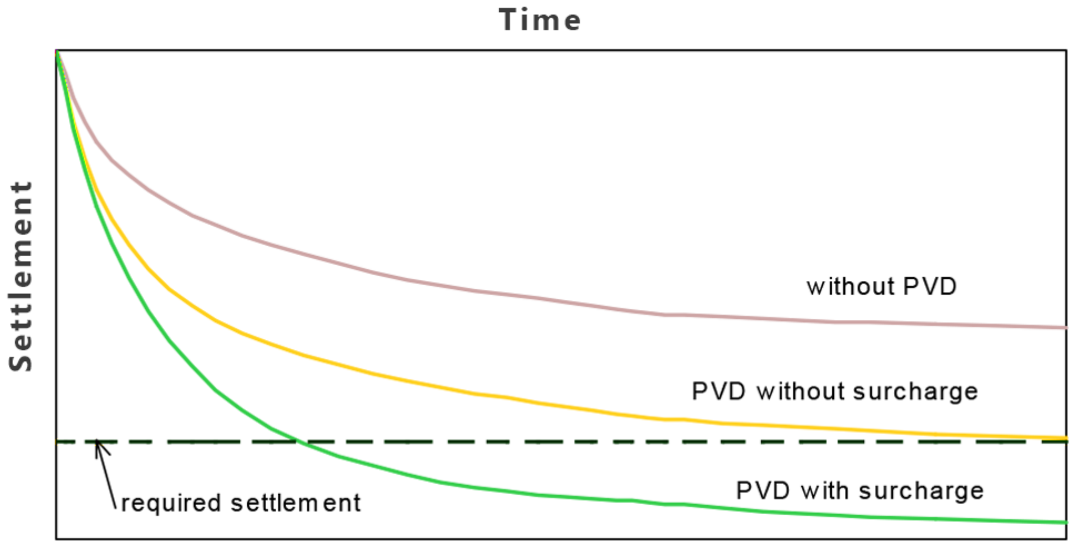


Figure 3.14: Graph of soil settlement with change of PVD surcharge. [7]

The installation area has been subdivided into panels depending on the installation depth, platform levels, or other constraints. The size of each panel is in general 50 x 50 meters. The surveyor has set out the four corners of each panel with pegs. In case the corner of the panel and drain position do not match; also, the drain position closest to the corner point has been required for setting out. The individual drain position has been marked by pulling a nylon string, marked with the required drain spacing along the alignment of the drain positions. The anchor plate or pieces of colored raffia rope have been used to mark the position of the drain. During installation, the rig may thereby drive over the installed drains. The Driving with the tracks over the installed wick drains has no effect on the functionality of the wick drain because the effective part of the drain has been closed located the ground. When the rig needs to turn around it, has traveled to a clear area and turn over there. Figure 6 shows PVD methods Figure 7 Shows the Area Distributions of three methods.

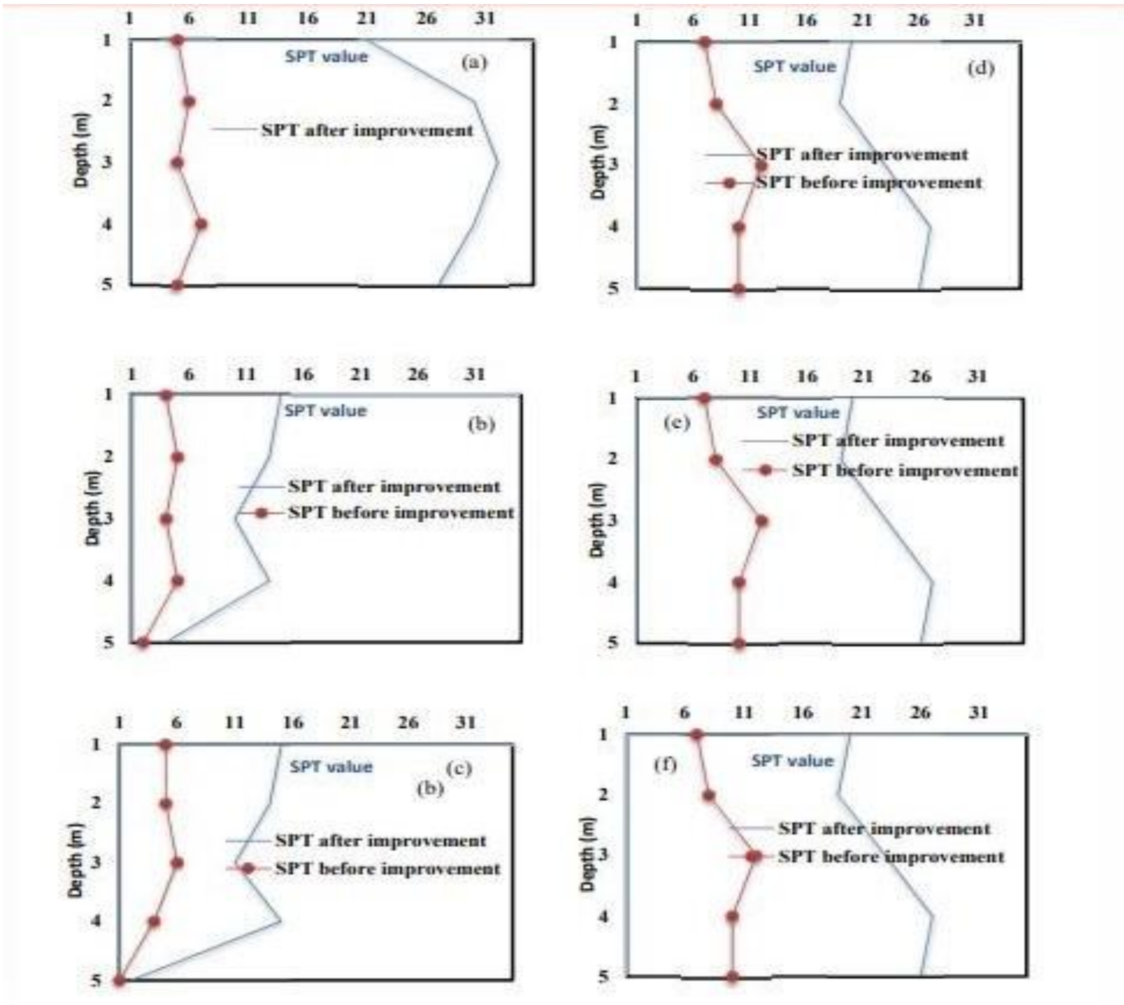


Figure 3.15: Soil improvement before and after DC & SCP [7]

Construction of metro rail embankment on soft soil is a big challenge. The selection of Soft soil improvement techniques is very important before the implementation process. Good engineering judgment comes from a good understanding of soil behavior and past experiences in dealing with similar types of soil and geotechnical problems. A different method of soft soil improvement technique has been described in this research paper. This research verification of soil improvement is done by SPT before and after the soil improvement of the Dhaka Metro Rail project. In this research, the prospect of soft soil improvement technique (SCP and DC) metro rail system in Dhaka city has been evaluated. Two methods (DC and SCP) have been selected among the different soil improvement techniques. The measurements of SPT before and after construction have been analyzed. The SPT profile increases vigorously after the soil improvement. Between the two methods, SPT value after DC greater than the SPT value after SCP. [7]

CHAPTER- 4

Results and Discussion

4.1 Introduction

Soft soil improvement is the most important work for the soil condition of Bangladesh

Here we have discussed about soil condition about Bangladesh and the Dhaka city.

And also studied on various types of improvement techniques used worldwide. Most commonly used improvement techniques in Bangladesh are also discussed in this research paper along their cost estimation variable.

4.2 Specific Aim 1

The specific aim of this research paper, to determine the cost efficient soft soil improvement technique in Bangladesh. There are many types of improvement techniques used worldwide which is depends on some of principle object. We mainly work on four kinds of improvement techniques. 1) Sand compaction pile, 2) Soil replacement compaction, 3) Prefabricated vertical drain (PVD), 4) Dynamic compaction (DC). We have applied both of all improvement techniques on a specific construction area at namapara, khilkhet, Dhaka. We found variation of cost after applying above mentioned improvement techniques on the same construction area.

Cost variation shown in below tables:

Purpose	Amount (taka)
total price of sand	3,09,760
total cost of excavation	2,41,758
Total cost of borehole execution	3,92,040
Total cost of sand compaction pile execution	9,43,558
So cost per square feet	**(9,43,558 / 4,356) = 216.6**

Table 4.5: Estimated costing of **sand compaction pile (SCP)**

Purpose	Amount (taka)
total cost of excavation & disposal	7,23,313
total cost of compaction & transportation	4,10,770
total price of sand	17,53,280
total price of ¾ khoa	4,90,050
Total cost of soil replacement execution	33,77,413
So cost per square feet	**(33,77,413 / 4,356) = 775.34**

Table 4.6: Estimated costing of **Soil replacement compaction**

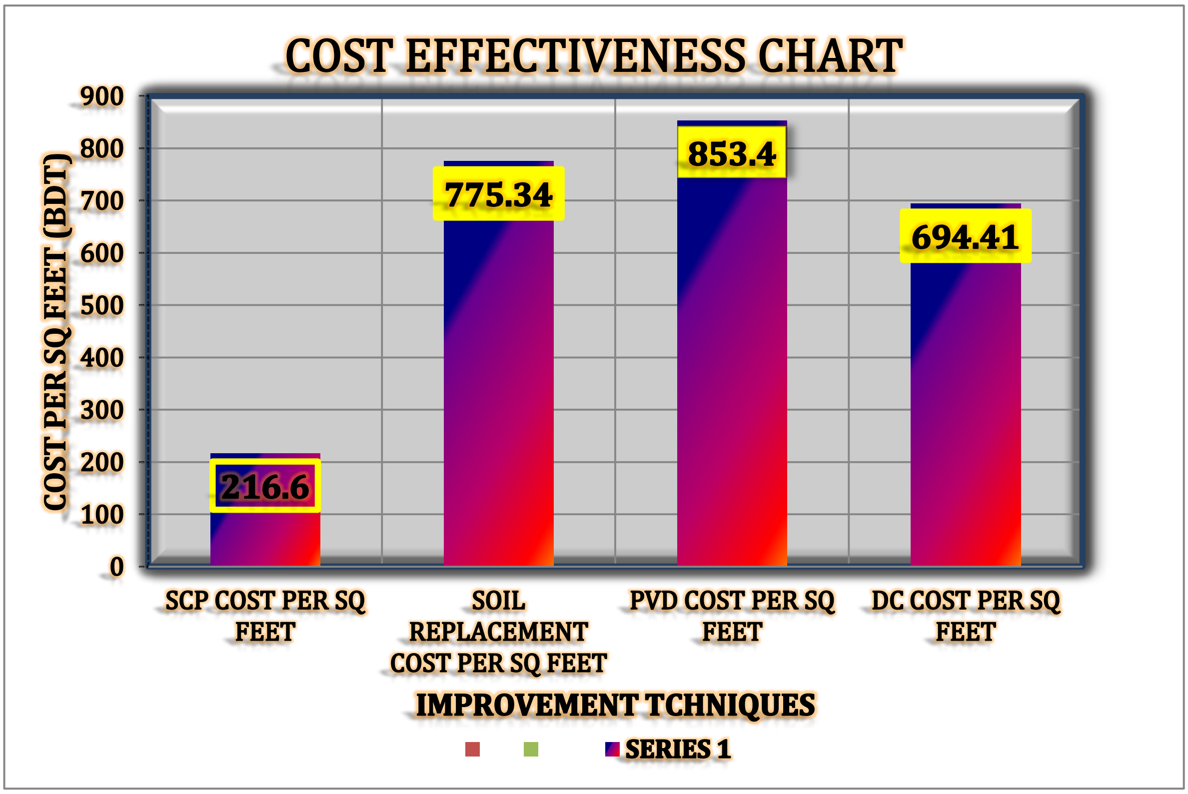
Purpose	Amount (taka)
total cost of excavation & disposal	7,23,313
total cost of compaction & transportation	4,10,770
total price of sand	17,53,280

Total required woven geotextile	2,07,084
total price of filter jacket	4,31,244
Total installation cost	1,91,664
Total cost of PVD execution	37,17,355
So cost per square feet	**(2,583,272/ 4,356) = 853.40**

Table 4.7: Estimated costing of **prefabricated vertical drain (PVD)**

Purpose	Amount (taka)
total cost of excavation & disposal	7,23,313
total cost of compaction & transportation	4,10,770
total price of sand	17,53,280
Contractual compactor equipments cost	82,500
Cost of leveling equipment	55,000
Total cost of dynamic compaction	30,24,863
So cost per square feet	**(30,24,863 / 4,356) = 694.41**

Table 4.8: Estimated costing of **Dynamic compaction (DC)**



4.3 Summary

After estimate all of improvement techniques cost, we marked out different cost per square feet at the same project for the different soft soil improvement techniques. From the above four table we noticed that, to improve that very soft soil condition, sand compaction pile improvement technique is mostly cost efficient from other three types improvement techniques and very easy to execution. But this type improvement techniques used only for low rise construction design.

CHAPTER-5
Conclusions and Future Works

5.1 Conclusions

Mainly in this paper we have research about the cost efficient soft soil improvement techniques. We have described about soil condition of Bangladesh and also Dhaka city. As the condition of soft soil of Bangladesh, soft soil improvement is the most essential part of civil and geotechnical engineering. We worked on specific area to improve the very soft soil condition. There are many improvement techniques to improve the soft soil condition which already we described in methodology part of the research paper. Popular four improvement techniques in Bangladesh are applied to improve the soft soil of that specific area. Mainly we focused on the cost efficiency of these techniques. The estimate of cost already given in result part of this research paper. We found nearly variation of cost of these techniques at same area. as a result we mark out that **sand compaction pile (SCP)** is the best cost efficient improvement technique for this work area. But we have to remember that by which application of improvement technique increase the bearing capacity. It depends on various things like what kind of construction will be designed on this area, what is the N value of SPT test etc.

From the result of cost efficiency we marked that for SCP improvement technique cost is 216.6 taka per square feet. Then for dynamic compaction improvement technique cost is 694.41 taka per square feet. Serially for soil replacement compaction & prefabricated vertical drain and soil replacements cost is 775.34 taka & 853.40 taka per square feet. But those estimate of cost will vary case to case depend on construction design and soil condition.

As well as from our study we reached to our specific aim, that is sand compaction pile (SCP) the best cost efficient soft soil improvement technique for our projected area.

we found that sand compaction pile improvement techniques is the most cost efficient & popular techniques in Bangladesh but we also have to remember that how much strength is safe for designed construction. based on this we have to make the decision what kind of improvement techniques we should to apply.

5.2 Limitations and Recommendations for Future Works

Coronavirus disease 2019 (COVID-19) has created a challenging, yet opportunistic, engineering work in which to conduct sample collection of soil and assess research methodology. In particular, results from this study do not provide any indication of the prevalence of the conditions described in this work in the wider sample collection of Dhaka city actually found of lockdown restrictions. Finally, within the timescales of the research, it will unfortunately not possible to seek sample collection from specific location, so the institutional perspective is limited to people specific health issues.

On the other hand for application of various improvement techniques need many equipments and materials, which was limited in this project area. Many of the data were collected from different company's contract sheet, which is so confidential thing of a company. It was difficult to collect those contract sheets from different developer company.

The prefabricated vertical drain & Dynamic compaction techniques are rarely applied in Bangladesh. In the Air port terminal 3 construction project, prefabricated vertical drain technique was applied for runway. For that reason, many of data were highly confidential to explore. To know the geotextile filter jackets price we meet with higher authority of Samsung developer companies of korea.

We investigate only on **soft** soil improvement, so we cant ensure that sand compaction is the best improvement technique for all construction. Because for construct a structure need to analyze the total soil condition of projected area, but this soft soil cost estimation is only for a part of total soil of this projected area. So improvement technique may varies place to place depends on its total soil condition (SPT value), designed structures required strength and total load of structure (live load & dead load) coming to the soil.

For the future work need to execute that, which application of improvement techniques will give the best bearing capacity or strength of projected work area & also define that which technique will insure the best cost efficiency & best bearing capacity for that project assuming as a residential Building construction.

For completing this execution, have to check the further strength after applying improvement techniques. To determine the further strength or bearing capacity of projected area, there are few field and laboratory test.

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APPENDIX - I

Estimated Cost calculation of SCP improvement technique:

Costing of sand compaction pile:

Total Area: 4356 sqft

Total borehole: 484

Casing pipe dia: 12 inch

Hammer weight: 950 kg

Distance between each borehole to other: 2 feet

Depth of borehole: 18 ft

Sand costing

Sand: 1.8 FM

Sand required per bore hole: 16 cft (with compaction volume)

Total Sand required : (16 X 484) = 7,744 cft

Price of per cft : 40 tk

So total price of sand: (40 X 7,744) = 3,09,760 taka

Excavation costing

Contractual excavation cost per cft = 11.1 tk

including (machineries equipment + soil disposal transportation)

total excavated soil volume = 21,780 cft

So total cost of excavation: (11.1 X 21,780) = 2,41,758 taka

Borehole & filling execution cost

Contractual cost per feet of 1 borehole = 45 taka

Cost of 1 borehole= (18 X 45) = 810 taka

So total cost of 484 borehole = 3,92,040 taka

Total cost of sand compaction pile execution = (3, 09,760 + 2, 41,758 +3, 92,040) = 9,43,558 taka

So cost per square feet should be (9,43,558 / 4,356) = 216.6 taka

Estimated Cost calculation of Soil Replacement improvement technique:

Excavation & transportation cost

As per contract to soft soil excavation & disposal (including loading –unloading)rae is = 11.07 taka per cft.

Total volume of soft soil is = 65,340 cft

So total cost of excavation & disposal (11.07 X 65,340) = 7,23,313 taka

Sand & khoa compaction & transportation cost

Contractual Embankment & compaction with procedure sand for 95% comaction including loading, transportation, unloading rate is = 9.43 taka per cft.

Total volume of filling area is = 43,560 cft (depth =10 feet)

So total cost of compaction & transportation (9.43 X 43,560) = 4,10,770 taka

Sand & ¾ size khoa cost

Sand: 1.8 FM

Price of per cft : 40 tk

Total volume of sand = 43,832 cft (with compaction)

So total price of sand: (40 X 43,832) = 17,53,280 taka

¾ khoa

Price of per cft : 90 tk

Total volume of khoa = 5,445 cft

So total price of ¾ khoa: (90 X 5,445) = 4,90,050 taka

Total cost of soil replacement execution = (7,23,313 + 4,10,770 +17,53,280 + 4,90,050) = 33,77,413 taka

So cost per square feet should be (33,77,413 / 4,356) = 775.34 taka

Estimated Cost calculation of PVD improvement technique:

Excavation & transportation cost

As per contract to soft soil excavation & disposal (including loading –unloading) area is = 11.07 taka per cft.

Total Area: 4356 sqft

Total volume of soft soil is = 65,340 cft

So total cost of excavation & disposal (11.07 X 65,340) = **7,23,313** taka

Sand compaction & transportation cost

Contractual Embankment & compaction with procedure sand for 95% compaction including loading, transportation, unloading rate is = 9.43 taka per cft.

Total volume of filling area is = 43,560 cft (depth =10 feet)

So total cost of compaction & transportation (9.43 X 43,560) = **4,10,770** taka

Sand cost

Sand: 1.8 FM

Price of per cft : 40 tk

Total volume of sand = 43,832 cft (with compaction)

So total price of sand: (40 X 43,832) = **17,53,280 taka**

Geotextile price per sft = 47.54 tk

Total required geotex = (4356 x 47.54) **= 2,07,084 tk**

Installation length is 8 feet + extra 2 feet for absorbed water flow = 10 ft

Distance between each borehole 2 m

Total borehole = 2,178

Length of hole = (2178 x 10) =21780 feet

Geotextile filter jacket unit price is = 19.8 tk per feet.

So total price of filter jacket = (21780 x 19.8) = **4,31,244 tk**

Contractual installation cost = 11 tk per running feet

Total installation cost = (17424 x 11) = **1,91,664 tk** (bore hole length 8 ft in soil)

Total cost of PVD execution = 37,17,355 taka

So cost per square feet should be (2,583,272/ 4,356) = 853.40 taka

Estimated Cost calculation of DC improvement technique:

Excavation & transportation cost

As per contract to soft soil excavation & disposal (including loading –unloading) area is = 11.07 taka per cft.

Total Area: 4356 sqft

Total volume of soft soil is = 65,340 cft

So total cost of excavation & disposal (11.07 X 65,340) = **7,23,313 taka**

Sand compaction & transportation cost

Contractual Embankment & compaction with procedure sand for 95% compaction including loading, transportation, unloading rate is = 9.43 taka per cft.

Total volume of filling area is = 43,560 cft (depth =10 feet)

So total cost of compaction & transportation (9.43 X 43,560) = **4,10,770 taka**

Sand cost

Sand: 1.8 FM

Price of per cft : 40 tk

Total volume of sand = 43,832 cft (with compaction)

So total price of sand: (40 X 43,832) = **17,53,280 taka**

Contractual compactor equipments cost is **= 82,500 taka** (per day 16500 tk & 5 day to complete)

Cost of leveling equipment = **55,000 taka** (per day 11000 tk)

Total cost of dynamic compaction = (7,23,313 + 4,10,770 + 17,53,280 + 82,500 + 55,000) = 30,24,863 taka

So cost per square feet should be (30,24,863 / 4,356) = 694.41 taka

APPENDIX - II

Sample collection Photograph


Shot on realme 8 Pro | 108MP


Shot on realme 8 Pro | 108MP


Shot on realme 8 Pro | 108MP