Agartala–Bangladesh Railway Embankment Construction Over Soft Soils Incorporated with Prefabricated Vertical Drains: A Case Study

Rai Bahadur Reang, Sujit Kumar Pal, and Sanjay Paul

Abstract Three embankments of different dimensions for the railway tract at contiguous locations are being constructed over soft soils using prefabricated vertical drains for connecting two cities, Agartala and Dhaka. Prefabricated vertical drains were supplied from Maccaferri and the installation rig machineries were provided by IRCON. PVDs were installed in triangular pattern with three different spacing (0.7, 0.8, and 1.0 m) with according depths (15, 6, and 7.5 m). For conducting physical and engineering properties, soils were collected from different locations as well as from different depths using auguring and wash boring method at suitable intervals along with SPT tests. It has been observed that the natural soil profile was composed of three different layers of different thickness; sandy silty-clay at top, silty-clay in the middle, and sandy silty-clay at bottom, respectively, overlying the hard stratum. A sand layer of thickness 0.2 m is being provided underlain by a strip drains made up of polypropylene, which accelerates and helps sand layer draining off the water from PVDs, over which paralinks were also laid that function as reinforcement to embankment soil deposits. Settlements predictions of the existing soils were made and determined. Different results were obtained at various locations. Without PVD, the settlement of the soil strata at chainage Ch-03 + 900 to Ch-04 + 400 km is observed to be 2305 mm and the corresponding settlement time is 189306 days. While the design was made considering PVD the consolidation settlement and time gave as 1660 mm and 122 days, respectively.

Keywords Prefabricated vertical drain · Stratified soft soil · Settlement

R. B. Reang (✉) · S. K. Pal · S. Paul
Department of Civil Engineering, NIT Agartala, Tripura, Tripura, India
e-mail: raireang@springer.com

S. K. Pal
e-mail: skpal1963@gmail.com

S. Paul
e-mail: sanjaypaul76@gmail.com

S. Patel et al. (eds.), *Proceedings of the Indian Geotechnical Conference 2019*, Lecture Notes in Civil Engineering 134, https://doi.org/10.1007/978-981-33-6370-0_41

1 Introduction

Preloading combined with prefabricated vertical drains (PVDs) has been used extensively used in the construction of large-scale infrastructure for highways, railways, ports, and airports [1–7]. Barron [8] proposed the original analytical solutions to theoretically analyze the consolidation process of vertical drained ground. However, the performance of the PVD system is still difficult to accurately predict because the consolidation rate of PVD-improved foundation is controlled by several factors [9–12]. Prefabricated vertical drains are commonly used to decrease the drainage path within soft soils to accelerate the time of primary consolidation. PDVs are displacement drains of small volume that exhibits considerably with fewer disturbances to the soil mass than the displacement sand drains. In this railway project, there are three construction sites (under same project) for which settlements of soil mass due to installation of PVDs were predicted based on which the embankment shall be constructed. But, only one site is discussed in this paper. An analytical solution was proposed to predict the settlement and determined using IRC:75, IS:8009 (Part-1) and Bowles formula. Different settlements were observed for different sites. Since the three construction sites are consist of different types of soil layers, it has been observed that the proper knowledge of keep maintaining spacing and depth to which PVDs are thrust into the existing soil are important factors for settlement evaluation for stratified field soils. The size of the installation mandrel and installation rig shall be kept same all through the project. Installation of PVDs and construction of embankments are under progress. Laboratory and numerical study are also being carried out to validate the field settlement and other mechanism of reaction to soil disturbance and finding its solution. With this new approach, a modified effective drain spacing and depth of the PVD shall be evaluated for layered soil consisting of different type of soils.

2 Importance of Prefabricated Vertical Drain

It is very important to stabilize soft soil before commencing any major construction work to prevent out the settlement. Many soft clay strata contain thin bands of silt or sands which result in the instability of embankments due to the horizontal spread of excess pore pressure vertical drains relives these excess pore pressures and thus avoids the occurrences of instability. The time required to reach a higher degree of consolidation under preloading improved drainage should be used in the form of prefabricated vertical drains. In order to expedite the settlement process and reduce building of pore water pressure, it is necessary to restrain the flow path through the soil. This can be achieved by placing prefabricated vertical drains at a regular spacing in the soil. PVDs are selected over vertical sand drains for its feasibility in installation and its low cost. When a heavy load, such as a road embankment or other structure is placed on the top of clay or silty-clay soil, considerable sudden settlement may occur due to squeezing out of excess pore water pressure, thus the soft soil consolidated. This kind of settlement often causes serious construction problems. But, when PVDs are installed before commencing any civil engineering construction and structure over the soil, the settlement takes place in gradual manner and thus no serious abruption of the soil and no consequent casualties are observed.

3 Field Study

In this project, prefabricated vertical drains are to be used in the construction of embankments for broad gauge railway lines between Agartala (India) and Dhaka (Bangladesh) at chainages Ch-03 + 900 to Ch-04 + 400 km, Ch-04 + 400 to Ch-04 + 700 km, and Ch-04 + 700 to Ch-05 + 100 km, i.e., there are three different construction sites (under same project) in between 3.9 and 5.1 km from Agartala railway station (Tripura) and only 0.7 km away from international fencing line (border between India and Bangladesh). The existing sites consist of stratified soft soils covering vast area all around extending to great depths. Embankments of different heights, such as 6, 6, and 9 m high, are to be established at stages on these sites. Installation of prefabricated vertical drains at chainage Ch-03 + 900 to Ch-04 + 400 km is under progress, and therefore only this chainage is discussed in this paper. The study of the soil profile indicated that the top of the stratification contains the light gray soft sandy silty-clay. The next layer observed in the stratification contains the silty-clay which is then followed by sandy silty-clay. The next layer of stratification is moderately weathered rock. Table 1 gives details of type of soil strata at the chainage Ch-03 + 900 to Ch-04 + 400 km.

3.1 Properties of the Soil Strata, Embankment Fill, PVD, Drainage Composite, Paralink

The settlements of the existing soil stratums can be accelerated by using prefabricated vertical drains (PVDs) with surcharge. With the use of PVDs, water flows out horizontally as well as vertically, i.e., three-dimensional consolidations occur while

Table 1 Type of soil strata at chainage Ch-03 + 900 to Ch-04 + 400 km

Stratum	Description	Depth below ground level (m)	Thickness (m)
I	Light gray soft sandy silty-clay	0.8	0.8
II	Silty-clay	11.50	10.70
III	Sandy silty-clay	13.20	1.70
IV	Moderately weathered rock (in situ rock)	–	–

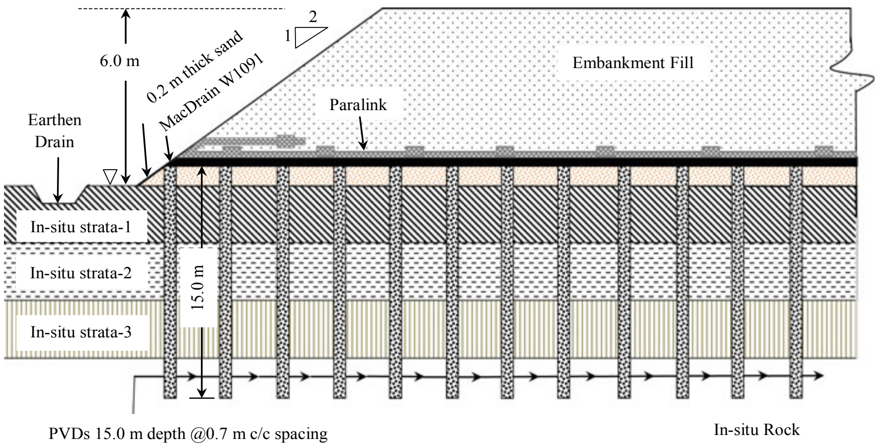

Fig. 1 Typical cross section (a portion of the total embankment width of 106 m) of railway track (Ch-03 + 900 to Ch-04 + 400 km)

prefabricated vertical drains are used. Therefore, on application of PVDs along with preload the time required for settlements can be drastically reduced. Based on the study of properties of existing soil, the ground improvement technique using prefabricated vertical drains (PVDs) was designed. The spacing of PVD was designed as 0.7, 0.8, and 1.0 m for these three sites. At chainage Ch-03 + 900 to Ch-04 + 400 km the spacing and depth were kept as 0.7 and 15 m, respectively, with triangular patterns to achieve the expected settlement within the desired consolidation period. At this chainage, the height of the embankments is 6 m. The consolidation settlement is expected to be 1660 mm. A typical cross section of the embankment is shown (Fig. 1).

The details and properties of the soil strata, embankment fill, prefabricated vertical drain, drainage composite, paralink, and sand blanket are given in the following.

The details of the soil strata are given in Table 3. Properties of the prefabricated vertical drains and paralinks are tested as per ASTM and EN ISO methods. The installing rig had been provided by IRCON (a central PSU of the Indian Government). The drainage composite is used in the field with the basis of pressure and discharge requirement and the type used in this project is Geocomposite MacDrain W1091 (having a "W" configuration as longitudinal parallel channels) and paralinks are also to be used as reinforcement to embankment. Paralinks is a high strength geogrid manufactured from high tenacity polyester yarns. Locally available well graded sand shall be applied over the field soil bed as sand blanket to facilitate the drainage of water. Properties of geocomposite and prefabricated vertical drains are given in Tables 2 and 4, respectively.

Table 2 Details of the geocomposite (MacDrain W1091) used in this project

Properties	Test method	Average value
Thickness (mm)	EN ISO 98,631	9.00
Tensile strength (kN/m)	EN ISO 10,319	18.00
In plane flow capacity (l/s)	EN ISO 12,958	0.38
Apparent opening size, O_{90} (μ)	EN ISO 12,956	110.00

Note All the data are collected from IRCON, a central PSU of the Indian Government, Agartala region

3.2 Construction of the Embankment

After the completion of installation of prefabricated vertical drains, preload (embankment material) along with surcharge loading shall be placed over the existing soil bed in stages up to the required height as shown in Table 5. The embankment material of which properties are different from the existing field soil shall be collected from other locations. In this project, 10 days interval for each 0.5 m rise in the embankment shall be adopted up to 60 days. After that, the next 3 m height shall be completed within 30 days and the other 3 m to be within 32 days. When the expected consolidation period is over and the soil has consolidated up to the required extent same as evaluated from the design, the surcharge loading has to be removed to arrive at the working level and the surface is to be properly rolled. Once this is completed commencement of construction of the railway lines may be carried out on the improved ground.

3.3 Estimation of Settlement

For cohesive soft soils, the consolidation settlements are of major concern as this is a long-term phenomenon. Since the very first objective of PVD installation is to consolidate the soil bed, the total settlement was determined by using conventional method of settlement analysis before the installation of PVDs started. Total settlement of a soil bed is summation of elastic (immediate) settlement (S_i), primary consolidation settlement (S_P), and secondary consolidation settlement (S_s) as shown in Eq. (2). In this project, primary consolidation settlement was mainly focused barring initial and secondary consolidation settlement for the calculation of total settlement [a conventional Eq. (1)] and was determined using IRC:75, IS:8009 (Part-1) and Bowles formula. Primary consolidation settlement (S_p) and total settlement (S_t) are calculated as,

$$S_p = \frac{C_c H}{1 + e_0} \log\left(\frac{p_0 + \Delta p}{p_0}\right) \quad (1)$$

where

Table 3 Parameters of the soil strata at chainage Ch-04 + 100 km

Sl. no	Stratum	Thickness (m)	Specific gravity (G)	Liquid limit (LL), %	Plastic limit (PL), %	Plasticity index (PI), %	Saturated unit weight (γ_{sat}), t/m^3	Effective unit weight (γ_{sat}), t/m^3	Influence factor after Osterberg ($I_{\sigma z}$)	Net incremental pressure at the layer top (Δp), t/m^2	Initial void ratio (e_0)	Compression index (c_c)	Poisson's ratio (μ)	Influence factor (I_s)	Modulus of elasticity (E_s), t/m^2
1	I	0.80	2.73	49	26	23	1.60	0.60	0.500	20.206	1.820	0.351	0.30	0.002	180
2	II	10.50	1.57	46	24	22	1.07	0.07	0.499	20.147	0.836	0.235	0.30	0.026	180
3	III	1.70	2.72	36	23	07	1.83	0.83	0.498	20.119	1.040	0.234	0.30	0.004	661

Note All the data are collected from IRCON, a central PSU of the Indian Government, Agartala region

Table 4 Details of the PVD used in this project

Properties	Test method	Typical value
Core configuration		
Core material	ASTM D 276	PP
Width (mm)	ASTM D 3774	100.00
Thickness (mm)	ASTM D 5199	4.00
Width-width tensile strength (kN/m)	ASTM D 4595	≥7.00
Tensile strength (kN/m)	ASTM D 4595 EN ISO 10,319	≥2.50
Elongation at 0.5 kN (%)	ASTM D 4595 EN ISO 10,319	≤10
Discharge capacity, 300 kPa ($i = 1$) (cm^3/s)	ASTM D 4716	≥100
Permeability (cm/s)	ASTM D 4491	$\geq 1.4 \times 10^{-4}$
Permittivity (s^{-1})	ASTM D 4491	0.44
Apparent opening size, O_{90} (μ)	EN ISO 12,956	<85

Note All the data are collected from IRCON, a central PSU of the Indian Government, Agartala region

Table 5 Embankment stage construction details for Ch-03 + 900 to Ch-04 + 400 km

S. No	Height of embankment (m)	Total number of days for construction and waiting period for consolidation
1	0.5	10
2	1.0	20
3	1.5	30
4	2.0	40
5	2.5	50
6	3.0	60
7	6.0	90
8	9.0	122

$$\Delta p = 2qI_{\sigma z}$$

q = Total pressure at the base of embankment.
$I_{\sigma z}$ = Influence factor after Osterberg.
C_c = Compression index.
e_0 = Initial void ratio.
And,

$$S_t = S_i + S_P + S_s \tag{2}$$

Table 6 Embankment geometry and its geotechnical parameters

S. No.	Parameter	Design value
1	Embankment height (m)	6.00
2	Embankment side slope (V:H)	1:2
3	Embankment width at top (m)	106.00
4	Embankment length at top (m)	106.00
5	Embankment width at base (B) (m)	130.00
6	Embankment length at base (L) (m)	130.00
7	Horizontal projection of embankment side slope along width (a) (m)	14.50
8	One half of the embankment width at top (b) (m)	53.00
9	Unit weight of embankment material (γ) (t/m^3)	1.90
10	Total pressure at the base of embankment (q) (t/m^2)	20.2061
11	Location of settlement estimation in embankment	Center

The results of various parameters and primary consolidation settlement of each layer are given in Table 7. Embankment geometry and its geotechnical properties are shown in Table 6. Total primary settlements are observed as 2305 mm. After applying depth factor (I_F), rigidity factor, and pore water correction factor, the estimated total consolidation settlement was observed as 1660 mm. By adopting this settlement value, the time required to reach the desired degree of consolidation was determined considering with and without PVD. The best fitted design was opted for this project thereafter.

3.4 *Estimation of Time Required—without Using Prefabricated Vertical Drain*

When huge surcharges are imposed on a natural soil bed, the soil consolidates, i.e., three-dimensional consolidations occur but in a slow manner while no PVDs are used. The time required for three-dimensional consolidation settlement onto this soil is calculated as,

$$t = \frac{T_V \times d^2}{c_V} \tag{3}$$

Laboratory test results revealed that the coefficient of vertical consolidation (c_V) of the soil of layer II was 2.45×10^{-4} cm^2/s (0.772632 m^2/yr) and this value was adopted in the calculation of settlement time required. The expected degree of consolidation (U) was 99% and therefore the corresponding time factor (T_V) was obtained as 1.781 from the design curve. The length of the PVD to be embedded was 15 m long. And, the length of the drainage path was also taken as 15 m. Hence, using

Table 7 Results of various parameters and primary consolidation settlement

Layer No	Thickness of layer (m)	Center of layer from base of the embankment (z), (m)	$\alpha = \tan^{-1}[(a+b)/z] - \tan^{-1}(b/z)$	$\beta = \tan^{-1}(b/z)$	$I_{\sigma z} = (1/\pi) \times [\alpha(1+b/a)+\beta]$	Overburden pressure, (t/m^2)	Total pressure at the base of embankment (q), (t/m^2)	Primary consolidation settlement (S_P), (m)
I	0.80	0.40	0.002	1.563	0.500	0.240	20.206	0.192
II	10.70	6.15	0.025	1.455	0.500	0.855	20.206	1.907
III	1.70	12.35	0.048	1.342	0.498	1.935	20.206	0.206
Total primary consolidation settlement								2.305

Eq. (3) the consolidation time period to reach the required degree of consolidation was observed to be 518.649 years (189,306.97 days). This duration are minimized by multiple times by using PVDs that will reduce construction cost as well.

3.5 Estimation of Time Required—Using Prefabricated Vertical Drain

In order to accelerate the time of consolidation settlement, prefabricated vertical drains are used. Triangular pattern was selected over square pattern for PVD installation. From design calculation, spacing (s) and coefficient of horizontal consolidation (c_h) were opted as 0.7 m and $2c_{v,}$ respectively. And, the time required was calculated using Hansbo's equation, as follows:

$$t = \frac{D^2}{8 \times c_h} \times \left[\frac{1}{1 - \left(\frac{d}{D}\right)^2} \times \ln\left(\frac{D}{d}\right) - \frac{3}{4} + \frac{1}{4}\left(\frac{d}{D}\right)^2 \right] \times \ln\left(\frac{1}{1-U}\right) \quad (4)$$

where

$$D = 2\sqrt{\left(\frac{A}{\pi}\right)} \text{Effective diameter of area covered by each drain} = 0.73511\,\text{m};$$

where

$$\begin{aligned} \text{where A} &= \text{Area treated by single PVD} \\ &= 0.866 \times \text{s}^2 \\ &= 0.866 \times (0.7)^2 \\ &= 0.42434\,\text{m}^2 \end{aligned}$$

$$d = 2\left(\frac{b+t}{\pi}\right) = \text{Effective diameter of each drain} = 0.0662;$$

where $b = 100$ mm, $t = 4$ mm

$$U = \text{Degree of consolidation settlement} = 99\%.$$

It has been observed that 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. After putting values of all the parameters, the time required for settlement was obtained from Eq. (4) as 122 days that is only about

4 months of total consolidation period obtained without using PVDs and thus ultimately the construction cost will also be lessened that any civil engineer aims at.

4 Conclusion

All the results of the parameters required for PVD design are evaluated in the laboratory prior to commencement of the construction in the field. Installation of prefabricated vertical drains at site Ch-03 + 900 to Ch-04 + 400 km is under progress that will be followed by the installation at Ch-04 + 400 to Ch-04 + 700 km and Ch-04 + 700 to Ch-05 + 100 km. Without using PVD, the settlement of the soil strata at Ch-03 + 900 to Ch-04 + 400 km is observed to be 2305 mm and the corresponding settlement time is 189306 days. The PVD design revealed that the consolidation settlement of the existing soil strata is about 1660 mm when PVDs are used. The corresponding time required to obtain this settlement is 122 days. Thus, prefabricated vertical drains may be used to expedite consolidation settlement of the layered soft soils discussed in this paper.

Acknowledgements The foregoing project on Agartala–Dhaka railway track embankment construction and Prefabricated Vertical Drain design and installation is under the supervision of a renowned companies—Maccaferri Environmental Solutions Private Limited, India and Indian Railway Construction Company (IRCON, a central PSU of the Indian Government) and we gratefully acknowledge them for their collaborative support during writing this paper, especially to Mr. Raman Singla (AGM, IRCON, Agartala Project) and his team.

References

1. Arulrajah, A., Bo, M.W., Leong, M., Disfani, M.M.: Piezometer measurements of prefabricated vertical drain improvement of soft soils under land reclamation fill. Eng. Geol. **162**, 33–42 (2013)
2. Cascone, E., Biondi, G.: A case study on soil settlements induced by preloading and vertical drains. Geotext. Geomembr. **38**, 51–67 (2013)
3. Indraratna, B., Rujikiatkamjorn, C., Ewers, B., Adams, M.: Class A prediction of the behavior of soft estuarine soil foundation stabilized by short vertical drains beneath a rail track. J. Geotech. Geoenviron. Eng. (2010). https://doi.org/10.1061/(ASCE)GT.1943-5606.0000270,686-696
4. Karim, M.R., Lo, S.C.: Estimation of the hydraulic conductivity of soils improved with vertical drains. Comput. Geotech. **63**, 299–305 (2015)
5. Karunaratne, G.P.: Prefabricated and electrical vertical drains for consolidation of soft clay. Geotext. Geomembr. **29**(4), 391–401 (2011)
6. Vu, V.: Optimal layout of prefabricated vertical drains. Int. J. Geomech. https://doi.org/10.1061/(ASCE)GM.1943-5622.0000434, 06014020 (2014)
7. Watabe, Y., Shinsha, H., Yoneya, H., Ko, C.: Description of partial sandy layers of dredged clay deposit using penetration resistance in installation of prefabricated vertical drains. Soils Found. **54**(5), 1006–1017 (2014)

8. Barron, R.A.: Consolidation of fine-grained soils by drain wells. Trans. ASCE **113**(2346), 718–754 (1948)
9. Abuel-Naga, H.M., Pender, M.J., Bergado, D.T.: Design curves of prefabricated vertical drains including smear and transition zones effects. Geotext. Geomembr. **32**, 1–9 (2012)
10. Bo, M.W.: Discharge capacity of prefabricated vertical drain and their field measurements. Geotext. Geomembr. **22**(1), 37–48 (2004)
11. Chai, J., Miura, N.: Investigation of factors affecting vertical drain behavior. J. Geotech. Eng. (1999). https://doi.org/10.1061/(ASCE)1090-0241(1999)125:3(216),216-226
12. Sathananthan, I., Indraratna, B., Rujikiatkamjorn, C.: Evaluation of smear zone extent surrounding mandrel driven vertical drains using the cavity expansion theory. Int. J. Geomech. **6**(355), 355–365 (2008). https://doi.org/10.1061/(ASCE)1532-3641(2008)8