Ground Soil Improvement Work for the Construction of Udaipur Station Yard in State of Tripura by Using Pre-fabricated Vertical Drains (PVDs)

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1.0 History

In connection with construction of New BG Line fromAgartala to Sabroom (111.8 km) in State of Tripura, Report on Pre-construction Survey and Geotechnical Investigation was submitted by RITES in May, 2011. The Project consists ten Stations and connects three districts of the Tripura state namely, Sipahijala, Gomati, and South Tripura. City Udaipur, a famous pilgrim place is the District Headquarter of Gomati District. Commissioning of the project has been planned in two phases, Phase-I:Agartala–Udaipur Section (44.11 km) in March 2016 and Phase-II, Udaipur-Sabroom Section (67.69 km). As per the Survey Report submitted by RITES, to avoid displacement of peoples from heavily populated urban area and involvement of thick Sal tree forest land,the Construction of Udaipur station yard has been proposed between km 41-43 and the site of construction has been shown as vacant and paddy land. In Geotechnical investigation of site carried out by RITES, it was concluded that the sub-soil in general are medium to good quality. The sub-soil is characterised by its very soft to soft/medium, silty clay layer below which a loose to medium dense and then dense silty land layer is existing. Further due to presence of poor quality soil up to 12.5m below existing ground level, deep foundation was recommended for the construction of structures in yard. However, no ground soil improvement work was recommended by RITES for the construction of 6.2 m high embankment.

Construction of Embankment on proposed site of Udaipur started on 20.12.2010without adopting any ground soil improvement work. Earthwork was completed approximately 80% in the Yard during March' 2012, for 4 lines including island platform between line no. 3 & 4 with average height from 5 m to 5.2 m from km 41.8 to 42.85. However during construction, failure of embankment was noticed first in September-2011 when embankment height was 3 m to 3.5 m, shear failure occurs on the edge of the embankment due to settlement and the heaving up of the ground soil up to 30 m from the Toe (Fig.-1). Last failure of embankment occurred on March-2012 and after that further earthwork was stopped.

Further geo-technical and hydrological investigation was carried out and it was found that the site of construction of Udaipur station yard is situated at low lying area. Earlier there was a lake, known as Sukhsagar. It is pounded throughout the year and during the monsoon the average height of water level rises to 3m to 4m above the original ground levels. Construction of Embankment has divided the pounded area (low lying area) in to two parts. Now water flows from upstream to downstream through km 41.90 and 42.400 opening provided in the Embankment. It was noted that apart from cracks in embankment, heaving up of ground level occurred up to 30 m from the toe of the Embankment.

RDSO, Lucknow was requested to visit the site in December 2012 and after having site visit, field & laboratory test, RDSO submitted their Consultancy Report on Rehabilitation of Unstable formation (from km 41.85 to km 42.80) at Udaipur Station Yard in Agartala-Udaipur-Sabroom, New B.G. line project, NFR in January 2014. Key Recommended of RDSO were are as given below:-

a) Construction of embankment, having slope of 4.5:1 for 3.1m height from GL (i.e. for lower half portion of embankment) and slope of 2.5:1 for rest 3.1m height of embankment (i.e. for upper half portion of embankment) with 26.5 m wider sub bank at 3.1m from top.
b) Construction of embankment should be carried out in stages with measurement of settlement & pore pressure. The recording should be done regularly during construction. Earthwork should be stopped when pore pressure ratio of sub soil exceeds beyond 0.7 or distressing of embankment noticed visually during construction until settlement stop and pore water pressure dissipates

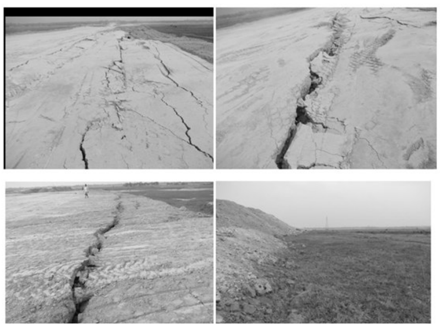

Fig.1: Photographs of Failed Embankment

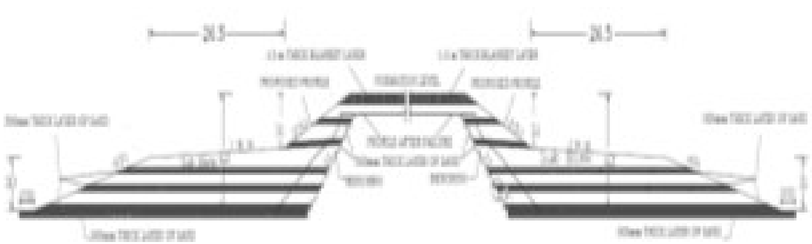

Fig. 2: Profile of Embankment and Sub-bank Recommended by RDSO

However, due to additional requirement of land for the construction of wide sub banks, more time required for stage construction, time constraint and to avoid large settlement of embankment in future.IIT, Guwahati was also requested to study the site conditionin June, 2014. After detail site investigation, IIT Guwahati submitted report in April 2015. Key recommendations of IIT Guwahati are given below:

a) The site comprises of 9-13 m of soft clay below the existing ground level (EGL). Suitable ground improvement measures need to be adopted prior to the embankment construction.
b) The existing embankment must be stripped off and should be rebuilt after implementing appropriate ground improvement scheme.
c) Owing to the time constraint of the project and unavailability of stone aggregate nearby to the site, using PVDwould be the feasible ground improvement measure.
d) It is recommended that stage-wise construction of embankment should be adopted by allowing sufficient time between each stage.
e) It is advised to develop the entire station yard area up to a height of 2 m before rising the railway embankment to full height.
f) Proper drainage, provision of berm and slope face protection measures should be adopted for the rebuilt embankment.

Accordingly, method for ground soil improvement work using prefabricated vertical drains (PVDs) for the construction of Udaipur Station yard has been adopted.The Details of use of PVDs for the construction of Udaipur yard are discussed below:

2.0 Prefabricated Vertical Drains (PVDs):

Prefabricated vertical drain (PVD) can be defined as any prefabricated material or product consisting of a synthetic filter jacket surrounding a plastic core. Because of their shape, they are also known as band or wick drains. Prefabricated vertical drains are commonly used to decrease the drainage path within soft soils to accelerate the time of primary consolidation. Prefabricated vertical drainsare artificially created drainage paths which can be installed by several methods and can have a variety of physical characteristics. The vertical drains can reduce settlements from years to months. Due to this reason, most settlement occurs during construction phase itself, and post-construction settlements are reduced to bare minimum.The details of PVD and schematic diagram showing its function is shown in Fig-3.

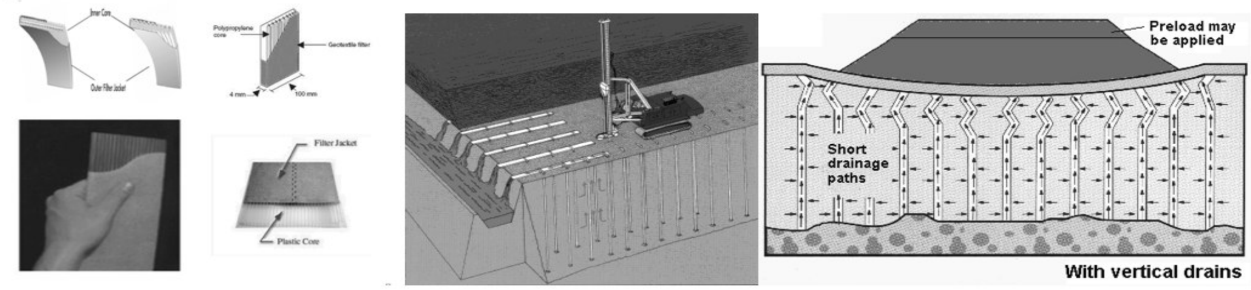

Fig. 3: Prefabricated Vertical Drain and its function

The stages of construction of embankment on soft soil using PVDs are as given below:

1. Site Clearance and Levelling.
2. Marking of Points.
3. Installation of PVDs.
4. Laying of Coarse sand.
5. Laying of Non-Woven Geo-textile
6. Laying of Granular Blanket
7. Installation of Instruments for Monitoring
8. Laying of Woven Geo-textile
9. Stage construction of embankment

Initially site was cleared from vegetation and any debris present. Top Slush layer of soil was removed and was back filled to provide firm platform for installation rig. The marking of point for installation of band drain shall be done as per the prior approved grid plan. At Udaipur triangular grid plan at a distance of 0.8 m has been adopted. The Fig.4 shows the clearing of site, marking of points and installation of PVD using hydraulic rig weighing 10 Tonne mounted on 30 Tonne base machine, a rectangular mandrel of size about 120 mmx 60mm (external dimension) having thickness of 8 mm was used to install PVDs.

Fig. 4: Site Clearance & Levelling, Marking of Points & Installation of PVDs

The section of the embankment used for the construction of 6.2 m high embankment is shown in Fig. 5. After the installation of PVDs 150 mm thick layer of coarse sand has been provided. Top of the PVD over the working level shall remain in this layer. Over the coarse sand non-woven geo-textile has been provided thereafter 300 mm thickness granular material confirming to Table 300-3 of MORT&H Specifications (Class III preferred for fast drainage) has been provided. A layer of Woven geotextile has been placed at the top of the granular blanket layer to prevent the intrusion of surcharge earth to the granular blanket layer. Fig. 6 shows the sequence of work executed in the field after installation of PVDs.

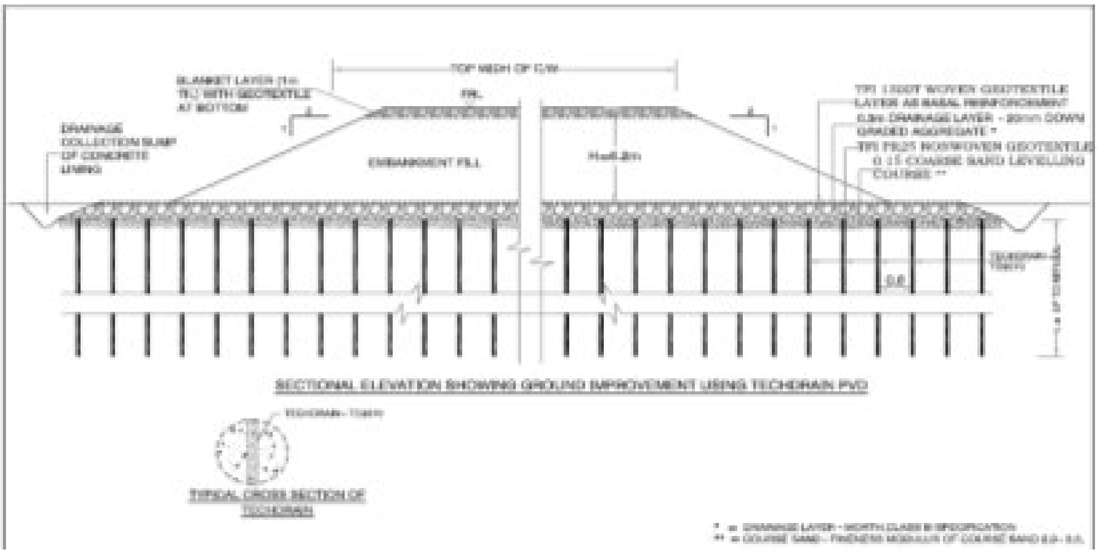

Fig. 5: Schematic Diagram Showing Section of Embankment construction at Udaipur

Fig. 6:Sequence of work after installation of PVD.
a) Laying of Coarse sand.
b) Laying of Non-Woven Geo-textile.
c) Laying of Granular Blanket. d) Laying of Woven Geo-textile.
e & f) Stage construction of embankment.

For the monitoring of the ground soil improvement scheme, following instruments have been provided:

1. Piezometers – Casegranade Type/Porous Tube
2. Settlement Recorders – Plate Type.

Casagrande type piezometer is basically a porous tube connected with the stand pipe. The pore pressure variation is measured by measuring the variation water level in the stand pipe. The pore pressure variation is measured by measuring the variation in water level in stand pipe. To measure the water level in stand pipe electronic water level indicator (electrical sounding device) shall be used. The recorder sounds beep when the tip of this recorder touches the water level in the stand pipe. The depth can be directly measured with a special non expandable measuring tape attached to this recorder

The Plate type settlement recorder is being used for measuring the settlement of virgin soft soil in which a pipe is connected to a square base plate made of mild steel. The size of the base plate has been kept as 400 mm x 400 mm x 10 mm thick and the same is to be placed on the virgin ground. Fig. 7 shows Casagrande type piezometer and settlement recorder used in the field.

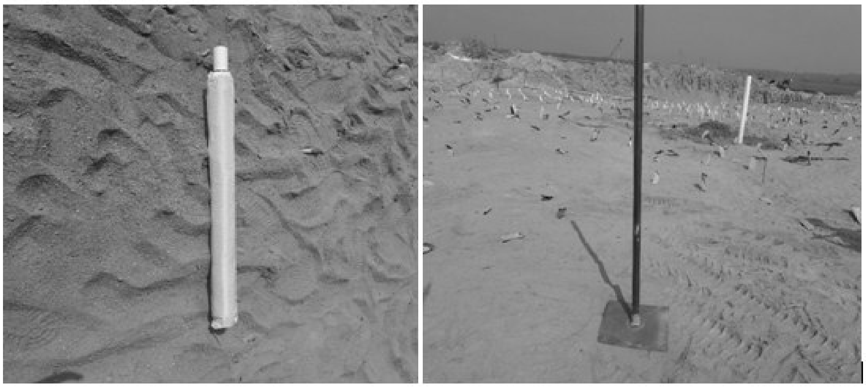

Fig. 7: Casagrande type Piezometer & Plate type Settlement Recorder

The construction of embankment by using PVDs for ground soil improvement at Udaipur Station yard of Agartala-sabroom New Line project is in progress, the original soil parameters and design details for the use of PVDs are discussed below:

3.0. Design Calculation for Udaipur Station Yard

3.1 Original Soil Parameter

Depth of of soft Clay (H)	13.25 m
Average Density of soft soil (γ_f)	16.34 KN/m^3
Drainage path (Single Drainage)	13.25 m
Coefficient of vertical consolidation (C_v) [Assumed] (Assumed)	4.39 x 10^{-4} cm^2/sec
	1.3835 m^2/year
Coefficient of horizontal consolidation (C_h)	6.58 x 10^{-4} cm^2/sec
	2.075 m^2/year
Average degree of consolidation	95 %
Ch /Cv ratio of the soil	1.5
Cohesion	0.04 kg/cm^2 (4.00 kPa)
Angle of Internal Friction	19^o

Embankment Parameters:

Density of Embankment (γ)	19 kN/m^3
Height of Surcharge (h)	2.5 m

3.2 For Virgin Soil

a) Safe Bearing Capacity

Ultimate Bearing capacity , qult	=	c x Nc	
Where, c = Avg. Cohesion of soil layer	=	4.00	kN/m^2
Nc = Bearing capacity factor	=	5.14	
Hence, Ultimate Bearing capacity, qult	=	20.56	kN/m^2
Safe Bearing capacity, qsafe	=	qult / FoS	
Where, FoS = Factor of Safety	=	2.5	
Hence, Safe Bearing capacity, qsafe	=	8.22	kN/m^2
Pressure intensity to be supported (of Embankement)	=	141.8	kN/m^2

Hence, Ground Improvement is required.

b) Settlement of Soft Clay

Settlement of the soft clay layer is calculated as $\delta = \frac{C_c}{1+e_0} \times H \times \log\left(\frac{P_0 + \delta P}{P_0}\right)$

Where,

Thickness of soft clay layer, H	=	13.25	m
Compression index, Cc	=	0.25	
Initial void ratio, e_0	=	0.69	
Initial overburden pressure, P_0	=	γ_{sub} x H/2	
	=	43.26	kN/m2
Increament in pressure, δ_P	=	141.8	kN/m2
Hence, total settlement of the layer, δ	=	1.242	m
	=	1242	mm

C) Time for 95% Consolidation:

Average depth of soft soil layer is 13.25 m.

Single drainage has been considered as the bottom layer of gravel and weathered. $t = \frac{T_v H^2}{C_v}$

Where, T_v = dimensionless time factor for degree of consolidation

C_v = coefficient of vertical consolidation

= 1.3835m²/year

H = drainage path = 13.25 m for single drainage

Time required for 95% degree of consolidation,

T_v = 1.127

$$t = \frac{1.127 x 13.25^2}{1.3835}$$

$$t = 14292\_Years$$

$$t = 51199\_days$$

Required days are 51199; therefore there is a need to consider other option to expedite the consolidation of soil. Prefabricated vertical drain may be used to minimize the number of days required for 95 % consolidation. The details of

3.3 By Using PVD

Drain Properties:

Width of TechDrain (PVD), a = 100.0 mm

Thickness of TechDrain, b = 4.00 mm

Equivalent diameter of PVD $d_w = 2(a+b)/\pi$

d_w = 66.21 mm

3.3.1 Computation of Time Period for 95% Consolidation:

With **0.8m** Spacing:

Degree of consolidation required, U	= 95
Spacing of PVD, S	= 0.8 mt.
Pattern of installation	= Triangular
Hence, Area treated by single band drain, A	= 0.866 x S^2
	= 0.554 m^2
Equivalent diameter of cylindrical column, D	= 2 * sqrt (A / π)
	= 0.84 m
Equivalent diameter of band drain, d	= 2 * (b + t) / π
	= 66.21 mm
	= 0.067 m

Time period for consolidation is calculated as per HANSBO's equation,

$$t = \frac{D^2}{8 c_h}[F(n) + F(s) + F(r)] \ln \frac{1}{1-U_h}$$

Where,

$$F(n) = \ln\left[\frac{D}{d_w}\right] - \frac{3}{4} \quad F_s = \left[\left(\frac{k_h}{k_s}\right) - 1\right] \ln\left(\frac{d_s}{d_w}\right) \quad F_r = \pi z (L - z) \frac{k_h}{q_w}$$

Hence using above equation,

Hence, time period for consolidation, t =0.0425 * [1.78+0.34+0]*2.9957

= 0.27 yrs.

= 3.31 months

=100 days for 95% Consolidation

3.3.2 Stage wise construction and corresponding Settlement

Height of embankment, m	P_0, kPa[H/2*6.53]	δP, kPa [(Δh*19)+24]	No of Days	Settlement due to load with time, mm	Cumulative Settlement, mm	Time* period, days	Uh	Cumulative settlement, m (achievable)	U
0	43.26	0.00	0	0.00	0.00	0	0.00	0.00	0
0.5	43.26	33.50	20	0.488	0.488	20	0.45	0.22	17.75
1	43.26	43.00	20	0.099	0.587	40	0.70	0.42	33.71
1.5	43.26	52.50	20	0.089	0.676	60	0.84	0.56	45.37
2	43.26	62.00	20	0.081	0.756	80	0.91	0.69	55.67
2.5	43.26	71.50	20	0.074	0.831	100	0.95	0.79	63.76
6.2	43.26	141.80		0.407	1.238	**			

* Considering 20 days of time period after execution of each stage of 0.5m height.

3.3.3 Construction Plan for Embankment:

From the above following construction plan for the 6.2 m heigh embankment has been proposed:

Stage	Height of embankment, in m	Time Required for Stage	Cumulative Time in days	Corresponding degree of consolidation after Completion of each stage
1	0.5	20	20	0.45
2	1	20	40	0.7
3	1.5	20	60	0.84
4	2	20	80	0.91
5	2.5	20	100	0.95
6	6.2	-	-	**

** As per PVD calculation mentioned above, at 100 days - 95% of consolidation will be achieved. Hence, No waiting period is necessary after 95% of consolidation (i.e. 100 days).

Stage wise construction and corresponding gain in bearing capacity:
Gain in strength due to consolidation* = k x U x δs
Where, k = 0.11 + 0.0037 x PI

PI = 18

Hence, k = 0.1766

Density of embankment = 19 kN/m^2

No of days in above table is considered as total time required for execution and waiting period for each stage. After completion of days given for each stage, next stage of execution (increase in embankment height) shall be started

3.3.4 Gain in Shear Strength and Factor of Safety during Stage Construction:

Height of embankment, (m)	No of Days	Corresponding degree of consolidation	Initial Cohesion, (kPa)	Increased pressure δP [due to DL (kPa)	Gain in Cohesion value	Final Cohesion, kPa	Bearing Capacity of soil, in kN/m^2	FoS
0	0	0	4	0	0	4	20.6	-
0.5	20	45	4	9.5	0.75	4.75	24.4	2.57
1	20	71	4	19	2.38	6.38	32.8	1.73
1.5	20	83	4	28.5	4.18	8.18	42	1.47
2	20	91	4	38	6.11	10.11	51.9	1.37
2.5	20	95	4	47.5	7.97	11.97	61.5	1.3

* K = 0.11 + 0.0037x PI is Skempton expression to determine constant kto used for the relation of undrained shear strength and effective overburden pressure. [Reference: Advance soil mechanics by Braja M Das, Table 7.5, pg 449]. The expression is for normally consolidated clay. Hence, for intermediate partly achieved consolidation stage, the gain in shear strength shall be k x Ux δs

The overall stability is also checked for maximum height of embankment, i.e. 6.2m and for intermediate heights during construction, with increased shear parameters, at corresponding degrees of consolidation. The analysis has been carried out by using Software Reinforced Slope Stability Analysis, ADAMA Engineering, Inc. The FoS as achieved through analysis are tabulated below.

Height of embankment, (m)	FoS Global Stability, Static Condition	FoS Global Stability, Seismic Condition
6.2	1.58	1.08
2.5	3.38	1.72
2.0	3.91	1.83
1.5	4.99	1.74
1.0	8.40	1.94
0.5	24.78	1.85

4.0 Conclusion:

With the use of prefabricated vertical drains, the time required for the construction of embankment has been reduced considerably at Udaipur yard. The construction of embankment after installation of PVDs at Udaipur Station yard has already been started. Instrumentation and Monitoring with settlement gauges and piezometers are being done as per the methodology and design and a comparison of the final settlement obtained is to be made with the anticipated settlement considered while designing. Detailed analysis of settlement data, pore pressure dissipation, gain in shear strength are to be done and a comparison statement shall be prepared for these against the initial values calculated/assumed during design stage and thus performance and functioning of PVD shall be evaluated based on the comparison statement after completing the stage construction of embankment.

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