Efficient sub-surface Drainage in Reinforced Soil Structures through use of Multi Linear Geocomposite

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ABSTRACT: This paper presents a case study of using Multi-Linear Geocomposite DrainTube® as a sub-surface drainage system in the rehabilitation of a Reinforced Soil Structure (RSS) structure in Himachal Pradesh, India. The project, originally completed in 2019, partially collapsed during the monsoon in 2022 due to inadequate drainage. Rehabilitation was completed in 2023, and the structure has since performed satisfactorily. This study highlights the importance of proper drainage in Reinforced Soil Structures, demonstrating the advantages of the selected geocomposite solution for ensuring optimal conditions for a dry reinforced soil in compliance with design parameters.

KEYOWRDS: Drainage, DrainTube®, geocomposites, rehabilitation, Reinforced Soil Structures.

1 INTRODUCTION

Reinforced Soil structures (RSS) are composite structures consisting of alternating layers of compacted backfill and soil reinforcement elements that are connected to a facing. The stability of RSS is derived from the interaction between the backfill and soil reinforcements, involving friction and tension. When compared to traditional RCC retaining structures, superior performance, and significant direct and indirect cost savings that can be realized when this technology is used have resulted in its widespread adoption around the world.

Design as well as execution of RSS plays an important role in the stability of the system. Sometimes due to improper backfill material (which has high plastic fines), a well-designed structure might suffer failure. A study conducted by Koerner & Koerner [1] showed that 61% of wall failure are due to the placement of silt and/or clay type of soils. The design of RSS is based on the free draining backfill and they are not designed for any pore water pressure developed due to the presence of water. [2, 3]. The major issue associated with using such fine-grained material as a backfill is that they have low to extremely low hydraulic conductivity.

The soil reinforcement experiences higher loads when positive pore water pressures develop. Prevention of the formation of adverse pore water pressures in reinforced backfill walls are achieved by the installation of sufficient drainage systems. Multi-linear drainage geocomposites, such as DrainTube®, offer a high-performance and flexible sub-surface drainage solution. Characterized by high transmissivity and creep resistance, DrainTube® serves as an efficient alternative to conventional drainage galleries. Its notable advantages include high discharge capacity and effective filtration and separation under sustained high normal pressure throughout the design life of the RSS.

In this paper, we analyse the implementation of a multi-linear drainage geocomposites (DrainTube®) in the rehabilitation of an MSE structure in Himachal Pradesh, India.

2 FINDINGS

The project was originally completed in 2019 as part of a road joining Solan to Kalka. The height of the wall was around 21 m, and it was built with the wrap around geogrids with no facia. This structure experienced a failure at the onset of heavy rains in June 2022.

To establish the probable causes for failure, a site reconnaissance was done. After visiting the site, the major cause for the failure anticipated was the improper drainage, inferior backfill used while constructing the wall. Ingress of water during monsoons, in-side such systems accelerate the chances of failure. These issues lead to a global failure of the structure. The picture of the failed structure is shown in Figure 1. The authorities had to close the road for the normal traffic. However, the other section of road was intact, and it was functional for normal traffic.

Figure 1. Image of the failure of the wall section after the 2022 monsoon.

The condition of remaining existing structure was deteriorating, and im-mediate rectification was needed. Thus, a method was required which can rehabilitated the existing structure and which could be constructed at a faster rate to save time and thus, saving money associated with time.

3 METHODOLOGY

3.1 *Description of the RSS rehabilitation project*

Dismantling the existing wall at the site is a tedious and time-consuming task, involving the removal of flexible pavement, fascia panels, and reinforcement. For the construction of a nearly 22-meter-high wall, a strap length of 15 meters (0.7 times the height) would be required to be placed at the base of the structure. Cutting into the existing stable embankment to lay such long straps would have compromised the stability of the hill above and necessitated the closure of a portion of the existing road, which was in use by traffic. Therefore, a rectification method was employed to construct the new structure.

The rectification work involved the use of galvanized solid soil nails, termed TerraNail®, to strengthen the existing embankment. Over this distressed wall a new shored reinforced soil structure, TerraLink®, was constructed. New structure of height 7m was constructed with flexible welded wire mesh facia and geosynthetics strap reinforcements (Geo-Strap®) as soil reinforcement.

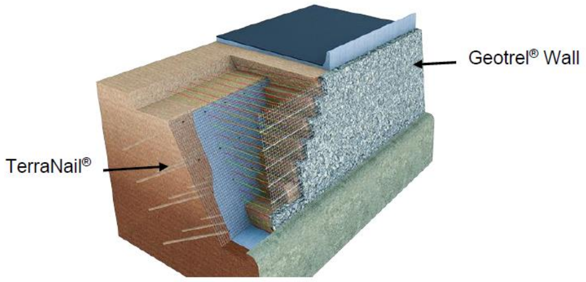

Figure 2. Image of the failure of the wall section after the 2022 monsoon.

For TerraLink®, the design objective is to develop a soil nailing layout to address the postulated failure mechanisms. Each nail must also be capable of resisting local stresses acting on it. The relevant modes of failure for stability analysis include rotational failure, either partially or totally through the soil nail block, which involves breakage and/or pull-out of soil nails. Bishop's slip circle method was adopted to assess these failure mechanisms.

Since the back face is sufficiently strengthened with TerraNail®, there are no disturbing forces acting on the TerraLink® structure. Consequently, the TerraLink® structure has been designed as an independent slope mass without considering earth pressure behind it. Soil reinforcement was provided based on the minimum required strength, and overall stability was verified accordingly. The total force mobilized in the high-adherence GeoStrap® soil reinforcement is transferred to the soil nails through a direct connection mechanism. The soil reinforcement is directly connected to the nail heads, and nail pull-out resistance has been checked for long-term design conditions.

The TerraLink® connection system involves placing additional soil reinforcements between the reinforcement layers of the Reinforced Earth® structure from the back face. These are mechanically connected to the soil nails installed in the existing hill slope structure.

3.2 *Multi Linear drainage geocomposite system*

A freely draining, frictional material is specified for use as the technical backfill material in RSS. The free-draining property of the backfill material is crucial in ensuring that hydrostatic pressure does not develop within the structure. When RSS is constructed in areas characterized by hilly terrain, it becomes very important to supplement the free draining backfill material with an efficient sub-surface drainage system that can quickly drain out the discharge corresponding to high precipitation or heavy seepage events.

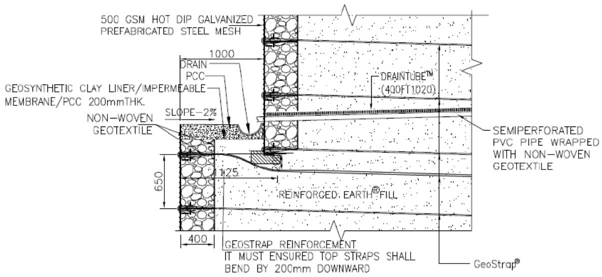

Figure 3. Detail drawing of drainage system

Given the case, with the presence of monsoons, a drainage system was implemented using a multi-linear geocomposite, DrainTube®.Multi-Linear drainage geocomposites are ''manufactured products composed of a series of parallel single drainage conduits regularly spaced across the width sandwiched between two or more geosynthetics'' as per ASTM D4439. DrainTube® is a Multi-Linear drainage geocomposite using perforated corrugated mini-pipes made in polypropylene as drainage conduits and highly designed non-woven needle punched geotextiles for filtration/separation (Figure 4).

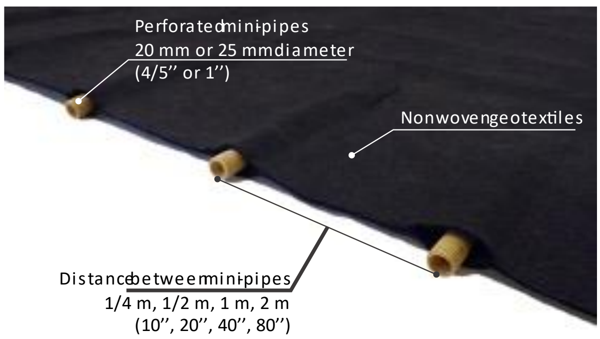

Figure 4. Composition of DrainTube®

The main characteristic of the product is that it keeps its drainage capacity over time even under high load. Figure 5 shows the transmissivity of the product measured for loads between 24 kPa and 2400 kPa at several gradients. It can be observed that the product is not load sensitive when confined under a soil layer.

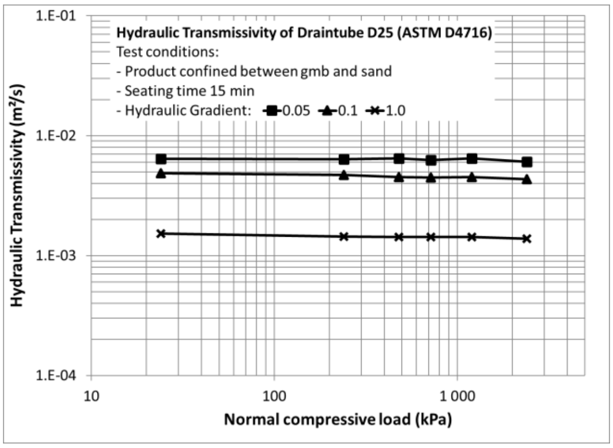

Figure 5. Hydraulic transmissivity of the Draintube multi-linear drainage geocomposite for several loads.

Figure 6 presents the variation over time of the transmissivity of the geocomposite under 2400 kPa for 1000 hours. Again, no variation of the transmissivity is observed. Unlike other geocomposites, the multi-linear geocomposite is not sensitive to creep in compression when confined under a soil layer.

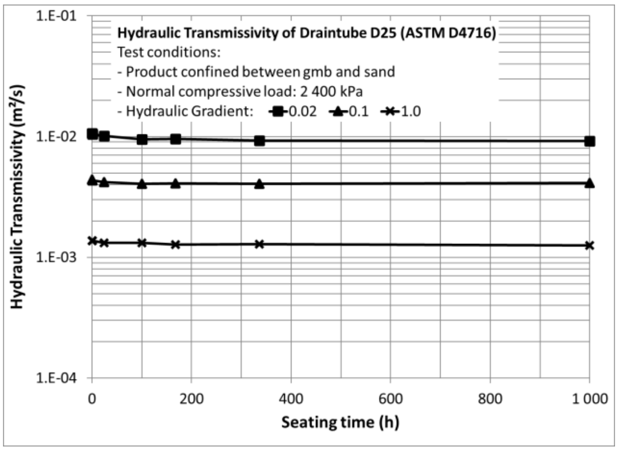

Figure 6. Hydraulic transmissivity of the Draintube multi-linear drainage geocomposite under load and over time.

This resistance to creep in compression is specific to this multi-linear geocomposite. It is documented by Saunier et al. and in the ASTM D7931 Standard Guide for specifying drainage geocomposites and make this geocomposite adapted for mining projects like for base dam drainage, and for civil projects like drainage of highway's foundations or MSE Walls at the base, in the interlifts and on the cut-slope.

3.3 *Drainage design*

There is a linear relationship between the distance between the mini-pipes in the DRAINTUBE product and its in-plane flow rate (or Transmissivity), so the product is selected as a function of the required flow capacity (or Transmissivity) determined from the project specific conditions.

Afitex Group has developed a software for the design of geosynthetics used in drainage applications. The software, named Lymphea, assists designers in the hydraulic selection of drainage geocomposites as well as granular drainage layers using site-specific conditions. It is based on formulas and calculation methods well recognized by the geosynthetics drainage industry and it also includes the ability to design multi-linear drainage geocomposites. Lymphea software allows for a wide range of parameters to be determined to better adapt to the site-specific requirements. Considering its usage throughout the world, it also works in both ISO and ASTM environments, using either SI or US units.

The software is based on a previous model developed with LIRIGM university research laboratory at the University of Grenoble (France) and CEREMA (formerly Laboratoire Regional des Ponts et Chaussées de Nancy). It has been updated and improved with the contribution of the SAGEOS (CTT Group, Quebec), the CEGEP of Saint-Hyacinthe (Quebec), and the University of Saskatchewan (USASK) in Alberta (Fourmont et al.). This software is free and available online on request.

Considering the RSS project, Lymphéa has been used to calculate the performance of DRAINTUBE® 400 FT1 D20 to act as a drainage system into the reinforced structure. The parameters chosen are the followings:

- Slope = 2%
- Drainage length = 15,1 m (the maximum length in the design)

It is shown on Figure 7 that DrainTube® 400 FT1 D20 can drain a long term flow of minimum 2.00E-6 m/s (or 1.73 m3 of water per day) per meter of width with a saturation of the mini-pipes of 6%.

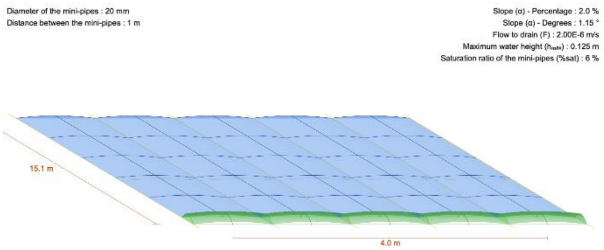

Figure 7. Lymphéa's Calculation sheet for RSS.

3.4 *Multi-Linear drainage geocomposite installation and monitoring*

The geocomposite is installed in a similar way than a thick geotextile. Rolls are lighter than other drainage geocomposites with the same performance and they can be installed with a limited crew (2 or 3 people + a light equipment). DrainTube® can be deployed by hand by unrolling the product in the direction of the flow. The connections along the sides of the rolls are made by simple overlapping. They can be secured by sewing or welding. At the end of the rolls, flow continuity is achieved by placing the mini-pipes side by side or connecting them with the snap couplers provided.

In the case of a MSE wall, DrainTube® is manually unrolled on the base from the top of the cut slope (Figure 8). If necessary, DrainTube® can be nailed to the cut slope if there is no access to the top of the slope and the product is installed from the bottom.

Figure 8. Installation of the DRAINTUBE behind MSE walls

When installed on the flat surface between the strips of reinforcement, like for the RSS project, DrainTube® is manually unrolled on the compacted fill. The end of the product is ending at the face and the product is directly discharging outside the wall.

It is not mandatory to monitor DrainTube's behavior after years. Engineers from time to time asked to get an expertise or a monitoring of DrainTube® after a certain amount of time of usage. The fact that DrainTube® is made of pipes helps this type of investigation. All the different exhumations of geocomposite, after 10 to 12 years of use, showed a very stable behavior in time on behalf the most important proprieties of the product i.e., filtration opening size, flow capacity, strength.

Figure 9. Example of monitoring in pipes after 12 years. Canada.

4 DISCUSSION

Reinforced Soil Structures (RSS) systems rely heavily on effective drainage systems to maintain stability and prevent failures. Traditional drainage systems have been established through guidelines and standards such as BS 8006. These systems are designed to manage water infiltration and control pore water pressure, thereby enhancing the stability and longevity of RSS.

Conventional RSS sub-surface drainage systems are comprised of a combination of chimney drains - installed using graded granular material and perforated pipes wrapped with non-woven geotextile. While the graded granular material used in the chimney drain comprises non-renewable natural resources like sand and gravel that must be mined from a quarry, the perforated pipes are many times inflexible and may be subjected to breakage if the technical backfill material undergoes internal settlement, especially in tall RSS structures.

DrainTube® technology is meant to replace natural drainage material such as gravel or sand. It is important to notice that those material are generally used in combination with one or 2 layers of separation geotextiles. When using this geocomposite all those layers (gravel and geotextiles) can be replaced. This leads to a significant gain in construction time.
Reducing environmental impact by using geosynthetics instead of granular materials is also very important to consider, as design engineers play an important role in minimizing the environmental footprint of their project. It is demonstrated that, when considering the life Cycle Assessment of the product, using a drainage geocomposite instead of a natural material can save up to 70% of the Green House Gas emissions (figure 6).
Finally, because of their light weight, multi-linear drainage geocomposites generate lower GHG emissions per unit area than other drainage geocomposites like geonet geocomposites and cuspated geocomposites, for the same performance.

Material	Average Embodied Carbon (kg CO_2e/m^2)			
	Manufacturing (Cradle to Gate)	Transportation	Installation	Total
Drainage geocomposite	2.85	0.1	0.1	**2 - 3.5**
Gravel layer+ separator geotextile	4.7	1.04	1.29	**7.03**

Fig. 6. Example of compared Embodied Carbon values between a gravel layer and drainage geocomposite.

The structure has shown no signs of distress after one season of rain, indicating that DrainTube® effectively prevents water accumulation and subsequent pore water pressure development. The provided fill and drainage arrangement efficiently managed all seeped water, significantly improving structural stability.

5 CONCLUSION

The case study of the Himachal Pradesh Reinforced Soil Structure (RSS) highlights the critical role of effective drainage systems in maintaining the stability and integrity of such structures. The implementation of the Multi-Linear Drainage Geocomposite, DrainTube®, in the rehabilitation project demonstrated significant improvements in managing water infiltration and preventing the development of adverse pore water pressures.

The failure of the original structure due to inadequate drainage underscores the importance of selecting appropriate drainage solutions, especially in regions prone to heavy precipitation. The use of DrainTube® not only provided a high-performance drainage solution but also offered advantages such as high transmissivity, resistance to creep, and ease of installation, which contributed to the overall efficiency and cost-effectiveness of the rehabilitation work.

The successful performance of the rehabilitated structure through a monsoon season without signs of distress validates the effectiveness of the DrainTube® system. This reinforces the necessity of integrating advanced drainage technologies in the design and maintenance of RSS to ensure long-term stability and durability.

Furthermore, the environmental benefits of using geosynthetics like DrainTube®, which significantly reduce the use of non-renewable natural resources and lower greenhouse gas emissions, make it a sustainable choice for modern geotechnical engineering projects.

Overall, this study emphasizes that proper drainage design, supported by innovative geocomposite materials, is crucial for the success and longevity of reinforced soil structures, particularly in challenging climatic conditions. The findings advocate for broader adoption of such technologies to enhance the resilience and sustainability of infrastructure projects.

6 REFERENCES

R. M. Koerner and G. R. Koerner, "A data base, statistics and recommendations regarding 171 failed geosynthetic reinforced mechanically stabilized earth (MSE) walls," *Geotextiles and Geomembranes,* vol. 40, pp. 20-27, 2013.

A. Agarwal, G. Ramana, M. Datta, N. K. Soni and R. Satyakam, "Pullout behaviour of polymeric strips embedded in mixed recycled aggregate (MRA) from construction & demolition (C&D) waste–Effect of type of fill and compaction," *Geotextiles and Geomembranes,* vol. 51, no. 3, pp. 405-417, 2023.

A. Agarwal, M. Datta, G. Ramana and N. K. Soni, "Geo-Congress 2022," in *Geo Congress* , Chicago, 2022.

British Standards Institution. (2016). *BS 8006-1:2010+A1:2016 Code of practice for strengthened/reinforced soils and other fills*. BSI Standards Limited.