

Behavior of Drain Tubes planar drainage geocomposite under extreme cold temperatures

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*Challenges from North to South
Des défis du Nord au Sud*

ABSTRACT

Drainage is a critical component of every construction in civil, environmental and mining engineering. Natural drainage material like gravel or sand is widely used but starts to be replaced by drainage geocomposites, more efficient in term of installation and environmental footprint. However, these solutions are not always adapted to the extreme climate of northern Canada. Indeed, the structure of the product and its chemical composition have a strong influence on its behavior under cold temperatures and some geocomposites can exhibit an important stiffness making them difficult to install. Their mechanical and hydraulic properties may also be affected. The use of drain tubes planar drainage geocomposites allow for the avoidance of these issues. This paper shows the main characteristics of this type of geocomposite, the lab tests results on its mechanical behavior under cold conditions and presents two case studies of a pond construction and a mine site rehabilitation in northern Canada.

RÉSUMÉ

Le drainage est un élément important dans l'efficacité des ouvrages de génie civil, de génie environnemental et minier. L'utilisation de matériaux naturels, tels que le gravier ou le sable, est largement répandue, mais tend à être remplacée par des géocomposites de drainage plus adaptés du point de vue de la mise en place et en termes de réduction de l'empreinte environnementale. Ces solutions ne sont pas toutes adaptées aux conditions extrêmes rencontrées dans le grand nord canadien. En effet, la structure du produit et sa composition chimique déterminent son comportement vis-à-vis du froid et certains géocomposites peuvent présenter une rigidité importante dans ces conditions, rendant leur installation difficile. Leurs propriétés mécaniques et hydrauliques peuvent également être affectées. L'utilisation de géocomposites de drainage à mini-drains permet d'éviter ces lacunes. Cet article présente les caractéristiques de ce type de géocomposite, les résultats d'essais en laboratoire sur son comportement mécanique face au froid et présente deux études de cas de réalisation de bassin et de la réhabilitation d'un site minier dans le nord canadien.

1 INTRODUCTION

Due to the location of construction sites and also the deadline for completion of works, construction sometimes needs to happen during winter or under very cold temperatures. Techniques and materials used shall be adapted to these encountered climate conditions.

The use of geosynthetics often reduces the technical limitations for construction and improves the reliability of the work but sometime even if the product exhibits great performances and reliability under common climatic conditions, it may be totally inadequate under extreme cold conditions. Especially being known that the lack or a poor design of the drainage is the cause of most of the failures of any construction, a particular attention should be paid to the choice of the drainage geocomposite.

Drainage geocomposites are composed of several types of material to serve several functions (at least drainage and filtration). They are mostly a combination of two geotextiles (generally non-woven needlepunched polypropylene or polyester fibers) with a drainage core in the middle (polypropylene tubes or high-density polyethylene geonet). The behavior of the entire product under cold temperature is dependant of the behavior of its most critical component.

2 GEONET GEOCOMPOSITE BEHAVIOR

Geonet geocomposites are composed of one or two non-woven needlepunched Polypropylene (PP) geotextiles heat bonded to a High Density Polyethylene (HDPE) geonet core.

2.1 Non-woven needlepunched geotextile behavior

Several studies made on non-woven PP or Polyester (PET) geotextiles showed that cold temperatures (up to -35°C) and freeze-thaw cycles don't affect their mechanical properties (Allen et al., 1982 and Caquel et al., 2009). In some cases, these conditions seemed to increase the tensile strength (Caquel et al., 2009). The manufacture process doesn't affect the behavior of these geotextiles.

2.2 HDPE geonet behavior

It is a well-known fact that creeps of HDPE geonet increase with the increasing temperature resulting of a loss of the thickness of the geonet and therefore a reduction in its hydraulic transmissivity (Narejo et al., 2004). But they are very few studies on geonet under cold temperatures.

Due to its high cristallinity, HDPE is susceptible to stress-crack. Stress cracking is a brittle fracture that occurs under a constant stress less than the yield stress or break stress of the material. It is a fundamental property of all HDPEs.

The environment factors like chemicals or temperatures can accelerate that phenomenon. That environmental stress cracking is even more critical for lining systems with PE geomembranes and HDPE geomembranes are more and more replaced by Linear Low Density Polyethylene (LLDPE) geomembranes that are less sensible to stress cracking (Cornellier et al., 2014).

The resistance to the environmental stress cracking is related to the polymer density, cristallinity and also rigidity of the geonet, not to its mechanical properties (Mok et al., 2008). So it is impossible to specify a minimum index value to guaranty the good behavior of a HDPE geonet under cold temperatures. Without tests from the manufacturer on the specific geonet geocomposite being used, this type of product should not be used under cold weather conditions.

3 DRAIN TUBES PLANAR DRAINAGE GEOCOMPOSITE

3.1 Product description

Instead of using HDPE geonet as drainage core, DRAINTUBE geocomposite is composed of corrugated and perforated PP pipes regularly spaced between the geotextile layers and running the length of the roll (figure 1).

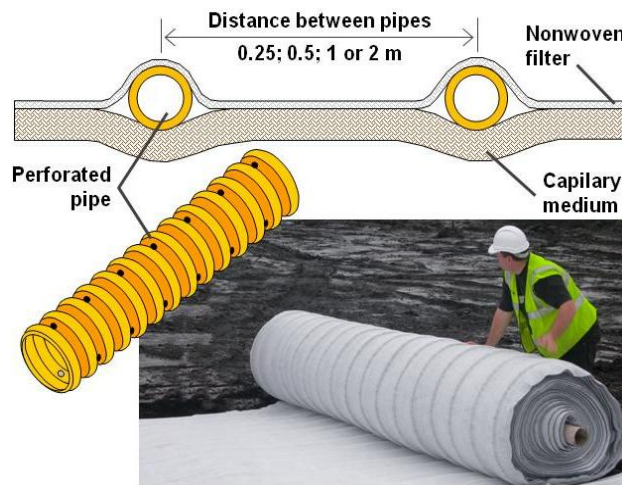


Figure 1. DRAINTUBE geocomposite description

As shown in paragraph 2.1, the geotextile components of the geocomposite are not sensible to cold temperatures. Laboratory tests have been performed on the PP pipes to determine their behavior under very low temperatures.

3.2 Pipe flexibility

The drain tube geocomposite pipes (25 mm diameter) have been tested with the ASTM standard D790 to evaluate the influence of temperature on the modulus of elasticity of the PP pipe (figure 2).

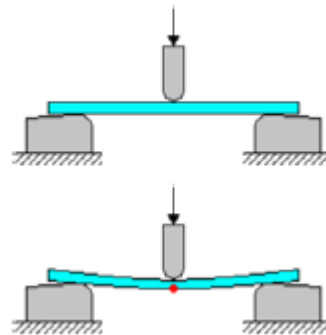


Figure 2. ASTM D790 test principle

The tests were performed at 23°C and -30°C, pipe exhibits a modulus of elasticity almost 3 times greater under -30°C than 23°C. That change has no consequence on the behavior of the pipe when it is unrolled as demonstrated by the ASTM D5636 that simulates the unrolling of the pipe around a 150 mm diameter mandrel. The test was performed at -70°C and no crack or any other failure was observed on the pipe (table 1).

Table 1. Test results on the pipes

Temperature	+23 °C	-30 °C	-70 °C
Apparent modulus of elasticity (Mpa) ASTM D790	8.99	24.54	-
Unrolling test Mandrel diameter 150mm ASTM D5636	-	-	OK no cracks

Even if the temperature may have an influence on the rigidity of the pipe of the drain tube planar drainage geocomposite, it doesn't affect the general behavior of the product under cold temperatures.

4 DESIGNING WITH DRAIN TUBES

The water reaching the geocomposite is collected by the nonwoven 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: i) passing through the filter; ii) flowing through the drainage layer and the mini-pipes; and iii) entering the mini-pipes. The head losses when passing through the filter are not taken into consideration when calculating the drain dimensions, as is generally the case for all types of drainage. The nonwoven drainage layer is considered to be saturated and the most important characteristic parameter is the 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 taken into account when determining the head losses into the geotextile drainage layer (figures 3 and 4).

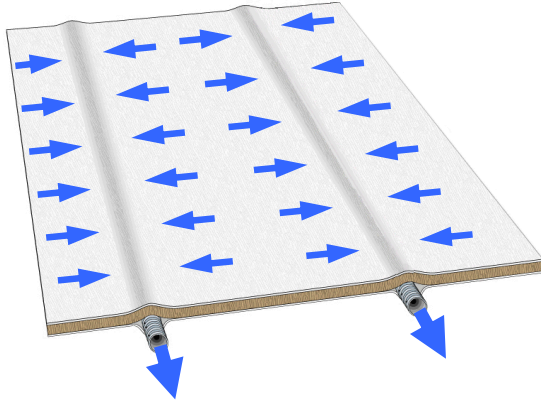


Figure 3. Considered flow path in the geocomposite



Figure 4. Drain tubes geocomposite water drainage

The flow Q_1 transported per unit of width is given by equation [1].

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

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 relationship described in the equation [2].

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

Where:

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

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

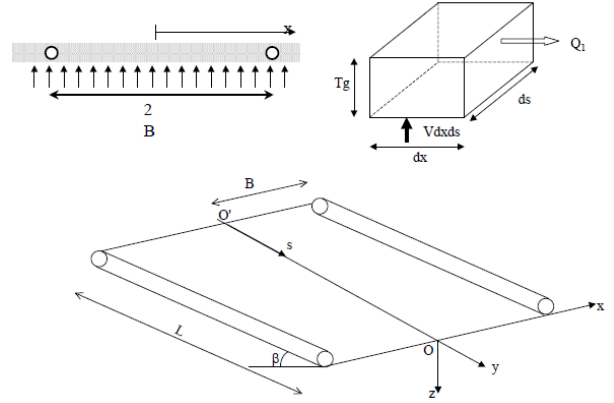


Figure 5. Modeling of the drain tubes geocomposite

The flow, dQ_1 , which enters perpendicularly via a surface element $(dx.ds)$ of the nonwoven layer is:

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

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

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

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,

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

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

$$dQ_2(s) = 2VB ds \quad [6]$$

$$\text{with } Q_2(s) = q_d i \chi(s) = \alpha i^{n+1} \chi(s) \quad [7]$$

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

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,

$$2VB = \alpha i^{n+1} \frac{d\chi s}{ds} \quad [8]$$

$$\chi s = \frac{2VB}{q_d i} s + c_1 \quad [9]$$

So the maximum length of drainage with the pipes staying unsaturated is:

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

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

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

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 (figure 6).



Figure 6. Lymphhea™ software

Given the flow to evacuate and the geometry of the site, it permits to determine the maximum length of drainage for the mini-pipes remaining unsaturated and the maximum hydraulic head between the pipes. The geocomposite is designed for the maximum hydraulic head to be inferior to its thickness.

5 CASE STUDIES

Drain tubes planar drainage geocomposites have been successfully used in several projects under extreme temperatures in the north of Canada.

5.1 Secondary drainage layer of a pond

Drain tubes planar drainage geocomposite has been used in 2014 for the secondary drainage layer of a tailing pond in Northern Quebec. Installation was performed during winter and the on-site recorded temperatures went down to -37°C (figure 7). The drain tubes planar drainage geocomposite didn't show any stiffness and its unrolling and placement was the same as usual.



Figure 7. General view of tailing pond during construction

A particular attention was paid from the manufacturing to the on-site storage for the geocomposite to stay dry. The packing was done so that no water could come into the rolls and freeze them.

5.2 Central Manitoba Mine phase 2 capping

Central Manitoba mine is located in Nopiming Provincial Park, 220 km northeast of Winnipeg, Manitoba, Canada. The mine was in production from 1927 to 1937, generating approximately 5,000 kg of gold (using cyanide) from 480,000 tons of ore (Richardson and Ostry, 1996). The proposed 1 m thick engineered soil cover included a 0.2 m thick, highly permeable basal granular drainage layer, which was ultimately replaced with a drain tubes planar drainage geocomposite. The objectives for Phase 2 at the CMM site included the removal of public-safety concerns, provision of a good medium for revegetation, and implementation of erosion-control measures to accelerate water collection away from the site and limit

water infiltration into the tailings, all based on the construction of an engineered soil cover on top of the tailings. Also, based on the fact that permeable natural materials were not found on site, the design had to consider alternate solutions in order to keep the project cost efficient and environmentally viable. The drain tubes geocomposite has been designed in replacement of 0.50 m of drainage material and two filtration geotextiles (figure 8).

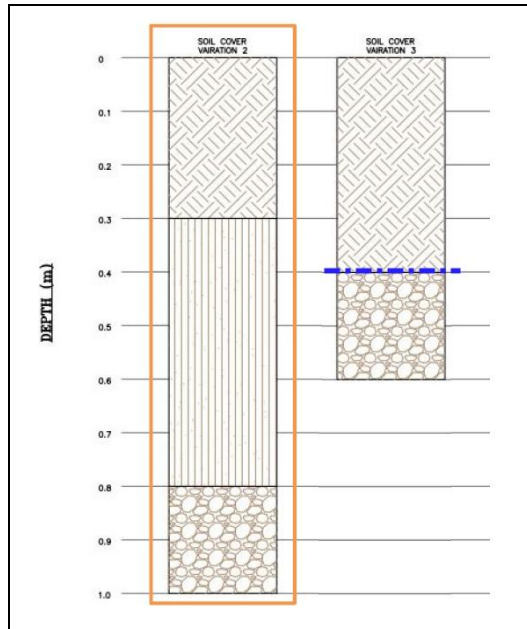


Figure 8. Comparison of the cross sections

The required flow to evacuate by the geocomposite was $2 \cdot 10^{-8}$ m/s on a slope of 100 m at 1%. The installed drain tubes geocomposite is able to evacuate a flow of $3.17 \cdot 10^{-7}$ m/s on a slope of 167 m at 1% staying unsaturated. The overall factor of safety on the drainage system is superior to 15. That system has a built-in safety factor that allows good long-term performance and should perform according to original requirements such as limiting erosion, limiting direct human exposure to tailings, shedding water away, and supporting the vegetative cover (Nan and Saunier, 2014).

Because the Drain tubes planar drainage geocomposite is installed on a silty clay material that is used as a backfill material to final grade the tailings, it has been decided to install the geocomposite during the winter, with a temperature below the frozen zone (Figure 9). The low compression resistance of this poor on site material led to consider frozen conditions in order to allow pieces of equipment working on its surface.



Figure 9. Silty clay backfill material

The installation of the 15 hectares of Drain tubes planar drainage geocomposite has been conducted during winter 2012 and winter 2013 without significant modification of installation procedures and installation rates (Figures 10 and 11).



Figure 10. Unrolling drain tubes on frozen backfill



Figure 11. Drain tubes installation

6 CONCLUSION

The use of geosynthetics in specific weather conditions requires using adapted materials. In case of cold temperatures, HDPE geosynthetics may not be recommended because of their sensibility to environmental stress cracking. Drain tubes planar drainage geocomposites composed of PP and/or PET have been shown (from lab tests and filed references) to be effective and reliable under such conditions. In all cases it is necessary to request a technical feedback (from producer, literature or laboratories) before using a geosynthetic out of its usual field of use.

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