Water drainage and gas collection with geocomposites - Hydraulic software

Stephan Fourmont[1*], *Justine* Decaens[2], *David* Beaumier[2]

[1]Afitex-Texel, St Marie, Quebec, Canada
[2]CTT Group Sageos, St Hyacinthe, Quebec, Canada

Abstract. Geosynthetic materials and, more specifically, drainage geocomposites are now widely used for water drainage and gas collection in applications as varied as final landfill covers, leachate collection in landfill cells, sub-slab depressurization systems under buildings, groundwater drainage under embankments, etc. The design methods used are based on the in-plane flow capacity of the geocomposites, which is determined by laboratory tests performed on 250-300 mm long product specimens. Fluid is injected into the thickness of the product and the drainage capacity is interpolated for an actual length of several meters. This paper presents the development of hydraulic design software for multi-linear drainage geocomposites, based on laboratory characterizations of the geocomposite and then validated with full-scale tests. The software gives a 3D model of the hydraulic curves in the geocomposite depending on the application for which the geocomposite is used, and the fluid to be drained (water, landfill gas, methane, air, etc.).

1 Introduction

The design of geosynthetic materials for drainage requires an excellent knowledge of the material's hydraulic properties. The determination of the drainage capacity of drainage geocomposites is based on in-plane flow as determined by laboratory tests according to ASTM D4716 [1], GRI GC15 [2], and ISO 12958-2 [3]. The initial type tests allow the designer to correlate the flow rate with the hydraulic head or hydraulic gradient. In addition to the basic hydraulic characterization, the long-term in-situ drainage capacity of the geocomposite is calculated from these laboratory test results using guidance documents that help the designer address the reduction factors to be applied to the drainage flow capacity as a function of the type of geocomposite, the engineered structure, type of fluid (water, gas), etc. The ASTM D7931 [4] standard guide (based on ASTM D4716 laboratory test), or the ISO/TR 18228-4 [5] standard guide (based on ISO 12958 laboratory test) greatly help the engineers in this regard, but certain points can be misleading for engineers without solid expertise in geosynthetics.

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[*] Corresponding author: sfourmont@afitextexel.com

1.1 Laboratory tests

The in-plane flow capacity (or Transmissivity) of geocomposites is developed to be compatible with the whole range of products on the market through ASTM and ISO standards. Because of the different physical characteristics of drainage geocomposites, the laboratory tests performed as per the standards may not be as accurate as expected.

For example, the size of the testing device typically used has a length of 250 mm to 300 mm, underestimating by at least 30% the drainage capacity of Draintube multi-linear drainage geocomposites (Blond et al. [6]). This is because the entrance and exit transition flow to the tested length causes additional head losses.

Moreover, taking a single test measurement (even after a seating time of several hours), may not account for the continuous compression of the tested product due to creep throughout its service life and lead to an overestimation of its in-situ drainage capacity. This is particularly noticeable for geocomposites with a monofilament core where the in-situ drainage capacity can be more than 10 times lower than the value measured in the laboratory test (Zanzinger [7]).

1.2 Boundary conditions

The drainage capacity of the geocomposite is determined by using laboratory tests with specific test conditions, such as hydraulic gradient, vertical compression load, seating time, and material(s) in contact with the geocomposite. It can be complicated for the designer to correlate these test conditions with the field conditions, or even more concerning, to be aware that the test conditions have a significant impact on the given results.

For example, using steel plates as boundary conditions when testing a drainage geocomposite does not address the geotextile intrusion into the drainage core. This phenomenon will occur in the field when the product is in contact with a soil layer. This typically leads to a significant reduction in flow rate for most drainage geocomposites, up to 90% reduction for geocomposites under high compressive loads (Zhao et al. [8]).

As for creep in compression, the sensitivity to the boundary conditions depends on the type and structure of the drainage geocomposite.

1.3 Terminology

The technical terms involved in hydraulic design can be a source of confusion for the designer. Indeed, depending on their field of expertise, geotechnical or geosynthetic, some identical terms do not represent the same quantities and are not directly comparable. One example is “Hydraulic Transmissivity”. It is not directly comparable between a granular layer and a geocomposite. The first one is an intrinsic value of a given granular layer, while the second one depends on many factors specific to the geocomposite environment such as the hydraulic gradient, the applied normal load, the material in contact, etc.

2 Software development

In the trend of Computer Assisted Design (CAD) for engineers, Afitex Group has developed a software for the design of geosynthetics used in drainage applications. The new software, named Lymphea, assists designers in the hydraulic selection of drainage geocomposites (including multi-linear drainage geocomposites) as well as granular drainage layers using site-specific conditions.

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.

2.1 Project presentation

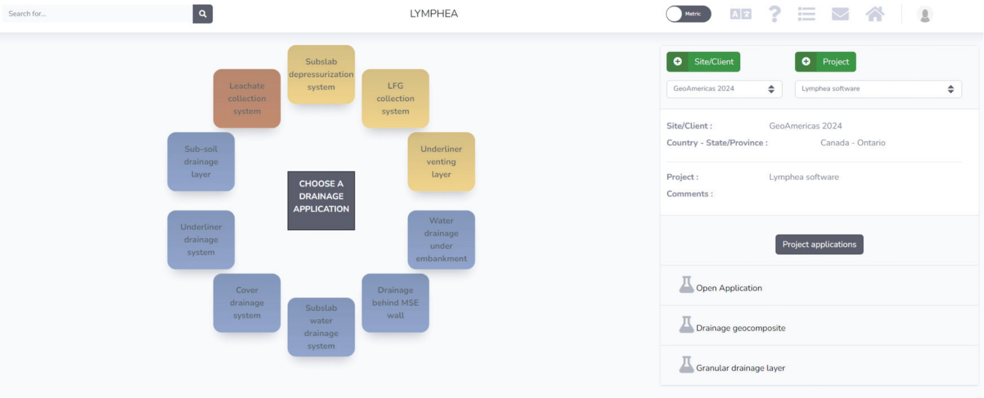
The development of the software has been divided into the following three main steps:

- The calculation core for multi-linear drainage geocomposites that has been implemented from the previous model and updated with a 3-year test program performed at SAGEOS and USASK laboratories,
- Calculation modules development for drainage geocomposites and granular drainage layers, based on standard design guidance documents from the geosynthetic industry and publications from specialists in these fields,
- User interface design to have a software that is easy to use and intuitive.

The software also offers design firms a company-restricted database allowing multiple users in the same company to share and update their projects.

2.2 User interface

The user interface has been developed to represent the engineer's needs and the design steps as closely as possible. The software is available in several languages (English, French, and Spanish), in SI and US units, and based on ISO and ASTM standards. When creating a new project, the user can choose between several available drainage applications (Fig. 1) such as Sub-slab depressurization systems, Drainage behind MSE walls, Cover drainage systems, or Leachate collection systems. It should be noted that the software allows for the design of drainage geocomposites for both liquid water and gas.



Site/Client : GeoAmericas 2024
Country - State/Province : Canada - Ontario
Project : Lymphea software
Comments :

Fig. 1. Home page of the software.

3 Calculation module for multi-linear drainage geocomposite

The calculation modules for multi-linear drainage geocomposites are based on the previous model initially developed and validated on several large-scale cell experiments 4 m (13 ft) long and 1 m (3 ft) wide at the LIRIGM university research laboratory (Faure et al. [9]), 10 m (33 ft) long and 2 m (6 ft) wide at the Draintube manufacturing site in France (Faure et al.

[10]), and confirmed many times since. The theoretical model in the software is based on the following flow conditions:

- Fluid supply with a homogeneous flow distribution perpendicularly to the geocomposite,
- Horizontal or non-horizontal position of the drainage layer with the flow condition down or reverse to the slope α,
- Perforated mini-pipes unsaturated, partially saturated, or fully saturated.

3.1 Hydraulic modelling for water

The fluid inside the drainage layer is assumed to flow perpendicular to the perforated mini-pipes. This hypothesis is conservative and reasonably good as the distance between the mini-pipes is 2 m (6 ft) maximum, provided the length of the mini-pipes is generally more than 10 m (32 ft). The head losses to enter into the perforated mini-pipes have been found insignificant compared to the head losses into the drainage layer. The governing equation of the hydraulic head in the multi-linear drainage geocomposite is then given by Equation 1 from Faure et al. [9]:

$$h_{max} = \frac{F \times D^2}{8\theta_{GT}} + \left(\frac{b}{b+1}\right) \times \left(\frac{F \times D}{a}\right)^{1/b} \times L^{(b+1)/b} - L \times \sin\alpha \qquad (1)$$

where F = Flow per unit area; θ_{GT} = Transmissivity of the drainage layer; D = Distance between mini-pipes; L = Length of drainage; a and b = constants experimentally determined from the flow capacity of the mini-pipes.

3.1.1 Flow capacity of the drainage layer

The drainage layer is composed of a non-woven needle-punched staple fibre geotextile. The drainage layer is protected from the surrounding soil by an additional filter layer, also included as part of the multi-linear drainage geocomposite that prevents soil particle migration. The flow carried out by the drainage layer is given by Darcy's law and is dependent on its Transmissivity.

A series of hydraulic tests have been performed at SAGEOS and USASK laboratories on several drainage layers under multiple loads to characterize their hydraulic Transmissivity. The transmissivity values considered in the software are in-situ Transmissivity, meaning that reduction factors have already been applied to reflect the long-term drainage capacity under load. Recommended reduction factors for geotextile drainage layers are given in the GRI White paper 4 [11]. Figure 2 shows an example of the long-term Transmissivity of a 200 g/m^2 (6 Oz/sy) drainage layer function of the vertical load applied.

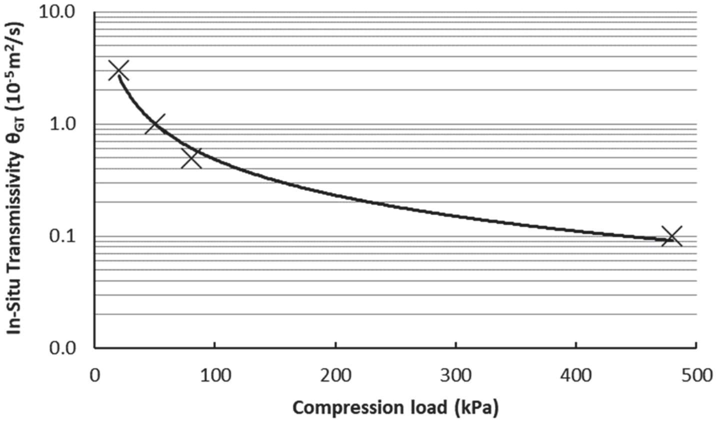


Fig. 2. In-Situ Transmissivity of a 200 g/m^2 non-woven needle punched geotextile drainage layer.

3.1.2 Flow capacity of the mini-pipes

Tests have been carried out at SAGEOS laboratory to characterize the flow capacity of the mini-pipes themselves and to confirm the experimental values previously obtained during the development and validation of the software. The flow capacity of the mini-pipes is a function of the hydraulic gradient and has been measured for the 3 mini-pipe diameters: 16 mm (5/8 in), 20 mm (4/5 in), and 25 mm (1 in) as shown in Figure 3. Mini-pipe lengths of 0.5 to 1 m (20 to 40 in) were tested, and the resulting flow capacity was calculated, excluding entrance and exit head pressure losses.

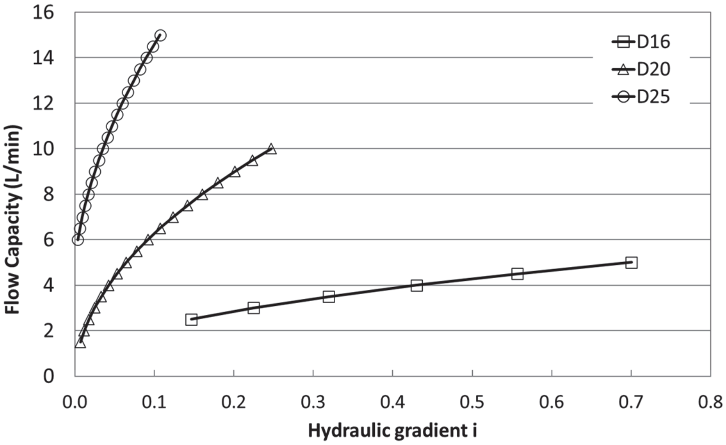


Fig. 3. Flow capacity of the 3 mini-pipe diameters.

For each mini-pipe diameter, the flow capacity implemented in the software is conservative compared to the test results. A factor of safety of 1.55 has been applied to the measured flow capacity values.

3.2 Hydraulic modelling for gas

The flow of a fluid in a drain is evaluated using the two non-dimensional parameters, Reynolds number (*Re*) and head loss coefficient (λ) as per Equations 2 & 3.

$$Re = \frac{Q \times d}{A \times v} \tag{2}$$

$$\lambda = \frac{2 \times g \times i}{(Q/A)^2} \tag{3}$$

where Re = Reynolds number, Q = Fluid flow (gas: Q_g, water: Q_w), A = Area, d = Hydraulic diameter of the pipe, v= Fluid kinematic viscosity (gas: v_g, water: v_w), λ = Head loss coefficient, i = Hydraulic gradient (gas: i_g, water: i_w) and g = Gravity

The gas flow capacity is modeled by considering that for the same Reynolds number, the head loss coefficient remains the same in the drainage geotextile layer and in the mini-pipes.

3.2.1 Flow capacity of the drainage layer

As per the previous statements, we obtain the gas transmissivity of the geotextile drainage layer function of its water transmissivity (Equation 4):

$$\theta_{GT_g} = \frac{\theta_{GT} \times v_w}{v_g} \tag{4}$$

where θ_{GT} = Water transmissivity of the geotextile drainage layer, θ_{GTg}= Gas transmissivity of the geotextile drainage layer

3.2.2 Flow capacity of the mini-pipes

The flow in the mini-pipes is turbulent, even for small hydraulic gradients. Then, considering that for the same Reynolds number, the head loss coefficient remains the same, the gas flow capacity of the mini-pipes can be calculated using the Equation 5:

$$Q_{P_g} = a \times {i_g}^b \tag{5}$$

where Q_{P_g} = Gas flow capacity of the mini-pipes, i_g = Gas hydraulic gradient

4 Calculation module for geocomposites

Use The calculation module for drainage geocomposite is based on Darcy's law and the in-plane drainage capacity from ASTM or ISO standard tests.
The hydraulic behavior of the drainage geocomposite is modelled using Equation 6 in an ISO environment and Equation 7 in an ASTM environment. A potential incoming upstream flow has also been taken into account:

$$q_p(\sigma, i, 100h) = FS \times \prod RF \times (F \times L + \ q_0) \tag{6}$$

$$\theta_{100}(\sigma, i, 100h) = FS \times \prod RF \times \frac{(F \times L + \ q_0)}{\sin\alpha + \frac{\cos\alpha \times h_{max}}{L}} \tag{7}$$

where $q_p(\sigma,i,100h)$ = In-plane flow capacity as per ISO 12958-2 (performance test) performed under a vertical load σ, a hydraulic gradient i, and a seating time of 100 hours with boundary conditions representative from the applications; $\theta_{100}(\sigma,i,100h)$ = Transmissivity as per ASTM D4716 (or GRI GC15) performed under a vertical load σ, a hydraulic gradient i, and a seating time of 100 hours with boundary conditions representative from the applications; FS = Factor of safety; $\prod RF$ = Reduction Factors.

$\prod RF$ is the product of the following reductions factors (Equation 8):

$$\prod RF = RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC} \tag{8}$$

where RF_{IN} = Reduction factor for geotextile intrusion into the drainage core; RF_{CR} = Reduction factor for creep in compression; RF_{CC} = Reduction factor for chemical clogging; RF_{BC} = Reduction factor for Bacteriological clogging.

The reduction factors are dependent on the type of application and are also product/technology specific. Recommended values for the reduction factors are given in the software and are generally taken from the ISO/TR 18228-4 standard guide. It is important to note that the reduction factors are to be applied on $q_p(\sigma,i,100h)$ or $\theta_{100}(\sigma,i,100h)$ i.e. on the 100 hours seating time test results.

Each parameter mentioned in Equations 6 & 7 can be chosen in the software as the value to be determined (as the unknown of the equation).

5 Calculation module for granular drainage layers

The calculation module for the granular drainage layer is based on two technical papers published by Giroud et al. [12, 13]. The approach used is to verify that the maximum water flow height is less than the thickness of the granular drainage layer, which becomes the maximum allowable water height. According to Giroud et al. [12, 13], the thickness of the liquid layer is influenced by the hydraulic conductivity of the granular layer, the angle of the slope, the drainage length, and the flow rate per unit area entering through the surface perpendicular to the flow direction. The modelling of the hydraulic behavior of the granular drainage layer is performed using Giroud's formula, where an incoming upstream flow has also been considered, as shown in Equation 9:

$$F \times L + q_0 = K \times \left(h_{max} \times \sin\alpha + \frac{{h_{max}}^2 \times \cos\alpha}{L}\right) \tag{9}$$

where F = Flow rate per unit area; L = Length of drainage; q_o = Incoming upstream flow; K = Hydraulic conductivity of the granular layer; h_{max} = Maximum height of water; and α = Slope.

As per the calculation module for drainage geocomposites, the user can solve for each parameter mentioned above as the value to be implemented (as the unknown of the equation) in the software. It allows the user to design a drainage solution with a granular layer function of the input data specific to the project. Reduction factors for chemical clogging (RF_{CC}) and biological clogging (RF_{BC}) can be addressed and applied to the hydraulic conductivity of the granular layer. The factor of safety (FS) is applied to either h_{max} or K, whichever gives the most conservative result.

6 Conclusions

The development of a software for the hydraulic design of drainage geocomposite and granular drainage layers is intended to help designers. 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. The Lymphea software allows for a wide range of parameters to be determined to better adapt to the site-specific requirements of each project. Considering its usage throughout the world, it also works in both ISO and ASTM environments, using either SI or US units.

Finally, the software is based on a previous model, initially developed and validated on a large-scale cell experiment and confirmed many times since. The user interface has been designed to be as intuitive as possible, and it guides the user by explaining the important steps and input data to be considered.

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