The importance of an efficient drainage behind mechanically stabilized earth walls

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ABSTRACT

The technique of mechanically reinforced walls with geosynthetics, such as geogrids, high tensile strength and modulus geotextiles, or metallic meshes, is widely used in North America. However, certain precautions are to be followed in this type of structures. One of them is described by the Geosynthetic Research Institute in their #345 white paper of good practices guide. This paper presents the importance of drainage behind these walls and is illustrated by a case study. This paper will also present the benefit of using a drain tubes horizontal drainage geocomposite instead of gravel in regards of cost efficiency and environmental footprint reduction.

RÉSUMÉ

La technique des murs renforcés mécaniquement à l'aide de géosynthétiques de renforcement, tels que des géogrilles, des géotextiles à fort module ou des armatures métalliques, est largement utilisée en Amérique du Nord. Certaines précautions sont néanmoins à suivre sur ce type d'ouvrages. L'une d'entre elles est décrite par le Geosynthetic Research Institute dans un guide des bonnes pratiques. Le présent document présente l'importance du drainage en arrière des ouvrages et l'illustre d'une étude de cas. Enfin, de nombreux avantages liés à l'utilisation d'un géocomposite de drainage avec mini-drains au lieu de matériaux granulaires seront présentés tel que l'accroissement de l'efficacité économique du projet ou la réduction de son empreinte environnementale.

1 INTRODUCTION

The Reinforced Mechanically Stabilized Earth (MSE) Walls technology, using reinforcement geosynthetics is used to help increase the slopes of works as ensuring their stability. However, certain precautions are necessary in this type of structure.

2 GRI #345 WHITE PAPER

One of them is described by the Geosynthetic Research Institute (Koerner and Koerner 2011) This guide of good practice first describes the different types of reinforced wall collapses that have occurred over the past thirty years in North America. Then, it analyses the failure of 82 MSE walls (23 reportedly had excessive deformation and 59 totally collapsed) (Fig. 1).

Figure 1. Example of a MSE wall failure

One of the conclusions was obvious: in 7 out of 10 cases, the failure was due to a lack of drainage. A recurrent problem with the design procedure of this type of structure is that the wall itself is usually designed by its manufacturer with the assumption that the backfill material will be self-draining or there will be no groundwater behind the wall. Thus, designs rarely provide drainage on the back side of the wall. During the construction phase, it is not common to change the manufacturer's engineering plans (this is the most common situation for private works, where 100% of the 82 failures appeared). In cases where there was groundwater behind the wall and no proper coordination between the manufacturer and the installing engineering firm on site, drainage design may be forgotten and hydrostatic pressure behind the wall may overload the retaining wall. This increases the load on the wall and thus reduces the factor of safety. In their conclusion, Koerner and Koerner (2011) present different recommendations for appropriate drainage and suggest that vertical and horizontal drainage, natural or geosynthetic, should systematically be present at the back face and the base of MSE walls.

3 CASE STUDY

In the context of the bypass of the southern part of the Fraser River in British Columbia (south Fraser Perimeter Road project), the future road is proposed along the south side of the river bank (Fig. 2) in order to relieve the Portmann Bridge access to the City of Vancouver from the neighboring cities located in the South (Surrey, Langley and Abbotsford). The new road directs traffic to the Alex Fraser Bridge, which is generally less busy.

Figure 2. SFPR project alignment

2.1 Context of the project

Because the space along the shore is limited and subject to relatively large hydraulic changes, the new road had to be placed in the extension of the existing one, along the river. Significant changes in the pattern of shoreline were made, leading to the construction of a large section of reinforced wall. The cross section of the reinforced wall had drainage on the back and below the wall as recommended by the GRI # 345.

Indeed, along the cut in the embankment, a separation geotextile, a 150 mm thick layer of crushed stone and a second separation geotextile were to be installed between the cut slope and the reinforced wall (Fig. 3). The aim of the drainage was to collect and evacuate the water from the wall (infiltration of rainwater, and groundwater).

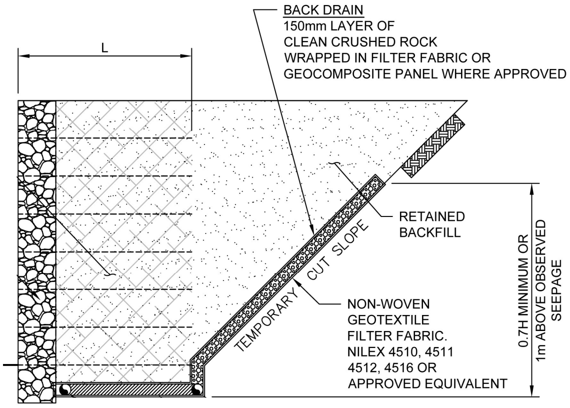


Figure 3. Typical cross section using the granular option

2.2 Problem to be solved

The problem to be solved by the general contractor in this project was installing the necessary drainage layer on a 1 to 1 slope. The only way to place the two geotextiles and the stone during the construction of the wall was to use the zigzag method. However, this method is very slow and costly in resources, material and equipments. In this project, the loss based on the initial quantities was 100% in stone and 200% in geotextiles. Thus the general contractor sought alternatives for drainage behind the walls.

2.3 Solution

The Drain Tubes Planar Drainage Geocomposites (DT PDG according to ASTM – Pic. 1) have been developed and used in North America since 2007. They are composed of nonwoven geotextiles that are needle-punched together with perforated, corrugated polypropylene mini-drains running the length of the roll. Nonwoven geotextiles are used to increase the mechanical and hydraulic properties of the product, while the mini-drains are the main hydraulic ducts of the geocomposite (Fig. 4).

Picture 1. Drain Tubes PDG

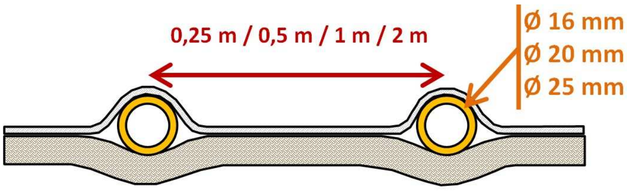


Figure 4. Drain Tubes PGD

2.4 Designing with Drain Tubes PDG.

2.4.1 Drainage

The water at the surface of the cut slope is collected by the non-woven drainage layer and transported to the mini- pipes after having passed through the filter. The geocomposite dimensions must take into consideration:

- the head loss when passing through the filter,
- the head loss when flowing through the drainage layer,
- the head loss when entering the mini-pipes,
- the head losses when flowing through the mini- pipes.

2.4.2 Hypothesis

The head losses when passing through the filter are not taken into consideration when calculating the drain dimensions. This is generally the case for all types of drainage. The non-woven drainage layer is considered to be saturated. The most important characteristic parameter is its transmissivity. For simplicity, the flow in this layer is assumed to be perpendicular to the direction of the mini-pipes. This assumption is safe because the gradient created by the slope is not taking into account when determining the head losses into the geotextile drainage layer. The flow Q_1 transported per unit of width is given by equation [1].

$$Q_1 = V_1 T_g = \theta i_1 \qquad [1]$$

Where:
V_1: flow transported by the layer,
T_g: thickness of the layer,
θ: transmissivity of the layer,
i: hydraulic gradient.

Laboratory tests have been carried out to establish the head loss when entering the mini-pipes. These tests illustrated that the head loss is negligible because they correspond to several millimeters of flow at most in the non-woven layer.

For this application, mini-pipes are in the direction of the slope. They are considered to be unsaturated. The slope is sufficient to consider a free surface flow inside the mini-pipes. The laboratory results indicate that the flow rate in the mini-pipes may be characterized by the following form relationship.

$$Q_2 = q_d i = \alpha i^{(n+1)} \qquad [2]$$

Where:
q_d : discharge capacity of the mini-pipe,
i : hydraulic gradient in the mini-pipe,
α, n : experimental constants.

2.4.3 Calculation of the maximum length of drainage for the mini-pipe to stay unsaturated

A uniform flow of intensity V is assumed to enter the drainage layer perpendicularly over a width of 2B, corresponding to the distance between mini-pipes as illustrated on figure 5.

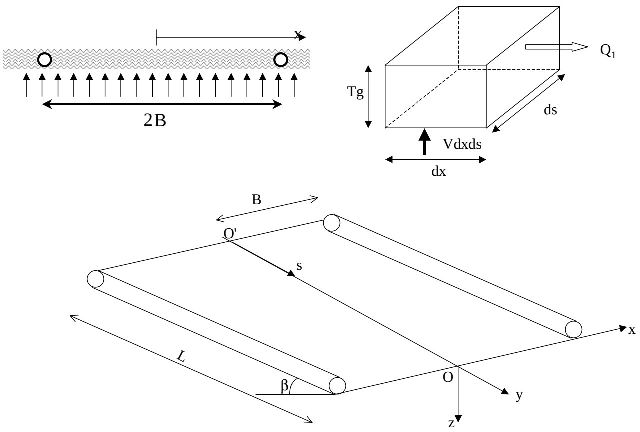


Figure 5 Flow modelisation

The flow dQ_1 which enters perpendicularly via a surface element (dx.ds) of the non-woven layer is:

$$dQ_1 = V dx ds \qquad [3]$$

Where the volume through the layer element (ds T_g) is:

$$Q_1(x, s) ds = V_1 T_g ds = -\theta \frac{dh_1}{dx} ds \qquad [4]$$

with :
Q_1 : flow in the non-woven layer,
T_g : thickness of the layer,
θ: transmissivity of the layer,
V : flow entering the layer,
V_1 : flow transported by the layer,
h_1 : hydraulic head in the layer.

Consequently,

$$\frac{d^2 h_1}{d^2 x} = -\frac{V}{\theta} \qquad [5]$$

Furthermore, the volume collected in an element of length «ds» of mini-pipe is given by:

$$dQ_2(s) = 2VBds \qquad [6]$$

With $Q_2(s) = q_d i \lambda(s) = \alpha i^{(n+1)} \lambda(s)$ [7]

with $0 < \lambda(s) < 1$ and $\lambda(0) = 0$; $\lambda(L_0) = 1$

where:
Q_2: flow transported by the mini-drain,
q_d: discharge capacity of the mini-drains,
i: hydraulic gradient in the mini-drain,
α, n: experimental constants.
L_0: maximum length for the pipe staying unsaturated

So,

$$2VB = \alpha i^{(n+1)} \frac{d\lambda(s)}{ds} \qquad [8]$$

$$\lambda(s) = \frac{2VB}{q_d i} s + c_1 \qquad [9]$$

With the boundary conditions, we obtain:

$$L_0 = \frac{\alpha i^{(n+1)}}{2VB} \qquad [10]$$

And the maximum hydraulic head into the drainage layer (between the mini-pipes) is:

$$(h_1)_{max} = \frac{VB^2}{2\theta} \qquad [11]$$

2.4.4 Use of LYMPHEA software

A software design (LYMPHEA) has been developed in cooperation with the Laboratoire Interdisciplinaire de Recherche Impliquant la Géologie et la Mécanique (LIRIGM) of the Joseph Fourier university of Grenoble and validated together with the Laboratoire Régional des Ponts et Chaussées (LRPC) of Nancy. In the software, the flow in the drainage layer is considered to be unidirectional and perpendicular to the mini-pipes. The software takes the following parameters into consideration:

- the transmissivity of the drainage layer under compression,
- the flow length in the mini-pipes,
- the flow slope in the mini-pipes,
- the distance between mini-pipes,
- the flow conditions in the mini-pipes (saturated, partially saturated or not saturated).

2.4.5 Specific design for SFPR project

In the SFPR project, the following assumptions were taken into account for calculation of the drainage behind the reinforced earth wall:

- maximum length of drainage: 23.55 m,
- slope: 100%,
- maximum load on the geocomposite: 100 kPa
- spacing of mini-pipes into the product: 0.5 m,
- transmissivity of the geotextile drainage layer under load: $1.00.10^{-5}$ m^2/s,

From Darcy's law [12], the maximum flow of water to be drained per unit of surface under the conditions of the project is:

$$F = K.e.i / L \ [m/s] \qquad [12]$$

where
K = hydraulic conductivity of the stone [m/s]
e = thickness of the stone layer [m]
i = hydraulic gradient
L = length of drainage [m]

In this project, with a given K of 1 cm/s, the flow to be drain was:

$F = 4.24\ 10^{-5}$ m/s

"Lymphéa" software allows the evaluation of the DRAINTUBE drainage geocomposite performance, and particularly in accordance to the design shown below (Fig. 5):

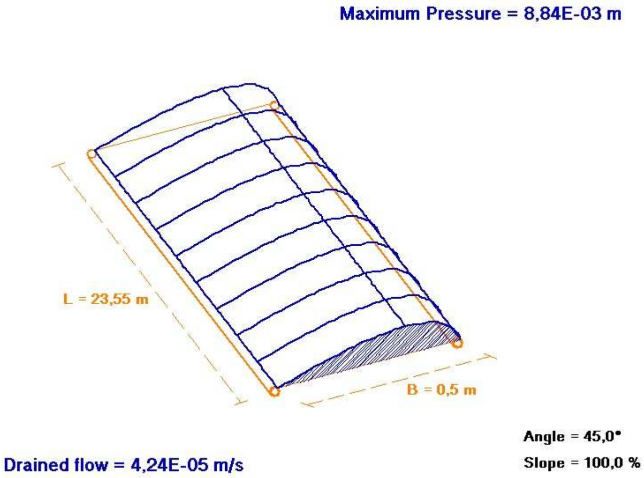


Figure 5. Lymphéa design sheet

Thus the above study suggested the selection of DRAINTUBE 400P FTF2 D25 F from Afitex-Texel to replace a 150 mm thick layer of washed stone. The new cross section of the wall is shown in Fig. 6.

The request issued by the contractor was been submitted to the Ministry of Transportation of British Columbia (BC MOT), based on a complete hydraulic study prepared by Afitex-Texel. The BC MOT agreed to introduce this technology to the approved civil engineering products list. The construction of the MSE wall lasted a year, from

March 2012 to March 2013. Over 15 000 m^2 of facing have been covered with this technology (Fig.7).

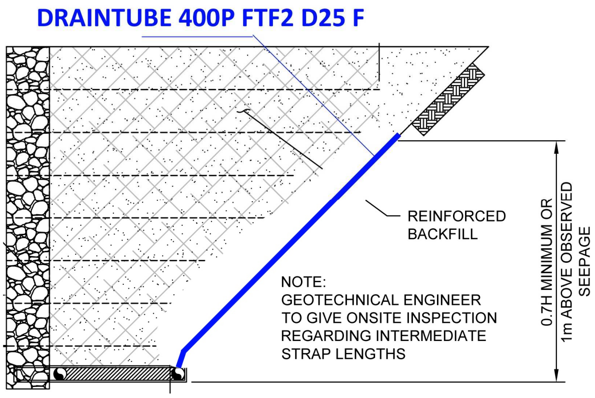


Figure 6. Typical cross section using a DTPDG

Figure 7. Installation of the DTPDG

3 DISCUSSION

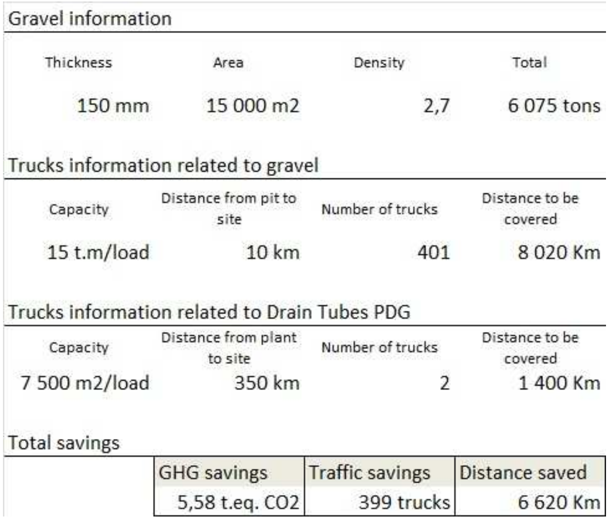
The benefits of using this type of geosynthetic solution are numerous:

a) it allows faster construction. In this project, sections of 2000 m^2 of drainage geocomposite were installed in 1 day versus 1-2 weeks with the traditional solution;

b) it reduces the costs of the project. Critically, the savings in geotextiles and stone;

c) it permits the conservation of natural materials for other uses. In any civil engineering project, the replacement of natural materials by geosynthetics can redirect the use of natural materials to more appropriate functions;

d) it allows a massive reduction of greenhouse gas emission. Saunier et al. (2009) reported the GHG savings on the proposed Highway 138 in Portneuf-sur-Mer. They estimate a savings of 1660 L of fuel and 4.58 equivalent CO_2 tons per hectare of covered area by a geocomposite versus a granular layer (Table 1). These data are comparable to the ones of the SFPR project in British Columbia.



Gravel information			
Thickness	Area	Density	Total
150 mm	15 000 m2	2,7	6 075 tons
Trucks information related to gravel			
Capacity	Distance from pit to site	Number of trucks	Distance to be covered
15 t.m/load	10 km	401	8 020 Km
Trucks information related to Drain Tubes PDG			
Capacity	Distance from plant to site	Number of trucks	Distance to be covered
7 500 m2/load	350 km	2	1 400 Km
Total savings			
	GHG savings	Traffic savings	Distance saved
	5,58 t.eq. CO2	399 trucks	6 620 Km

Table 1 . Comparison between the granular and the Drain Tubes PDG solutions and the related GHG savings

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