Ground improvement with PVD at Haldia, West Bengal, India: a case study with numerical validation

Smita Tung & Dola Roychowdhury
Z-Tech India, India

ABSTRACT: Construction of oil storage tank on ground with soft cohesive deposit requires ground improvement for achieving bearing capacity with reduction of large settlement. Haldia, major river port and industrial belt at 22.0667° N latitudes, 88.0698°E longitudes, located near the mouth of the Hooghly River, one of the distributaries of the Ganges. Alluvial deposit of Haldia, being highly impermeable, takes very long time to consolidate. Haldia Energy Ltd was commissioning a Coal based Thermal Power Plant for generation of power. An area of 220 m ×30 m on the proposed Power Plant is designated for Cooling Tower which ground needs to improve. As Installation of PVD increases the drainage path and reduce the settlement time, So, Haldia Energy Ltd adopted the PVD technology to improve the ground. This 220m x 30m part of Power Plant construction area was loaded by fly ash as a first stage loading for 45 days up to 6.5 m and second stage loading for 16 days up to 10.0 m. The proposed site has been treated by Pre fabricated vertical drain @ 1.25m ×1.25m triangular grid to accelerate the process of Pre consolidation. The present study has been carried out to investigate the effect of installation of PVD in soft clay at the project site in respect of the rate of settlement and rate of change of pore water pressure. Further two-dimensional numerical analysis has been carried out by PLAXIS 2D finite element software to investigate and validate the pore pressure development and settlement with field investigation. It has been observed that the rate of settlement and rate of dissipation of pore water pressure have been sufficiently decreased within the soil indicating improvement of the soft clay after an appreciable time.

Keywords: *Prefabricated Vertical Drain, PLAXIS 2D, Finite Element, shear strength, consolidation*

1 INTRODUCTION

Construction of structure on ground with soft cohesive deposit requires improvement for achieving bearing capacity with reduction of large settlement. Such ground improvement technique is broadly adopted worldwide in case of soft cohesive soil to cater to the large demand of growth of industries and development of infrastructure. Alluvial deposit of Haldia, is typical example of soft cohesive soil. Clay, being highly impermeable, takes very long time to consolidate. Installation of PVD in such a soil increases the drainage path and reduces the required time of settlement as well. The more the settlement occurs the more strength is gained by the soft soil. Preloading on soft clay with prefabricated vertical drains is one of the most popular methods to increase the shear strength of soft soil and control its post-construction settlement. The permeability of soils is very low, consolidation time to the achieved desired settlement or shear strength may take too long time (Holtz, 1987; Indraratna et al., 1994). Using prefabricated vertical drains (PVD), means that the drainage path is shortened from the thickness of the soil layer to the radius of the drain influence zone, which accelerates consolidation (Hansbo, 1981). This system has been used to improve the properties of foundation soil for railway embankments, airports, and highways (Li and Rowe, 2002). Kjellman (1948) introduced prefabricated band shaped drains and cardboard wick drains for ground improvement. Typically, prefabricated band drains consist of a plastic core with a longitudinal channel surrounded by a filter jacket to prevent clogging. The present study has been carried out to investigate the effect of installation of PVD on soft clay in respect of shear strength, permeability, consolidation parameters in addition to the rate of settlement and rate of change of pore water pressure. The uses of geo-synthetic reinforcement along the perimeter of the tank and prefabricated vertical drains (PVDs) in the foundation soil in conjunction with site preloading are expected to reinforce the foundation , accelerate consolidation and reduce post-construction settlement. For vertical drain design, the pressure changes would be monitored with strategically. In order to ensure stability two soil improvement techniques have been studied: prefabricated vertical drains (PVD) with preloading surcharge.

1.1 *Site location*

Haldia is 120 km away from Kolkata through NH-6 and 30 km from the nearest bank of Bay of Bengal. The geographical location of Haldia is, latitude: 22° 05' N, and longitude: 88° 03' E. Haldia is in close proximity where the climate is normal like other parts of South Bengal. The top soil of Haldia is soft clay and the layer has a tendency to settle under load. Any heavy construction on this soil is normally deleterious. Haldia Energy Ltd. is commissioning a Coal based Thermal Power Plant for generation of power. In this connection, the project authority has decided that the soil condition should be improved before starting any heavy construction. Installation of Pre-fabricated Vertical Drain (PVD) with Pre-loading is one of the methods which can improve the soil condition. Table 1 represents sub soil profile of site location of project site of Haldia Energy Ltd.

Figure 1: Site location of Haldia Energy Ltd.

1.2 *Problem Specification and Analysis:*

For construction of two Cooling Tower structures as part of building Thermal Power Plant at Haldia by Haldia Energy Limited, the foundation soil capacity was required to be improved. The requirement of safe bearing capacity for the Cooling Tower structures was 100 kPa, however, as per the sub-soil condition, available bearing capacity for the said structure was about 50 kPa. For improvement of the bearing capacity, the following two options were considered:

Option A: Ground improvement with Piling.

Option B: Ground improvement with PVD-Preloading method.

As the Option – B is economic and technically viable soulution so, it was preferable to adopt Option – B.

Table 1 Average Subsoil Profile

Stratum	Depth (m)	Description of Soil	Properties of Soil									
			N Value	NMC (%)	LL (%)	PL (%)	γ_b (kN/m^3)	Shear parameter		(m_v) m^2/kN $\times 10^{-4}$ Range (kPa)		
								C (kPa)	Φ	25-50	50-100	100-200
I	2.0	Soft to medium stiff brownish grey, silty clay with rusty brown patches. Grass roots noticed at the upper patches (CH).	3	30	57	23	19.1	40	-	4.20	4.10	3.30
II	7.0	Soft light grey clayey silt with fine mica flakes. (CI)	2	31	41	22	18.2	23	-	2.80	4.40	3.60
III A	19.50	Loose light grey with sandy silt with light clay, fine mica flakes and traces of decomposed vegetations. (ML)	8	-	-	-	18.0	-	28°	E = 5 Mpa, μ=0.35		
III B	22.50	Loose light grey with sandy silt with light clay, fine mica flakes and traces of decomposed vegetations. (ML/SM)	22	-	-	-	19.0	-	30°	E = 20 Mpa, μ=0.35		
IV	25.00	Stiff, light grey, clayey silt with mica flakes and thin laminations of silt fine sand. (CI)	8	34	43	20	18.4	49	-	1.16	1.50	1.70
V	28.00	Medium dense / dense light grey fine sand with mica flakes . (SM)	28	-	NP	NP	19.0		32°	E = 25 Mpa, μ=0.35		
VI	43.50	Medium stiff, grey, silty clay with laminations of silt.	11	41	55	25	18.0	60	-	1.73	1.54	1.30
VII	53.00	Stiff, light grey, clayey silt with fine mica flakes and laminations of silt/fine sand. (CI/CL)	32	28	38	21	18.5	9	25°	0.38	0.77	1.24
VIII	>65.00	Very dense, light grey silty fine sand with mica flakes. (SM)	>100	-	NP	NP	20.0	-		E = 50 Mpa, μ=0.35		

* Average standing water level= 0.80 m below Existing Ground Level

2 METHODOLOGY

2.1 *Field installation*

The cooling tower will be built on 200 m ×20 m thick raft foundation to carry a superimposed load of 100 kPa. An area of 220 m ×30 m on the proposed construction area was loaded by fly ash as a first stage loading for 45 days up to 6.5 m and second stage loading for 16 days up to 10.0 m has been shown in Figure 9. Typical cross sectional details of PVD has been presented in Figure 2. Ground improvement plan details of PVD insertion point have been shown in Figure 3. Figure 4 represents typical pictorial view of PVD insertion point of construction site. The proposed site has been treated by Pre-fabricated vertical drain @ 1.25m ×1.25m triangular grid to accelerate the process of Pre consolidation. The PVD at starting point and triangular grid pattern has been shown in Figure 5 and Figure 6. Discharge of excess pore pressure in the sub soil has been shown in Figure 7. Non Woven Geo textile was installed as separator has been shown in Figure 8. 3 no's settlement measuring rods were installed on the preloaded area to measure settlement under every stage of loading.

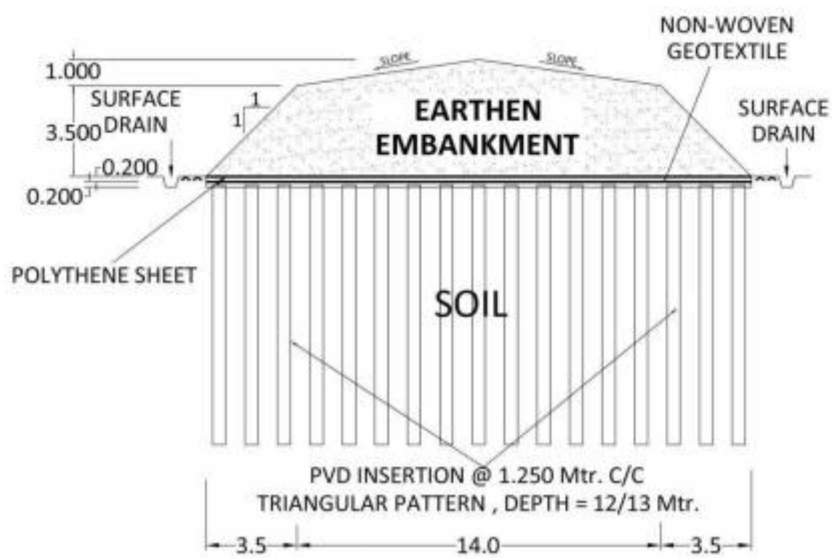

Figure 2: Cross Sectional details of PVD

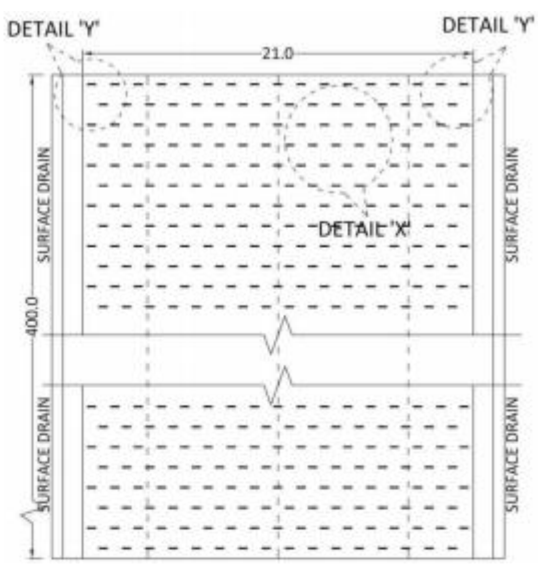

Figure 3: Ground Improvement plan Details

Figure 4: Installation of PVD in Site (Plan)

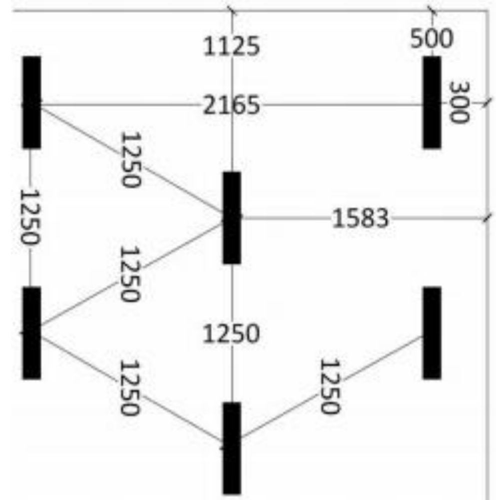

Figure 5: PVD installation of Starting Point

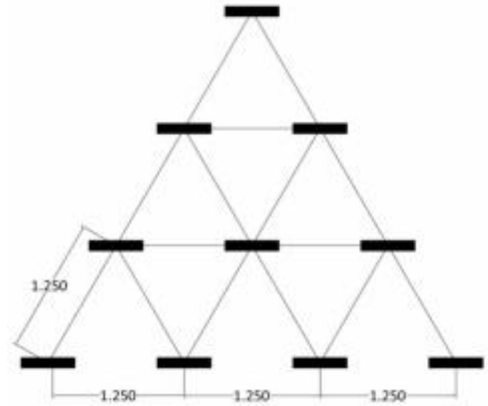

Figure 6: Triangular Grid Pattern of PVD

Figure 7: Discharge of excess pore pressure

Figure 8: Geotextile separator

Figure 9: Pre-loading with flyash, height – 10m

2.2 *Numerical modeling*

2.2.1 *Numerical formulation*

A vertical drainage system is installed in order to accelerate the consolidation process and help to improve discharge of excess pore pressure in the sub soil. In this way, a stable situation is reached more quickly, thus shortening the consolidation period dramatically to accelerated earthwork filling process.

Consolidation period for a given degree of consolidation of PVD (Kjellman, 1948)

$$t = D^2/ (8\times C_h) [\ln (D/d)-3/4] \ln[1/(1-u_h)] \qquad (1)$$

s = spacing of PVD

Where, t=Consolidation period (year)

D= Effective spacing (m) = 1.05×S (triangular pattern)

d= Effective diameter of the band drain (m)

u_h = Time factor for horizontal consolidation

Horizontal co-efficient of consolidation (Ch) is normally 2-4 times of vertical co-efficient of consolidation (Cv).

2.2.2 *Modeling in PLAXIS 2D*

Two-dimensional plane strain condition analysis has been considered in this finite element analyses using PLAXIS 2D. Material nonlinearity has been considered to model the soil using Mohr –Coulomb failure theory and elastic-perfectly plastic behavior of soil. In this present finite element analyses each node of the element has two degrees of freedom. Radial consolidation theories have been considered for drains as ax symmetric elements. Drains are modeled as plane strain elements. Figure 10 represents the cross section of PVD. Deformed shape of vertical drain has been shown in Figure 11.

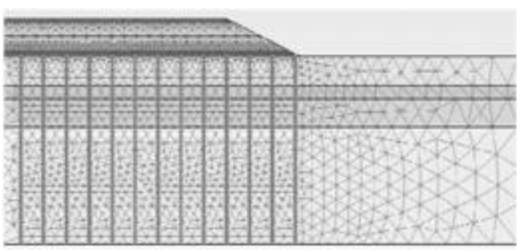

Figure 10: Meshing of cross section of PVD

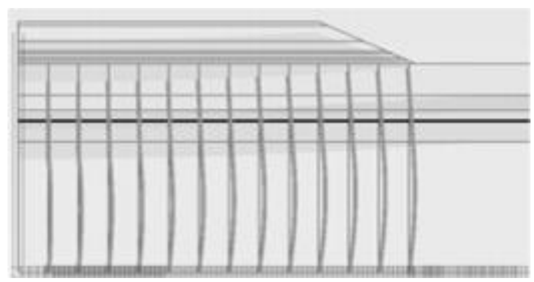

Figure 11: Deformed shape of vertical drain

3 RESULT

To investigate the soil behavior improved by PVDs under oil tank, a plane strain finite element analysis was conducted using the finite element code, PLAXIS 2D. Settlement and pore pressure variation with time have been presented analytically to validate field investigation data.

3.1 *Observation of settlement during preloading*

Preload has been kept for 35 days after a loading period of 61 days and in that stage settlement was occurred at a gradually decreasing rate. Table 2 represents the field time settlement data at the centre position. Figure 12 represents a graphical presentation of field settlement against time at loading condition. It has been shown that there is maximum settlement at the centre position and it gradually reduces in radial direction due to changes in equivalent diameter of drain. Field investigation and result from numerical analysis of settlement have been presented in Figure 13. It has been noticed that numerical result slightly deviates from field investigation after appreciable time.

Table 2: Observations during Preloading (at centre)

Sl No.	Loading Condition		Time (Days)
1.	During Loading		
2.			
6.		96	598

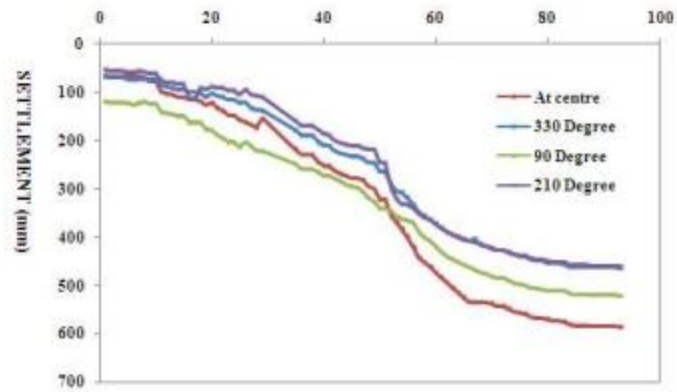

Figure 12 represents a graphical presentation of field settlement against time at loading condition.

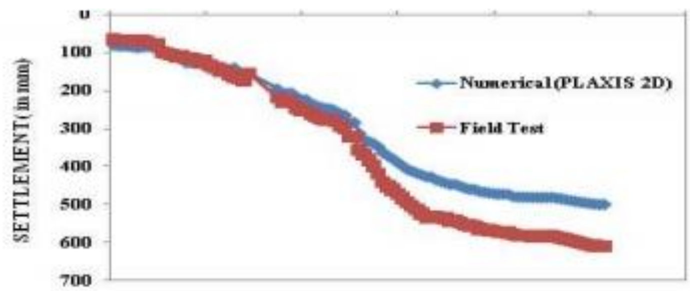

Figure 13: Validation of field investigation with numerical analysis of Settlement vs. Time at centre position

After preloading the consolidation time was reduced and the percentage of reduction in time after preloading was up to 30%. As the settlement of soil is observed by preloading hence the bearing capacity of the soil was improved

3.2 *Observations of excess pore water pressure*

Excess pore water pressure measured by piezometer has been validated analytically using PLAXIS 2D software in Figure. 14. The numerically computed excess pore pressure slightly deviated from the observed pore pressure by field investigation during loading stages. It has been investigated that after development of maximum magnitude of pore water pressure magnitude of pore water pressure is gradually reduced. It has been noticed that maximum development of excess pore water pressure is more than field investigation and time lag for numerically computed development of maximum magnitude of excess pore water pressure is less than observed pore water pressure by field investigation.

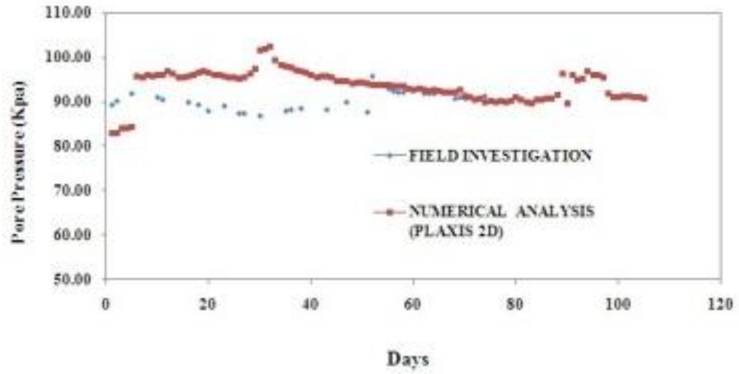

Figure 14: Validation of field investigation with numerical analysis of Pore Pressure vs. Time at centre position

3.3 *Observations of Ground improvement*

Table 3 presents the improvement of ground by installation of PVD. It has been noticed that net safe bearing capacity improved by approximately 50% by pre loading method.

Table 3: Observations of Improvement of ground

Item No.	**Untreated Ground**	
Net Safe bearing capacity (kPa)	50 kPa	
Estimated Settlement (mm)	331 mm	
Observed Settlement (mm)	-	598 mm

4 CONCLUSIONS

i) After preloading the consolidation time has been reduced and the percentage of reduction in time after preloading was up to 30%.

ii) Time settlement analysis observed from field investigation has been validated numerically by finite element method.

iii) Net safe bearing capacity improved by approximately 50% by PVD pre loading method.

iv) Time lag for numerically computed development of maximum magnitude of excess pore water pressure is less than field investigation.

REFERENCES

1. Hansbo S. (1981).Consolidation of fine-grained soils by prefabricated vertical drains. Proceedings of the 10th International conference on Soil Mechanics, Stockholm, 3, 677-682.
2. Holtz, R. D. (1987). Preloading with prefabricated vertical strip drains, Geotextiles and Geomem-branes, Vol. 6 (1–3), pp. 109–131.
3. Indraratna, B., Balasubramaniam, A. S., and Ratnayake, P. (1994). Performance of embankment stabilized with vertical drains on soft clay. J. Geotech. Eng., ASCE, Vol. 120(2), pp. 257-273.
4. Kjellman, W. (1948). Accelerating consolidation of fine grain soils by means of cardboard wicks. Proc. 2nd ICSMFE, Vol. 2, pp. 302-305.
5. Li, A. L. and Rowe, R.K. (2002). Combined effect of reinforcement and prefabricated vertical drains on embankment performance. Canadian Geotechnical Journal, Vol. 38, pp. 1266-1282.
6. Plaxis (2012) Plaxis Finite Element Code for Soil and Rock Analyses: Reference Manual 2D-Version 12. Delft, The Netherland