Soft Ground Improvement at the Rampal Coal Based Power Plant Connecting Road Project in Bangladesh

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ABSTRACT: Preloading with vertical sand drain (VSD) is presented as a soil improvement method in this paper. The work is based on a real life road (4 lane and 2 slow moving lanes) construction project carried out in Rampal sub-district of Bagerhat, Khulna, Bangladesh. The construction sequences and the basic design example of VSD for embankment works on very soft clay soil are discussed in this paper. This paper presents soft ground improvement using VSD including VSD installation, preloading techniques, settlement and stability, design calculation, observational method and analysis of monitoring data. No extra load has been used; preloading has been carried out with the self-weight of road in combination with fill embankment. Soil treated with VSD, has resulted in improvement of soil settlement.

KEYWORDS: Vertical sand drain, Soil improvement, Embankment, Road construction

1. INTRODUCTION

Fields of transportation plays a significant role in the progress of a country. In the construction of road, railway, airway, the alignment may have to be fixed through the soils which may not bear the traffic loads. In most cases, ground improvement is required. 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.

Colombo–Katunayake Expressway (CKE) is the first major highway in Sri Lanka; where Preloading, Preloading with surcharging, prefabricated vertical drains (PVD), sand compaction piles (SCP), stone columns (SC) and composite treatments have been used as soft ground treatment (Cooray, 1984). The composite treatment has been used at three locations-Peliyagoda (Ch 1+500–1+850) and Muthurajawela (Ch 11+250–11+930 and 12+050–12+450).

Wei-Bing and Jia-Huan (1989) has reported the consolidation analysis of a foundation at Lianyungang City with sand drain by vacuum preloading. Boring and testing result shows that the site has 10 m thickness of uniform clay. The area preloaded by the vacuum method is 4000 m^2, with 2800 sand drains being 10 m long, 7 cm in diameter and 1.2 m in spacing. Vacuum under membrane has been maintained at above 650 mmHg column. After pre-loading, the mean settlement of ground surface has been found to be 55 cm and bearing capacity has been increased from 3 T/ m^2 to 8 T/ m^2.

Similarly Woo et al. (1989) has explained, geotechnical improvement program for the second Bangkok International Airport project, Thailand. Non-displacement sand drains with preloading by surcharge or vacuum or dewatering have been tried in test section to investigate their effectiveness. The sub-soils at the project site have been fairly uniform. Five different soil strata have been identified within the top 35 m zone. They are weathered clay (up to 1.5 m), very soft to soft clay (1.5-11 m), soft to medium clay (11-15 m), stiff clay (15-25 m) and dense sand (below 25 m). The 40 m by 40 m test section has 460 sand drains installed in triangular pattern, with spacing of 1.75 m center to center. Each sand drain which has been installed by jet-bailer method has a nominal diameter of 26 cm and 14.5 m long. A 60 cm thick sand blanket has been placed on the ground surface to provide a firm working platform.

Sand drain has been used as soil improvement method in the land reclamation project for a steel mill complex construction in Korea. Average depth of sea water has been above 5 m before backfilling with sand. The unit weight of backfill material is about 16.67 kN/m^3 with an average soil friction angle of 30°. The in-situ soil profile can be generally described as about 5 m of very loose alluvial sand and loose silty sand followed by very soft silty clay and clayey silt up to a depth of 20 m. Underlying this is a 5 m thick dark gray stiff clay. Bedrock and in some places, sandy gravel are located below the clay layer. Standard penetration resistance (N values) have varied from 0 to 29, but more than 80% of the N values are below 10. Most of N values are between 0 and 2 in soft clayey soil and relatively higher N values have been encountered in stiff clay layer. The diameter of sand drains is about 0.5 m with spacing ranging from 1.8 m to 2.5 m for hot strip mill site, and from 2.0 m to 2.5 m for cold rolling mill site. Typical construction pattern of sand drains has been laid out in regular square pattern with an average sand drain length of 25 m (Shin, et al., 1993).

Radhakrishnan, et al (2010) has stated that marine clays has been found in coastal region of Mumbai. A number of Industries, dams, buildings and embankments are being constructed along the inland coastal areas where the soil is of soft clay associated with problems of settlement and stability. In order to analyze the stability of an embankment constructed on these compressible marine clayey deposits, laboratory consolidation testing is the basis for computing the settlement. Providing vertical sand drains (VSD) offers a better solution in accelerating the process of consolidation to eliminate the deleterious post construction settlements and also to acquire sufficient additional shear strength. An embankment has been constructed as an approach to a Railway Bridge, which is underlain by a soft marine clay layer of thickness varying from 3.5m to 15.6m at the critical location, for a length of nearly 600 meters. There is an impermeable weathered rock below the clay layer and the total height of the embankment at the critical location is 14 meters. Construction of the embankment has been done in 3 stages. The total construction time has been 2 years. The construction time for the 1st, 2nd, 3rd, stages are 3 months, 2.5 months, 5 months respectively and there is a rest period after the completion of each stage. Sand drains have been provided in conjunction with the preloading. Sand drains of 300mm diameter have been installed in triangular pattern with an effective spacing of 2.75m.

Indraratna, et al. (2010) has discussed three sites of Muar clay (Malaysia), the Second Bangkok International Airport (Thailand), and the Sandgate railway line (Australia). One of the test embankments on Muar plain has been constructed to failure. The failure is due to a “quasi slip circle” type of rotational failure at a critical embankment height at 5.5 m, with a tension crack propagating through the crust and the fill layer. The Second Bangkok International Airport or Suvarnabhumi Airport is about 30km from the city of Bangkok, Thailand. Because the ground water is almost at the surface, the soil has been suffered from a very high moisture content, high compressibility and very low shear strength. The soft estuarine clays in this area often pose problems that require ground improvement techniques before any permanent structures can be constructed. Under railway tracks where the load distribution from freight trains is typically kept below 7-8 meters from the surface, relatively short PVDs have been employed. The rail track of the Sandgate Rail Grade Separation Project is stabilised using short Prefabricated Vertical Drains (PVDs) in the soft subgrade soil. Site investigation included 6 boreholes, 14 piezocone (CPTU) tests, 2 in-situ vane shear tests and 2 test pits. Laboratory testing such as soil index property testing, standard oedometer testing and vane shear testing have been also performed. The groundwater level is at the ground surface.

The Ballina Bypass route in Ballina (New South Wales, Australia) has been built to reduce local traffic jams. To ensure ground stability and improvement, PVDs combined with surcharge and vacuum preloading are being utilized to consolidate the soft soils before the construction (Indraratna et al., 2012). A trial embankment has been built to the north of Ballina to evaluate the effectiveness of the technique in this area.

Long et al., (2013) has discussed three projects namely North-South Expressway (NSEW) project, CaiMep International Terminal (CMIT) project, and 3 test embankments (TS1, TS2 and TS3) at Suvarnabhumi Bangkok International Airport (SBIA) project in Thailand, where prefabricated vertical drain (PVD) with or without vacuum consolidation has been employed.

The railway embankment along the alignment of the project for the construction of double line track from Tongi to Bhairab Bazzar (including signaling on Dhaka- Chittagong main line) in Bangladesh is lying on soft ground between chainage 29+300 m to 64+265 m. Depending on the soft ground treatment, 29 sections have been identified; among which in 13 sections no treatment, surcharge loading in 2 section, remove and replacement technique for 7 sections and PVD installation in 7 section of the embankment is proposed (BRTC, 2013).

Shukla and Kambekar (2013) has proposed embankment for double track broad gauge railway line between Belapur-Seawood-Uran areas in Navi Mumbai for chainage 19000 to 20500. The study of the soil indicates that the top of the stratification contains the yellowish stiff clay. The next layer observed in the stratification contains the soft grayish marine clay which is then followed by yellowish stiff/hard clay with gravels. The next layers of stratification are completely weathered rock which is underlain by moderately weathered rock. The second layer of subsurface profile is identified as grayish soft marine clay. This layer undergoes heavy settlements and the duration required for settlement to take place is also very high. These settlements can be accelerated by prefabricated vertical drains (PVD) with surcharge. With the use of PVD water flows horizontally (radically) as well as vertically i.e. three dimensional consolidations. The time required for consolidation with prefabricated vertical drains is expected to be shorter as compared to the time required for the preloading alone without PVD. The expected consolidation settlement achieved by PVD from the calculation is slightly higher than actual field consolidation settlement. The closer the spacing in between prefabricated vertical drains, the shorter the time required for the consolidation process. The advantages of square pattern are that it is more convenient to lie out and manage on site.

Zein and Elgasim (2014) has investigated on the suitability of staged construction, sand drains and sand compaction piles soil improvement methods for the design of a 12m high earth embankment on weak and compressible alluvial clay deposits. The embankment site chosen for study is the location of the eastern abutment of Alhalfaya Bridge built across River Nile to link Omdurman city and Khartoum North town in Khartoum State, Sudan. The embankment is of the rolled earth type with a maximum height of 12.0m,30m top width and 78m bottom width with 1:2 (vertical: horizontal) side slopes. The soil profile comprised of a soft silty clay soil layer ranging in depth from 1.0m to 6.0m, underlain by a very loose to medium dense poorly graded fine to medium coarse silty sand or sandy silts extending to a depth of 14.0m. These alluvial deposits rest directly on the highly weathered sandstone formation. The natural moisture content varied from 26% to 42% with most values between 28 and 32%. The natural dry density ranged between 11.0 and 14.5kN/m^3. The use of vertical sand drains in soft clay accelerate the primary consolidation of clay since they bring about rapid dissipation of excess pore water pressure under embankment loading. Vertical drains are normally used where preloading alone will not be efficient. The installation of sand drains into relatively thick clay strata increases the rate of consolidation of the clay under the load by shortening the drainage path.

Bangladesh railway, Rajshahi has taken up a decision to construct a new railway track along Kashiani-Gopalgang-Tungipara section about 32 km in length (BRTC, 2016). The soft soil thickness varies from 4 to 12 m. PVD in triangular pattern with a 2 m spacing has been proposed.

This paper aims to discuss on the soil profile of the Rampal Coal Based Power Plant connecting road project and the suitable soft soil improvement technique for this project.

2. PROJECT DESCRIPTION AND LOCATION

Construction of the Rampal Coal Based Power Plant connecting road consists of 4 lanes and 2 lanes for slow moving vehicle. The connecting road is 5.76 km long resting on soft soil; required soil treatment is the major challenge for this project. Project has started on 01-03-2015 and has fully completed on 28-12-2016. Photograph of the site before starting any construction work is shown in Figure 1.

Figure 1 Panoramic photographic view of the site

The study site is located in the Rajnagar and Gauramba union of Rampal sub-district of Bagerhat. The latitude and longitude of the site are $22^0 37'00''$N to $22^0 34'30''$N and $89^0 32'00''$E to $89^0 34'05''$E respectively. The location of the site is shown in the Figure 2.

The aim of this project is to facilitate the improvement of sustainable power supply capacity of the Government through improvement and construction of the proposed Khulna 1320MWx2 Coal based Power plant connecting all weather road. The most challenging part of the project is soil improvement of the 5.76 km long soft soil under the road construction, stratify the formation of soil and record the level of the ground water. It is important to provide accessibility and transportation facilities for construction and setting up the proposed Power Plant within the planned projected time. It is also vital to evaluate the safe bearing capacities of the foundation at the different layers, encountered at the different borehole positions.

Figure 2 Project locations on the map.

3. GEOLOGY OF THE SITE

The geology of the project site comprises of Paludal Deposits (ppc) and Tidal Deltaic Deposits (dt). Geologically the site comprises Tidal deltaic deposits-light to greenish grey, weathering to yellowish grey, silt to clayey silt with lenses of very fine to fine sand along active and abandoned stream channels, including crevasse splays. This contains some brackish-water deposits. Numerous tidal creeks crisscross the area; large tracts are submerged during spring tides. Also this site consists of soft marsh clay and peat-grey or bluish grey clay, black herbaceous peat, and yellowish grey silt. Alternating beds of peat and peaty clay common in bils and large structurally controlled depressions; peat is thickest in deeper parts.

4. SUB-SOIL INVESTIGATION

The soil test report has been prepared on the basis of an agreement between of the proposed Khulna coal based plant connecting road of Local Government Engineering Department (LGED) at Rampal, Bagerhat and the Development Survey Consultant, a sub-soil investigation firm in Dhaka. The sub-surface investigation work includes execution of eleven borings extending to the depth of 11.0 m to 40.0 m, 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. The wash boring method has followed in drilling the boreholes after driving the casing pipe. Grain size analysis, specific gravity and direct shear tests has been performed in the laboratory for proper evaluation of the soil parameters. The disturbed soil samples are normally collected during the operation of SPT. These samples are those in which the natural soil structure gets disturbed during sampling. The samples represent the composition and the mineral content of the soil.

The top formation of soil existing roughly to the depth of 2.65 m (BH-6), 3.10 m (BH-1), 3.55 m (BH-3), 3.70 m (BH-4 and BH-5), 4.70 m (BH-2), 5.55 m/5.70 m (BH-7, BH-8 and BH-9), 6.65 m (BH-10) and 7.60 m (BH-11) is predominated by plastic nature consisting of grey and occasionally yellowish grey soft silty clay. Further below, a layer of grey non-plastic sandy silt occasionally mixed with trace clay exists to a variable depth of 7.85 m/ 8.0 m (BH-1 and BH-6), 9.00 m/10.0 m (BH-2, BH-3, BH-4 and BH-5), 12.0 m (BH-7), 13.65 m (BH-10), 15.70 m (BH-9), 16.50 (BH-11) and 17.70 (BH-8) measured from existing ground level of the investigated boreholes. The subsequent layers of soil existing to the depth of the investigation are also non-plastic by nature. The above non-plastic soil comprises grey sandy silt, sand silt mix and very fine sand with some/ little silt. The SPT Value with soil profile of 11 boreholes against respective interval of the depth is shown in Figure 3.

The consistency of the top layer of clayey silt existing roughly to the depth of 2.65 m (BH-6), 3.10 (BH-1), 3.55 m (BH-3), 3.70 m (BH-4 and BH-5), 4.70 m (BH-2), 5.55 m/5.70 m (BH-7, BH-8 and BH-9), 6.65 m (BH-10) and 7.60 m (BH-11) is usually very soft and soft and occasionally medium. Further below, the layers of the non-plastic sandy silt existing roughly to the depth of 7.85 m/8.00 m (BH-1 and BH-6), 9.00 m/ 10.00 m (BH-2, BH-3, BH-4 and BH-5), 12.00 m (BH-7), 13.65 (BH-10), 15.70 m (BH-9), 16.50 m (BH-11) and 17.70 m (BH-8) generally have been observed in a very loose and loose state. The subsequent deep layers of the non-plastic sand-silt mix, silty fine sand and fine sand existing to the depth of the investigation, generally have been observed in a medium dense to dense and finally to a very dense state. Moreover, the consistency of the layer of clayey silt existing in between the depths of 13.65 m and 16.50 m (BH-10) is usually stiff.

Unconfined compressive test value varies between 30 to 40 kPa for the underlying soil beneath the embankment. According to the Laboratory test result the specific gravity of the investigated soil usually varies from 2.60 to 2.65. The engineering properties of the investigated layers of soil, particularly, the values of the angle of the internal friction, obtained from the performance of the direct shear tests, vary from 19.0^{o}-39.0^{o}. Several consolidation tests have also been carried out in the depth of 4 m at different locations. Following data have been obtained from one dimensional consolidation tests: initial void ratio ranges between 0.70 and 0.90, compression index ranges between 0.25 and 0.35 and coefficient of consolidation for vertical drainage ranges between 0.005 and 0.015 m^2/day.

5. SOIL IMPROVEMENT METHODOLOGY AND DATA ANALYSIS

Vertical drains are installed under a surcharge load of 65 kPa to accelerate the drainage of impervious soils and thus speed up consolidation. These drains provide a shorter path for the water to flow through to get away from the soil. Time taken to drain clay layers can be reduced from years to a couple of months. A sand column of 250 mm diameter and 5 m was used. The column is then filled with sand and connected to a free-draining blanket of granular soil. Because of its low permeability, the consolidation settlement of soft clays takes a long time to complete. To shorten the consolidation time, vertical drains are installed together with preloading either by an embankment or by means of vacuum pressure. Vertical drains are artificially-created drainage paths which are inserted into the soft clay subsoil. Thus, the pore water squeezed out during consolidation of the clay due to the hydraulic gradients created by the preloading can flow faster in the horizontal direction towards the vertical drains. It is taken advantage of the fact, that most clay deposits exhibit a higher horizontal permeability compared to the vertical. Subsequently, these pore water can flow freely along the vertical drains vertically towards the permeable layers. Therefore, the vertical drain installation reduces the length of the drainage path and, consequently, accelerates the consolidation process and allows the clay to gain rapid strength increase to carry the new load by its own.

The alignment of this road project is situated on a marshy land. This land remains water logged throughout the year and shrimp culturing occurs there. Oceanic ebbs and tides caries sediment and silted, formed alluvium types land. As per soil profile presented in the Figure 3, up to 3.5m consists of very soft silty clay and from 3.5-9.0m contains loose to very loose sandy silt. SPT value varies from 1-4 up to a depth of 5m which indicates that the soil condition is poor (very soft soil). Atterberg limits are 35-56 (LL), 25-28 (PL) respectively and moisture content is 42%. Under this circumstance, Vertical Sand Drain technique has been employed for this project. In the foundation level of the road, total number of 1,10,000 vertical sand drain has been used. Depth of Vertical Sand Drain (with a 250mm diameter) is 5m from excavated ground level that means 5.6m from original ground level (OGL). Fineness modulus (FM) of sand (fine aggregate) is an index number which represents the mean size of the particles in sand. It is calculated by performing sieve analysis with standard sieves. The cumulative percentage retained

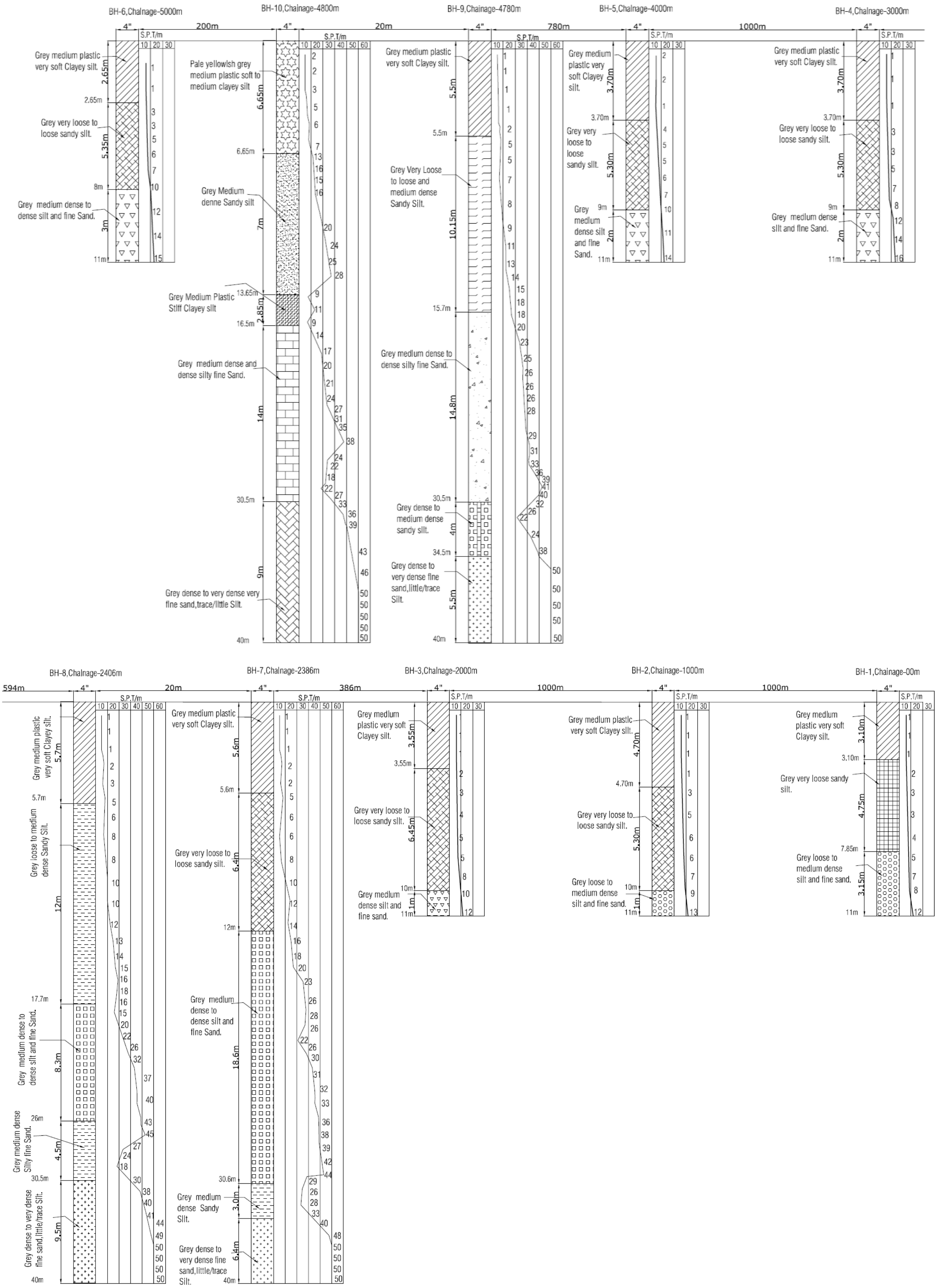

Figure 3 Soil profile with SPT values in the 11 boreholes

on each sieve is added and subtracted by 100 gives the value of fine aggregate. FM of sand has been used 1.8 for the vertical sand drains. Spacing between each sand drain is 1000 mm (1 m) and drains have been placed in a square pattern as presented in Figure 4.

Figure 4 Figure shows square pattern of VSD after completion of the work

Two layers (L1 and L2) have been considered for estimation of consolidation settlement.Thickness of layer 1 and layer 2 were 0-5 m and 5-10 m respectively. Unit weights of L1 and L2 in saturated phase are 16.50 kN/m^3 and 17.40 kN/m^3 respectively. Initial void ratio (e_o) of L1 and L2 were 0.81 and 0.8 respectively. Unit weight (γ_w) and Dry unit weight (γ_d) were 9.81 kN/m^3 and 15 kN/m^3 respectively. The estimated value of compression index C_C is 0.29. The location of the water table is assumed to be at the EGL. The load coming from the vehicular traffic has been assumed to be 65 KN/m^3. 552 mm primary consolidation has been estimated in the consolidation test. Due to high primary consolidation, square sand drain with double drainage condition has been selected. Coefficient of consolidation for vertical drainage (C_v) and coefficient of consolidation for radial drainage (C_{vr}) was 0.010 m^2/day. Drain radius 0.125 m has been considered. Average longest drainage path during consolidation (H_{dr}) was 5 m. 1 m of centre to centre spacing between two sand drains has been considered. In this site, theoretically using sand drain takes 90 days of time for 100% settlement and without sand drain only 236.33 mm settlement can be achieved in 90 days, as can be observed in Figure 5.

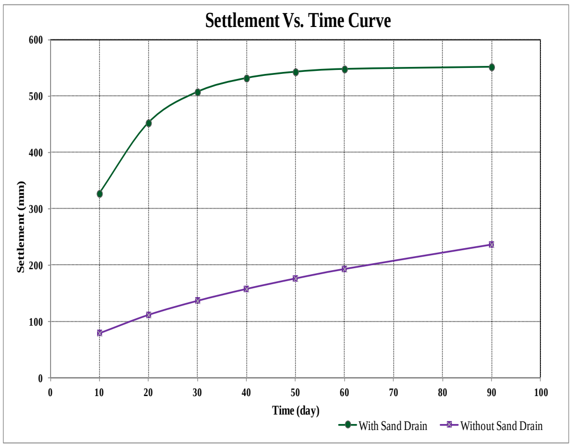

Figure 5 Settlement versus time curve for both with and without sand drain

It is always difficult to create the working field. The construction of ring bundth is a complicated task for bringing the soil from outside. Removing the water through dewatering process and excavating the upper soft soil layer are challenging. The construction processes of the VSD are described in the Figure 5. To construct the VSD, forty five tripods have been used in this project as presented in Figure 6.

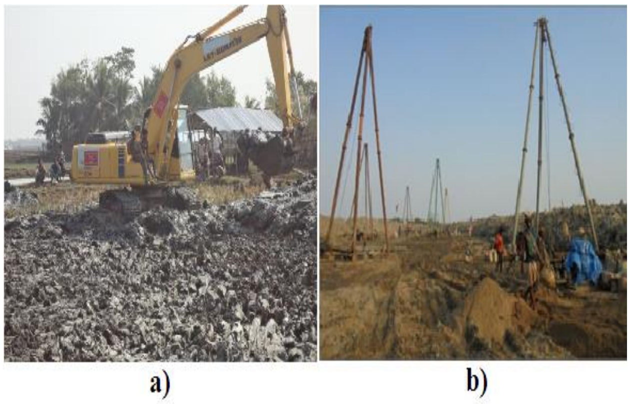

Figure 6 Figure a) shows that removing of soft clay before construction of the VSD pile and b)the construction of the VSD

Figure 7 shows the as built drawing of the road cross-section. After completion of the VSD, 600 mm of drainage layer (sand blanket) has been provided on top of the VSD. These layers have been composed of sand with FM 1.2, which have been compacted in layers of 150 mm thickness. Sylhet sand with one inch sizes of stone gravel were mixed in the ratio of 1:1 and have been provided as the filter layers at both side of the 600 mm of the drainage layer. Filter layers have been provided to prevent sand to come out along with the emerged water due to capillary action from the VSD and flow out to the outer side of the road.

The total height of the road embankment is 3m. This embankment has been constructed using compacted dredged soil filling (sandy clay, silty clay and silt, PL<20) in 150 mm layers. 150 mm base course, 150 mm sub-base and 250 mm improved sub-grade (ISG) have been used for slow moving road. 25 mm bituminous carpeting with 7 mm seal coat has been used for the slow-moving road. 175 mm base course, 250 mm sub-base course and 300 mm ISG have been used in 2 lanes of road. 80 mm bituminous carpeting and 12 mm seal have been used in two lanes of road. 125 mm of brick on end of ending has been used in two lane road. Turfing on land slope at end of the road is 1:2. In both sides of the road 1.5 thickness of turfing slope protection have been provided with clay. Top and bottom width of the six lane road including two slow moving roads are 30.40 m and 44.20 m respectively.

6. EMBANKMENT FILLING AND FINAL ROAD CONSTRUCTION

Dredged sand of the Mongla-Ghoshiakhali channel has been used as the embankment filling (around 3 m thick). Embankment has been filled in layer by layer with proper compaction as presented in Figure 8.

The improved subgrade layer (ISG) has been provided with sand of FM 0.8. The CBR value of ISG has been found 14% instead of 8%. Sub base layer of 250 mm thickness has been provided with 1:1 mixture of bricks khoa and sand for which CBR value has been found to be 80% instead of 30%.

At the top of the sub base layer, wet mix macadam has been constructed. Confirming the optimum moisture between khoa and sand; a mixture of khoa and sand (1.5 inch down khoa 60%, 1 inch down khoa 30% and local sand 10%) has been used for construction of the hard bed and 110% compaction has been found. Different stages of road construction after the VSD has been carried out are presented in Figure 9.

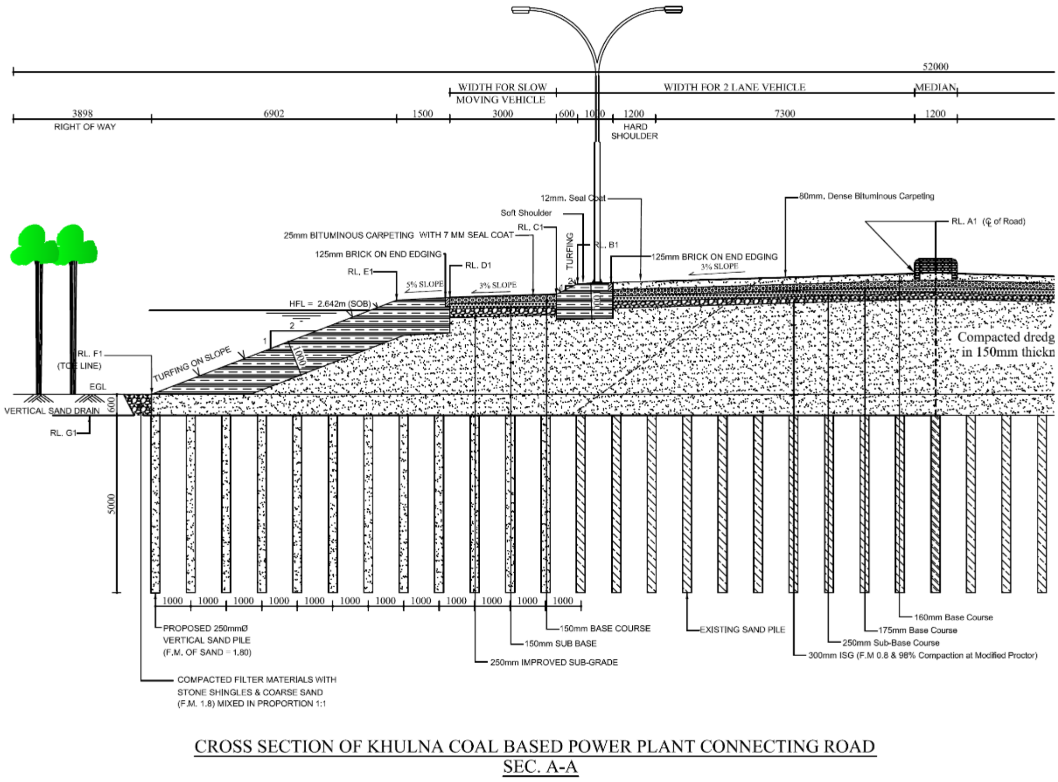

Figure 7 Final design for 4 lanes and 2 lanes slow moving road

a) **b)**

Figure 8 Figure a) shows embankment filled with Dredged sand of the Mongla-Ghoshiakhali channel and b) shows Embankment filling final layer (ISG bottom)

7. DISCUSSION

In the Khulna-Mongla highway project, the construction work is very challenging because of soft soil foundation layer. Due to low SPT value of soil, preloading with VSD technique has been employed to treat the soil. Sand has been used in the VSD having a FM value of 1.8. In total, 1,10,000 VSDs have been used in this project. 600 mm of sand (FM-1.2) blanket has been provided at the top of the VSD. For preloading, no extra load has been applied; self-weight of the embankment has been used as the load. In an average 3 m height of embankment has been constructed. In different layers of pavement ISG, sub-base, WMM, bituminous carpeting, dense carpeting and also in the both sides of the lane hard shoulder and soft shoulder have been used.

To measure the soil improvement, SPT have also been carried out after almost 100 days of VSD installation at three chainage locations. Figure 10 compares the SPT values at those locations before and after VSD installation. It has been observed that the SPT value improved significantly due to the installation of VSD. To measure the settlement, two settlement measuring plates have been placed in each kilometer. In total twelve settlement plates have been placed in the 5.76 km of road. After full completion of the embankment, the measured settlement has been found between 500 and 600 mm. According to the one dimensional consolidation test of undisturbed sample, the theoretical estimate of the settlement has been estimated to be around 552 mm.

a) **b)**

c) **d)**

Figure 9 Figure a) shows that mixture of aggregates close to OMC, b) shows compaction in progress, c) shows base course and d) shows completed road

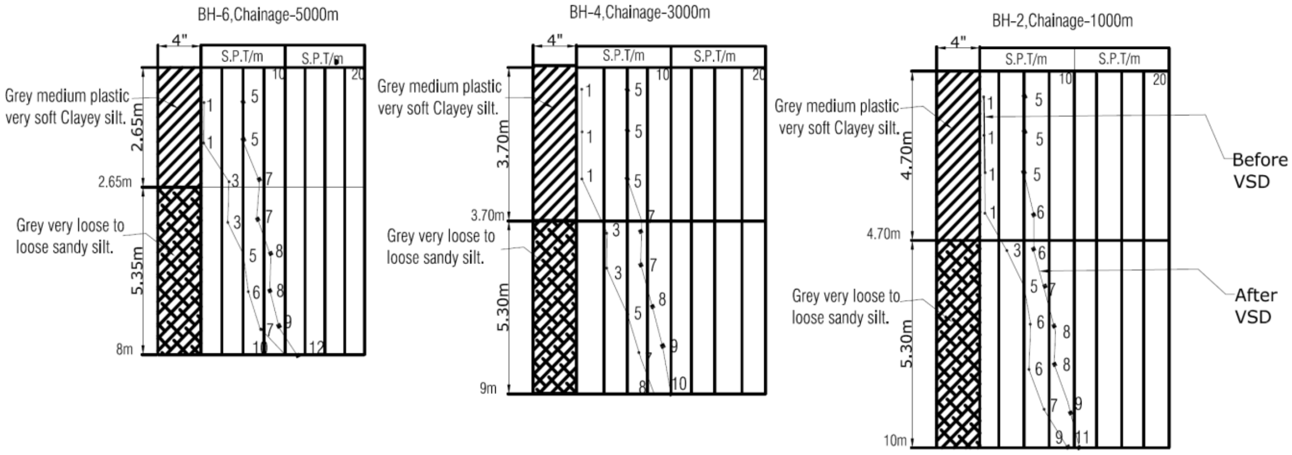

Figure 10 Comparison of SPT value before and after the soil improvement

8. CONCLUSIONS

The application of preloading with vertical sand drain (VSD) technique, as a soil stabilization method has been presented in this paper. Regarding the time consumption aspects and value of required work, soil strengthening by forming vertical sand drain is a more preferable technique. In this Rampal coal based power plant connecting road project 1,11,000 number of VSD has been installed at 1 m center to center spacing in square pattern upto a 5 m depth. Due to the installation of VSD, time for settlement has been reduced from almost one year to only 90 days. SPT values also improved due to the VSD installation. In twelve locations along the embankment, settlements have been measured. Measured settlement varies from 500 to 600 mm along the embankment profile. The concept of the soil improvement using VSD beneath the road embankment with tripod for installation purpose is not only cost-effective but also safe, reliable and time-saving as shown through the success of the project.

9. ACKNOWLEDGEMENTS

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