Ground Improvement Using Pvds and High Strength Geogrid for Railway Project

Sukrati Pandit, Sonal Kulkarni, Ratnakar R. Mahajan, and Raman Singla

Abstract India and Bangladesh have commenced the development of the Agartala-Akhaura railway initiative to enhance railway connectivity between the two nations. This project, initially envisioned in 2010, gained momentum when India and Bangladesh entered into a Memorandum of Understanding (MoU) in 2013, addressing various issues, including this railway project. Spanning 15 km in the west Tripura district, this railway will link Akhaura in Bangladesh with Agartala, the capital city of Tripura, via Nischintapur situated along the Indo-Bangla border. IRCON, a central PSU of the Indian government has been working in close collaboration for this prestigious project. Project authorities faced challenges pertaining to the construction of rail embankments at peculiar chainages due to the presence of weak soft clayey soils with some decomposed wood, which extended up to greater depth. The soil strata were found to be susceptible to low bearing capacity and excessive settlement causing deep seated foundation failure. Construction of railway tracks with heavy axle load demands well compacted substrata with bearing capacity or in other ways, higher load carrying capacity and the consolidation settlements lying within the permissible limit. In light of this, Prefabricated Vertical Drains (PVD) with basal reinforcement of high strength geogrid as a suitable ground improvement solution to improve the soft soil and to facilitate the construction of embankment is provided. The deep ground improvement solution of PVD & basal reinforcement not only lessens the differential settlements but also enhances the bearing capacity. This paper presents the challenges faced during the execution of the project along with the design philosophy involving geosynthetics for ground improvement.

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1 Introduction

Using prefabricated vertical drains (known as PVD, wick drains, or band drains) can speed up the settling process and shorten the time needed from years to months for consolidating soft cohesive soils. The majority of settling takes place during construction, which helps minimize post-construction settlement.

The drainage system of PVD features a flexible core that facilitates unhindered water movement both along and/or across it. Its filter consists of a non-woven geotextile with a distinct distribution of pore sizes. The materials utilized in crafting the drain core and filter include polyester, polyamide, polypropylene, polyethylene, and various other natural polymeric substances, either individually or in combination.

Agartala-Akhaura rail project, is one of the prestigious projects of approx. 15 km railway connectivity from Agartala, India to Akhaura, Bangladesh via Indo-Bangla border. It was planned to construct the railway track with embankments at different locations. From chainage Ch 3 + 900 to Ch 5 + 100, the stratum was found to be very weak soft clayey soils with some decomposed wood, which extends up to greater depth, hence requiring the ground improvement for carrying out the construction of railway embankment.

IRCON approached M/s Maccaferri Environmental Solutions Pvt. Ltd. to carry out the detailed design for the ground improvement from Ch 3 + 900 to Ch 5 + 100.

The main problems associated with the soft clayey soils were low bearing capacity, excessive settlement, and deep seated foundation failure (shown in Fig. 1). The bearing capacity observed for the locations was very low. Hence, ground improvement for increasing its bearing capacity or in other ways for increasing its load carrying capacity and reducing the consolidation settlement was required.

Considering the weak, compressible foundation strata, and discussions with IRCON and NIT Agartala, it was suggested to provide PVD with Embankment Reinforcement with high strength geogrid Paralink as the ground improvement solution.

Due to land acquisition issues, two different embankments were proposed and decided to merge at the end.

In this paper, a case history involving the use of PVDs for increasing the load carrying capacity of the subsoil and reducing its consolidation settlement is presented.

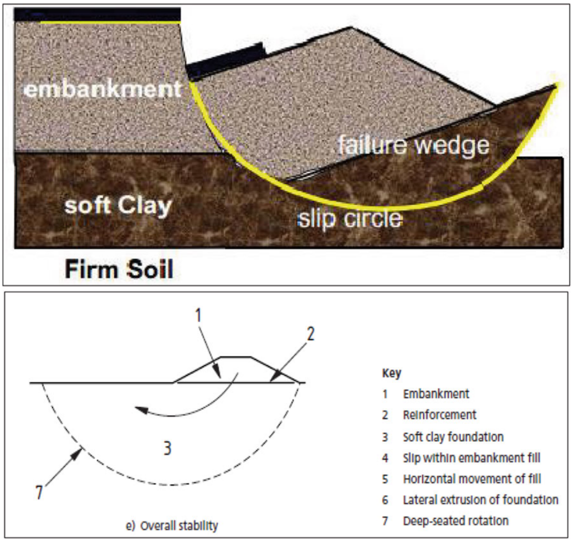

Fig. 1 Deep seated foundation and embankment failure

2 Site and Soil Conditions

In the vicinity of Agartala town, the surface layer comprises predominantly of loamy sands, clay loam, and loam, originating from colluvial and fluvial sediments from the Quaternary period, overlaying the Pliestocene formation. These sediments, known as Dupitila sediments, cover a significant portion of the region, including high lands and small mounds.

The stratification is characterized by loosely packed, unconsolidated materials such as sand, silt, clay, and sandy clay, primarily found in riverbeds and floodplains. These sedimentary layers are predominantly composed of deposits transported by rivers and form a blanket-like covering over the Dupitila rock group in this locality.

The primary lithological composition of this unit comprises coarse, medium, and fine sands, ranging in color from gray to white. Gray to dark brown sands is notably prevalent in the Haora River valley.

The initial stratum comprises of a gray, extremely soft sandy silty clay infused with decomposed material, extending just beneath the surface. Above it lies a second layer of blackish and dark gray, ranging from very soft to moderately sandy silty clay, also containing decomposed matter. Following this, the third layer is characterized by a gray clayey silty sand, while the fourth layer transitions into a darker gray, medium clayey silty sand.

The natural moisture content is found to be approx. 40% reasonably uniform across the site and the liquid limit lies between 20 and 53%. Plasticity index lies between 4 and 26% Void ratio is found to be greater than 1. Ground water level is observed to be at ground level.

3 Details of Proposed Solution

I. Application of Prefabricated Vertical Drain (PVD) along with its advantages

Using prefabricated vertical drains (known as PVD, wick drains, or band drains) can speed up the settling process and shorten the time needed from years to months for consolidating soft cohesive soils. The majority of settling takes place during construction, which helps minimize post-construction settlement. Typical vertical drains are the non-displacement band drain type of nominal width 100 mm and 4–7 mm thick as per MORTH.

The drainage system of PVD features a flexible core that facilitates unhindered water movement both along and/or across it. Its filter consists of a non-woven geotextile with a distinct distribution of pore sizes. The materials utilized in crafting the drain core and filter include polyester, polyamide, polypropylene, polyethylene, and various other natural polymeric substances, either individually or in combination.

A Typical PVD is shown in Fig. 2.

Consolidation in a compressible soil happens when water is pushed out of the soil pores. The duration of consolidation relies on the square of the distance the water needs to traverse to leave the soil. Introducing PVD reduces the drainage route length for water to escape the soil. Geocomposite drains, available as sheets or strips, are employed for vertical or horizontal water expulsion at the surface, substituting


Fig. 2 Prefabricated drains

traditional sand or gravel drainage methods. These geocomposite drains are more cost-effective, simpler and faster to install, and offer improved drainage capabilities.

PVDs are made of two main components, one is the core, and another is the filter geotextile (also known as filter jacket). These both components have their specific function to increase the consolidation rate. Functions of filter jacket include the prevention of soil particles entering the drainage core and allowing the water to flow in, to provide cover to internal drain flow.

The core serves several functions, such as creating an internal pathway for water flow within the drain, offering structural support to the filter jacket, and preventing the drain from experiencing stretching or buckling along its length.

The general purposes of PVDs encompass:

- Speeding up settlement processes
- Minimizing the duration required for consolidation
- Preventing settlements after construction is completed.

Core configuration:

PVDs are classified according to the configuration of their core. Typical PVD available in market is shown in Fig. 3.

II. High strength uniaxial geogrid (Paralink)

Designing and building embankments over soft soil presents numerous challenges. Constructing embankments on soft clay or organic peat poses particular difficulties due to their minimal strength and significant compressibility. When confronted with the task of erecting an embankment on a soft subsoil, various issues arise:

- Soft subsoil failure of in shear (failure in bearing capacity)
- Stability of embankment (lateral sliding & rotational stability)
- High compressibility and settlement of embankment (settlement).

To reduce the subsoil stresses and improvement in drainage, replacement of poor subsoil with good quality granular soil is recommended, use of geosynthetic reinforcement at the base of the embankment should be carried out. Construction of a basal platform to spread the loading on the ground prevents base failure and may reduce settlements.

ParaLink (as shown in Fig. 4) is a high strength geogrid manufactured from high tenacity polyester yarns. The bundle of polyester yarns is co-extruded with polyethylene to form the individual polymeric strip. A uniaxial arrangement of these strips connected to each other at intermittent intervals by polyethylene strips forms the geometry of the geogrid. ParaLink is used as an embankment reinforcement element. Geogrid has been used to increase the bearing capacity of poor foundation soils in different ways as per Koerner [2].

Fig. 3 Typical prefabricated vertical drain (Publication No. FHWA-NHI-16–027)

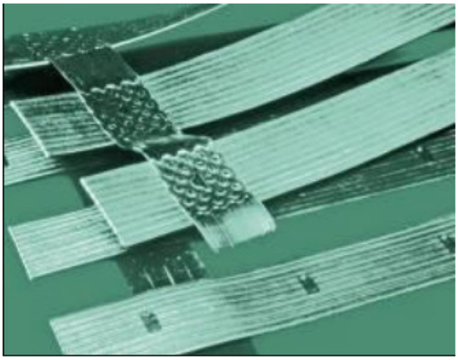

Fig. 4 High strength uniaxial geogrid (Paralink)

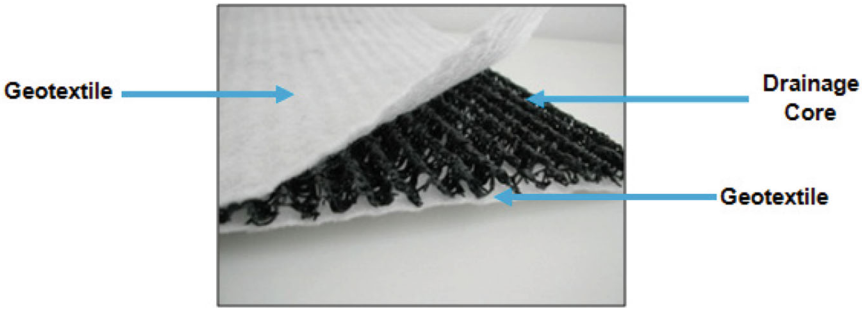

Fig. 5 Geocomposite drain (MacDrain)

III. Geocomposite drain (MacDrain)

When constructing embankments on unstable or fine-grained subsoils, such as soft clays, with a high water table, it is advisable to include a separator and drainage layer.

Due to the unavailability of good quality sand, gravel & aggregate for the drainage layer, geocomposite drain as a drainage layer was designed to provide appropriate drainage path for the water coming from subsoil (dissipating excess pore water pressure).

Geocomposite drains which can be sheets or strips are used for vertical or horizontal water removal at the surface replacing the conventional sand or gravel drainage as shown in Fig. 5. The geocomposite drains are less expensive, easy & quick to install, and provide better drainage.

4 Design Procedure and Design Considerations

a. Soil parameters used for the design & results obtained from maccaferri's design proposal are listed

See (Table 1)

b. Design procedure followed is listed

Design has been carried out targeting 95% of consolidation. PVD was designed as per IRC 75 provisions considering a width of 100 mm thickness of 4 mm and triangular spacing of 1 m. Ratio of coefficients of vertical and horizontal consolidation of 2 has been considered. Hansbo's equation was used to calculate the time required for the consolidation.

Table 1 Design considerations from Maccaferri's design proposal

Parameter	Ch 4 + 100	Ch 4 + 450	Ch 4 + 720
Max. height of embankment	6 m	6 m	6 m
Time required for consolidation without ground improvement (days)	189,306.973	20,705.4501	21,345.9039
Max. height of embankment (Preloading)	9 m	6 m	6 m
Depth of PVD	15 m	7.5 m	6 m
Coefficient of consolidation (C_v) $\frac{m^2}{yr}$	0.772	1.766	0.750
Time required for consolidation (days)	300	100	201
Settlement before consolidation process	1660 mm	729 mm	478 mm
Settlement after consolidation process	16.6 mm	21.87 mm	23.90 mm
Required bearing capacity $\frac{kN}{m^2}$	202	202	190
FOS against bearing capacity after consolidation process	1.59	2.00	1.78

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

For constructing high embankments on soft soils, in many cases ground may not have sufficient bearing capacity and it may have to undergo large amount of settlements. Design for the project has been carried out considering initial bearing capacity and accordingly, first stage loading has been designed. Next stage loading is designed considering the gain in shear strength due to previous loading and targeting lower factor of safety of 1.5. Gain in shear strength is calculated as per Skemptons formula mentioned in HRB SR No 13.

The integration of geosynthetic reinforcement into the foundation significantly improves embankment performance by countering shear failure within both the embankment and the soft soil. Basal reinforcement serves to stabilize an embankment situated on soft ground by inhibiting lateral spreading of the fill, foundation extrusion, and rotational failure. This stabilization is achieved as the reinforcement undergoes tension from shear stresses transmitted by the foundation soil and fill. Additionally, it has been observed that the reinforcement can mitigate some degree of differential settlement by facilitating a more even stress distribution across the soft soil [8]. Rotational stability of the embankment was carried out using method of slices. The tensile force required for rotational stability of embankment is determined from method of slices and this shall be long-term design tensile strength of reinforcement as per cl. 3.1, IRC: 11 3–2013. The calculation of the required strength for Paralink was performed according to the method contained in IRC 113. The details of paralink (basal reinforcement) obtained from Maccaferri's design proposal are listed below (Table 2).

The typical solution sketch for ground improvement is presented in Fig. 6.

Table 2 Details of Paralink applicability of designs from Maccaferri's design proposal

Parameters	Ch 3 + 700 to Ch 4 + 400	Ch 4 + 400 to Ch 4 + 700	Ch 4 + 700 to Ch 5 + 100
Borehole data referred	Ch 4 + 100	Ch 4 + 450	Ch 4 + 720
Paralink type (kN/m)	500	600	700
LTDS of Paralink (kN/m)	286.1	343.3	404.5

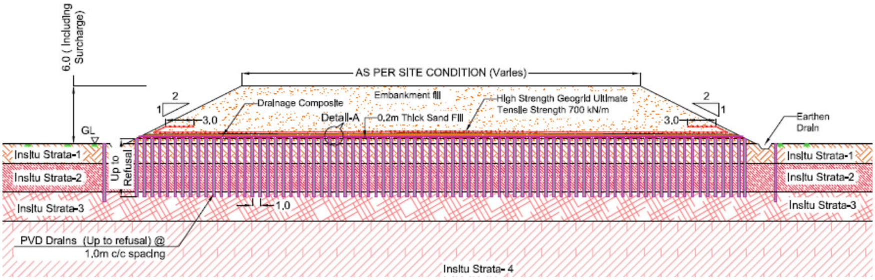

Fig. 6 Cross section of ground improvement for railway track

5 Construction Sequence

1. Installation of PVDs

2. Installation of geo-composite & application of surcharge loading

3. Installation of Paralink & placement of fill material as per approved drawings

6 Instrumentation Installation Guidelines

To examine how compressible soils respond to reclaimed fill, it's advised to employ geotechnical field instruments such as piezometers and settlement gauges for monitoring the consolidation behavior of the underlying soils. In this project, we employed field instruments like piezometers and settlement gauges to investigate the consolidation behavior of the underlying soils.

Installation was carried out as per the guidelines of the instrument manufacturing agency and approved drawings or engineer in charge. IRC 75 was referred for instrumentation details.

The installation of drainage systems was synchronized with the positioning of geotechnical monitoring devices. Extra caution was exercised to ensure that the installation of drains didn't disrupt any existing instrumentation.

7 Conclusion

In the area where the embankment is situated, the subsoil comprises dark-colored, soft silty clay containing decomposed material, reaching depths of up to 11 m. Designing structures on such soft, compressible clay soils has historically posed challenges for civil engineers. Constructing without appropriate soil treatment is typically unfeasible due to the unpredictable nature of long-term settlement. While surcharging can elevate pore water pressure, settling may still occur over a significant period, often spanning several years, as water encounters difficulty in finding pathways to exit the soil. PVDs are an effective way to increase the consolidation settlement within a short duration of time. The papers discussed about the ground improvement solution using PVDs & high strength geogrid for railway project. The consolidation time has been drastically reduced from 189,306 days to 300 days.

A scheme of PVD for accelerating consolidation of soft soil & layer of high strength geogrid for rotational stability has been provided. Preloading embankment heights varying from 6 to 9 m were proposed for a duration of 4 months. During this time, consolidation of soft soil occurred.

In order to minimize differential settlements and maximum stress acting on the base, a basal reinforcement system was provided using high stiffness-high strength geogrid named as ParaLink. Basal reinforcement provided additional rotational stability and load distribution.

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