Journal of Engineering Science 11(2), 2020, 37-44
DOI: https://doi.org/10.3329/jes.v11i2.50896

JES
an international Journal

DIFFERENT SOFT SOIL IMPROVEMENT TECHNIQUES OF DHAKA MASS RAPID TRANSIT PROJECT

Ripon Hore* and Mehedi Ahmed Ansary

Department of Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh

Received: 11 April 2020 Accepted: 01 November 2020

ABSTRACT

The objective of this research is to the analysis of the different soil improvement techniques and the comparable model of these soil improvement techniques. In Bangladesh, different soil improvement techniques were used by different construction firms to improve the soil bearing capacity, but many of them could not verify the techniques after improvement. The verification of the soil improvement techniques is more important than the implementation of the soil improvement techniques. A comparison has been made between results obtained from three soft soil improvement techniques. Analysis of the effectiveness of soft soil improvement technique before and after improvement technique. From analyses, it has been revealed that for Tongi to Uttara along the Project package CP01 soft clay layer is effective for Sand Compaction Pile (SCP) and the sand layer, which is susceptible to liquefaction is effective for Dynamic Compaction (DC) method. After the improvement standard penetration test (SPT) value increases dramatically; this is a significant finding of this research.

Keyword: *Dynamic Compaction; Sand Compaction Pile; Soft Soil.*

1. 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.

2. METHODOLOGY

2.1 Project Description and Location

Contract package CP-01 is for the Land Development of Depot area. The contract for this package has been

* Corresponding Author: *riponhore@gmail.com*

ISSN 2075-4914 (print); ISSN 2706-6835 (online)

awarded to Tokyu Construction Co. Ltd. The signing ceremony for this Contract Package was held on March 27, 2016 at the Pan Pacific Sonargaon Hotel in Dhaka. The area map has been shown in Figure 1.

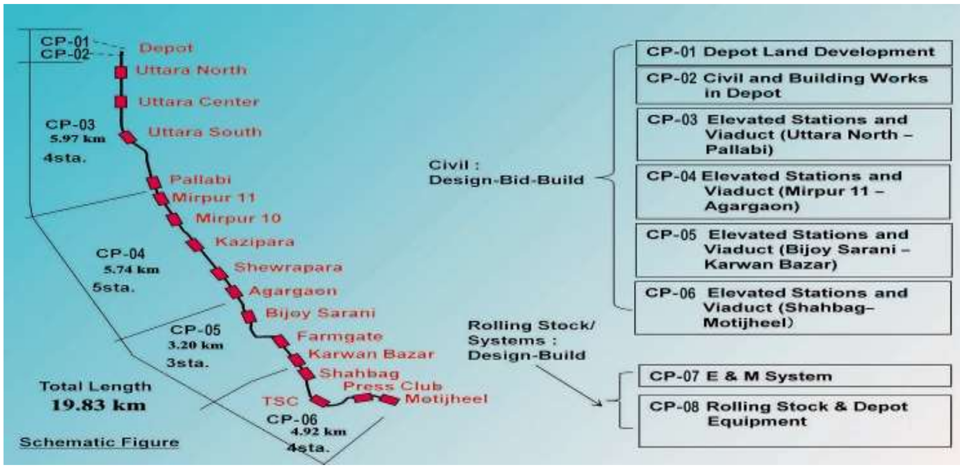

Figure 1: Location of MRT Project

2.2 Geotechnical Soil Properties

The sub-surface 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 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.

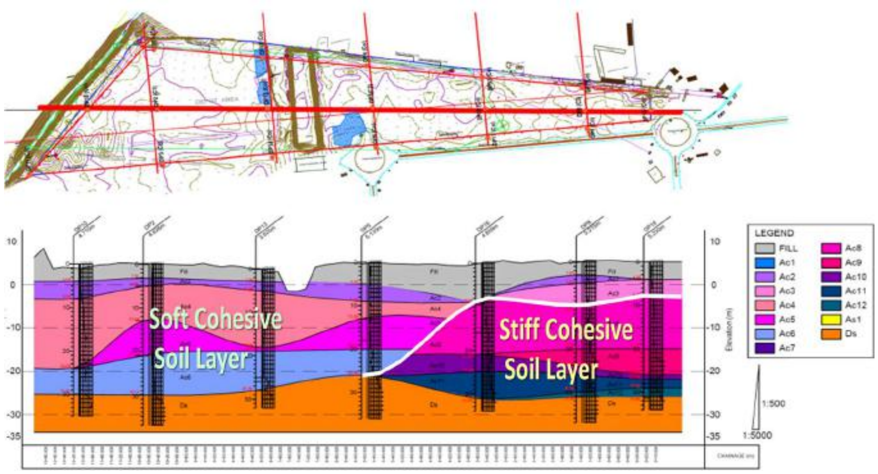

Figure 2: Soil Profile of MRT Line 6 Depot before Ground Improvement

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 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/m^2 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 q_u of these samples varied between 45 and 99 kN/m^2.

2.3 Soil Improvement Techniques

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

2.4 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: Outline of SCP Work

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.

2.5 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.

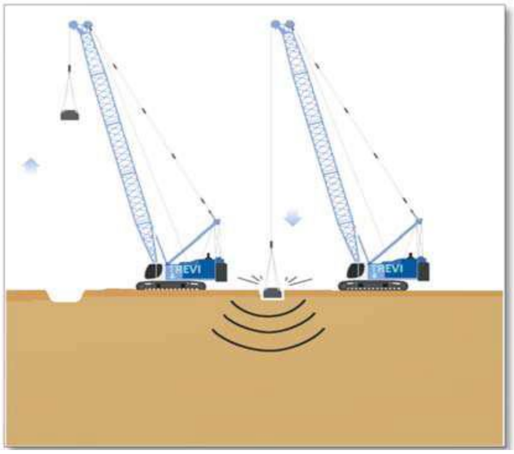

Figure 4: Dynamic Compaction Work

Figure 5: Execution of Dynamic Compaction Work

Table 1: Comparison of improvement between two techniques SCP and DC

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.

2.6 Compliance Standards

This method statement complies with the following standards.

a) Design Standards for Railways Structures and Commentary (Earth Structures) 2007 (hereinafter, "DSRSC-ES" – edited by Railway Technical Research Institute, Japan (hereinafter, "RTRI-J")

b) Design Standards for Railways Structures and Commentary (Seismic Design) 2012 (hereinafter, "DSRSC-SE)" – edited by RTRI-J, Japan

c) Bangladesh National Building Code (hereinafter "BNBC"). ASTM D 1586 "Preliminary design report for dynamic compaction (refer TGE C-15036-RE-001-Rev A)

d) Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils".

2.7 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.

Table 2: Summary of PVD

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		

Figure 6: PVD Method

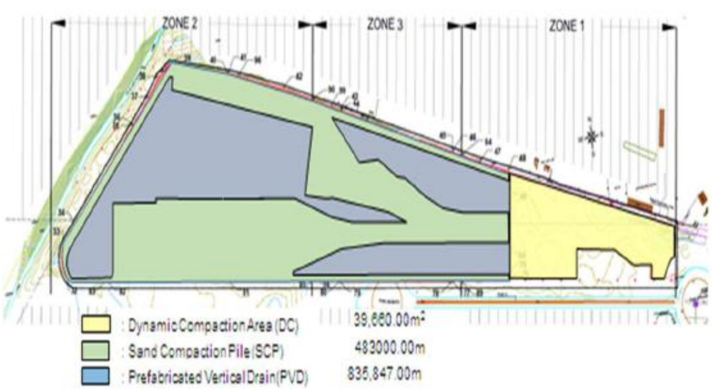

Figure 7: Area Distributions of three methods

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.

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 × 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.

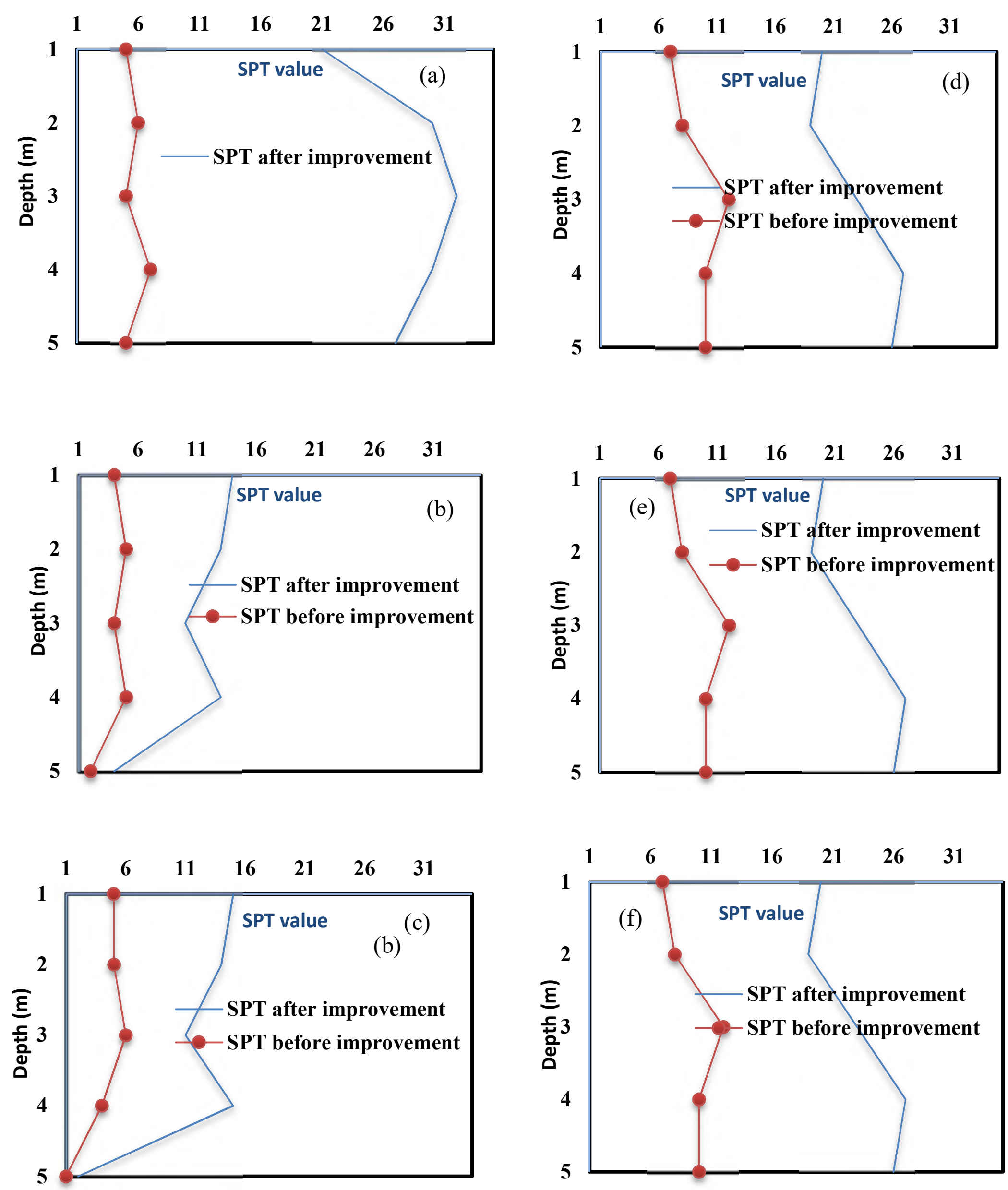

Figure 8: Soil improvement before and after (a-c) Dynamic Compaction (DC) and (d-e) Sand Compaction Pile (SCP)

3. RESULTS AND DISCUSSION

MRT project area above EGL loses dredged filling sand (fine silty sand) 3 to 5 meters thickness. Below the dredged filling sand layer soft clay deposit layer existence. Consideration fine content and water table of dredge sand filling layer liquefaction potential during the earthquake of the upper layer. On the other hand, consolidation settlement on the soft clay layer (below the upper layer) has been considered. Preliminary proposed the five methods of soil improvement. Removal of the dredge fill layer and replacement with suitable soil; installation of PVD in the soft clay layer along with the application of surcharge. Dynamic compaction for the upper layer and PVD with preloading for the soft clay layer. Deep mixing of cement slurry with soil (to improve both dredge fill and clay layer). Stone column (to improve both dredge fill and clay layer). Sand compaction pile (to improve both dredge fill and clay layer). Under considering the technical and financial aspect, specially subsoil condition of the area, relative cost, implementation time and equipment facilities, two options may be proposed. Removal of the dredge fill layer and replacement with suitable soil; installation of PVD in the soft clay layer along with the application of surcharge. Dynamic compaction and Sand compaction piles for different areas of the depot. BUET review the all aspect especially technical and financial part: Comments that "the analysis reveals that combination of dynamic compaction and sand compaction pile for will be most effective in terms of required subsoil improvement, the period of construction and cost. BUET experts would, therefore, recommend adopting dynamic compaction and sand compaction pile for improvement of the subsoil in the depot area as countermeasures for eliminating the risk of liquefaction and settlement problems. Then Authority divided the area into 18 sections and SCP and DC of subsoil improvement technique design. The SPT value before and after soil improvement SCP has been shown in Figure 8(a-c). The SPT value before and after soil improvement DC has been shown in Figure 8d to 8f.

4. CONCLUSIONS

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.

REFERENCES

Advani, M., and Tiwari G., 2005. Evaluation of public transport systems: Case study of Delhi metro. In Proceeding in START-2005 Conference held at IIT Kharagpur, India, 8.

Al-Soud, M. S., 2016. Numerical Analysis of Prefabricated Vertical Drains Improved Soft Soil beneath an Embankment During Staged Construction. Journal of Engineering and Development, 20(1), 151-163.

Bag, S., and Sen S., 2012. Kolkata metro railway and customer satisfaction: An empirical study, *International Journal of Multidisciplinary Research*, 2(3), 165-176.

Bergado, D. T., and Patawaran M. A. B., 2000. Recent developments of ground improvement with pvd on soft Bangkok clay. In Proc. Intl. Seminar on Geotechnics in Kochi, 2000.

Bo, M. W., Arulrajah A., Horpibulsuk S., and Leong M., 2015. Quality management of prefabricated vertical drain materials in mega land reclamation projects: A case study, *Soils and Foundations*, 55(4), 895-905.

BRTC (Bureau of Research, Testing and Consultation), 2013. Report on Review of Design Report for the Treatment of Soft Soil Areas of Embankment for the Proposed Construction of Double Line Track from Tongi to Bairab Bazar including Signaling on Dhaka-Chittagong Main Line, Department of Civil Engineering, April 2013, Bangladesh University of Engineering and Technology, Dhaka.

BRTC (Bureau of Research, Testing and Consultation), 2016. Report on Design of Foundation Treatment, Preloading with Staged Construction and Monitoring Scheme for the Construction of Railway Embankment from Chainage 0+550 km to 32+365 km of Kashiani-Gopalganj Section, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Chakraborty, S., Hore R., Ahmed F., and Ansary M. A., 2017. Soft ground improvement at the Rampal Coal Based Power Plant Connecting Road Project in Bangladesh, *SEAGS-AGSSEA,* 48.

Hansbo, S., 1979. Consolidation of Clay by Band Shaped Prefabricated Drains, Ground Engineering. 12 (5), 16-25.

Hore, R., Chakraborty S., and Ansary M.A., 2020. A Field Investigation to Improve Soft Soils Using Prefabricated Vertical Drain, *Transportation Infrastructure Geotechnology*, 7, 27–155. https://doi.org/10.1007/s40515-019-00093-8

Indraratna, B., Rujikiatkamjorn C., Vinod J. S., and Nimbalkar S., 2011. Physical and Chemical Ground Improvement for Sustainable Transportation Infrastructure under Cyclic Loads, Centre for Geomechanics and Railway Engineering, School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong City, NSW 2522, Australia, pp. 140-156.

Indraratna, B., Rujikiatkamjorn C., Kelly R., and Buys H., 2012. Soft Soil Foundation Improved by Vacuum and Surcharge Loading, Ground Improv. 165 (G12), 87–96. Long, P.V., Bergado D.T., Nguyem L.V. and Balasubramanium A.S., 2013. Design and Performance of Soft Ground Improvement Using PVD With and Without Vacuum Consolidation, *Geotechnical Engineering Journal of the EAGS and AGSSEA*, 44, 4, ISSN 0046-5828, pp. 36-51.

Lather, A. S., and Mohan S., 2007. A Comparative Study of Executive and Non- Executive Associates of Delhi Metro Rail Corporation for Their Level of Commitment and Personal Efficiency, Vision: *The Journal of Business Perspective,* 11(4), 13-20.

Murty, M. N., and Goldar B. N., 2006, Economic Evaluation of Investment Projects, Report of Project Sponsored by Planning Commission, Government of India.

Nakai, T., and Hinokio M., 2004. A Simple Elastoplastic Model for Normally and Over Consolidated Soils with Unified Material Parameters, Japanese Geotechnical Society, Soils and Foundations, 44(2), 53-70.

Nakai, T., 1985. Finite Element Computations for Active and Passive Earth Pressure Problems of Retaining Problems, Japanese Geotechnical Society, Soils and Foundations, 25(3), 98-112.

Peck, R.B., 1969. Deep Excavations and Tunnelling in Soft Ground", Proceedings of the Seventh International Conference on Soil Mechanics and Foundation Engineering, State-of-the-Art, pp. 225-190.

Reddy, S. K., Moosani and Divya P.V., 2013. Improving Engineering Properties of Soft Soil Using Preloading and Prefabricated Vertical Drains, *International Journal of Research in Civil Engineering, Architecture & Design*, 1(2), 08-12.

Ruenkrairergsa, T., Lin P. C., and Sunantapongsak S., 2001. Performance of PVD road embankment on soft Bangkok clay. In Proceedings of The International Conference on Soil Mechanics and Geotechnical Engineering Aa Balkema Publishers, 3, 2179-2182.

Saowapakpiboon, J., Bergado D. T., Chai J. C., Kovittayanon N., and De Zwart T. P., 2008. Vacuum-PVD combination with embankment loading consolidation in soft Bangkok clay: a case study of the Suvarnabhumi Airport Project, In Geosynthetics in Civil and Environmental Engineering, *Springer, Berlin, Heidelberg,* 440-449.

Sari, P. T. K., and Lastiasih Y., 2014. Slope Stability of Road Embankment on Soft Soil, Celebes International Conference on Earth Science (CICES). http://www.uho.ac.id/cices2014. pp. 1-11.

Shen, S. L., Chai J. C., Hong Z. S., and Cai F. X., 2005. Analysis of field performance of embankments on soft clay deposit with and without PVD-improvement, *Geotextiles and Geomembranes*, 23(6), 463-485.

STP Final Report, Strategic Transport Plan for Dhaka, Luis Berger Group Inc. and Bangladesh Consultant Ltd. (BCL), Dhaka Transport Coordination Board (DTCB), Ministry of Communications, Government of the People's Republic of Bangladesh, 2004.

Waheed, K.M.A., 2008. A Study on Application of Cut and Cover Method for the Construction of Metro Rail Tunnel in Dhaka City, M.Sc. Engg. Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, pp 20-31