Design and Properties of Geocomposite Drains applied in Civil Works

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Abstract

Drainage consists of the collection and transportation of precipitation, ground water and/or other fluids. The use of geosynthetic composite drains to substitute traditional granular drains has become more frequent due to several advantages these materials provide. With the variety of products available, the designer should understand drainage design principles to specify and select the correct product to use. The paper discusses the basic design principles of a drainage system and product testing that can be conducted to understand the long-term performance properties required for the drainage system to comply with a structures design life. A geocomposite drain should be characterized as a system rather than a set of individual layers to meet the required functions of filtration and drainage.

Keywords: *Geocomposites, drainage, design, properties, geodrains.*

1. Introduction

The SANS 10318 defines geocomposites as a manufactured or assembled material using at least one geosynthetic product among the components, used in contact with soil/rock and/or any other geotechnical sheet, used in civil engineering applications. The geosynthetic acts as a drain to carry fluid flows through less permeable soils. For example, geotextiles are used to dissipate pore water pressures at the base of roadway embankments; however, the low transmissivity has reduced their application to marginal structures. For higher flows, geocomposite drains have been developed specifically to collect and transport fluids having a transmissivity in the order of 1000 times more than geotextiles. These materials have been used as pavement edge drains, slope interceptor drains, and abutment and retaining wall drains. Prefabricated vertical drains (PVDs) have been used to accelerate consolidation of soft cohesive foundation soils below embankments and preloaded fills.

The main applications of geocomposites can be categorized into four groups: horizontal drainage; subsoil drainage; vertical drainage and landscaping. In Sousa, 2014, these applications are defined and is listed possible practical uses of these materials.

2. Geocomposite for Drainage Vs Traditional Drainage

There are many reasons that suggest the use of geocomposites in place of traditional drainage with sand and gravel. Sousa, 2014 describes in detail the various advantages, summarised by:

- Reduction of installation time and costs. A cost comparison is done in Sousa.
- There can be additional positive environmental impact due to reduced volume of materials being moved.
- Provide technical advantages to fit any technical/functional requirements.
- Geocomposites have a better guaranteed performance.
- All the technical properties of geocomposites were measured in laboratory and are listed in data sheets and technical documents.

2.1. French Drain Comparison

Laboratory tests were done at the University of Vale do Itajaí, in Brazil, to compare the flow rate of a traditional "French drain" (Figure 1), consisting of a rectangular or trapezoidal trench filled with sand and gravel, and wrapped with a filter geotextile, with the flow rate of a geocomposite with a perforated pipe at the bottom.

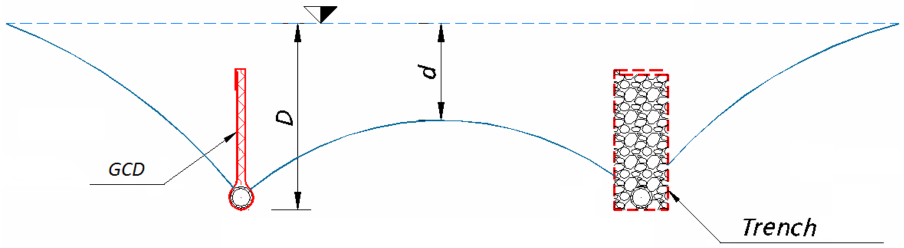

Figure 1. GCD vs Traditional "French drain" (Rimoldi, 2013).

Figure 2 shows the test apparatus used. It consisted of two identical compartments, one of which contained the geocomposite wrapped around a perforated tube and another compartment containing the traditional method for a subsoil drainage system. Water was introduced at the surface of both compartments at the same flow rate. There were a variation of characteristics used to achieve accurate results such as:

- Different tube sizes were used (100mm and 150mm);
- Different grain sizes for the traditional method (Gravel 2 (22-32mm particle sizes) and Gravel 3(22-62mm));
- Different geocomposite characteristics (used wide range of products available); and
- Different flow rates introduced at the surface.


Figure 2. Apparatus for testing.

The discharge of water through each tube after a period of 30min was measured. Many results were achieved, as an example it is shown in Table 1 the result using a Gravel 2 material for the traditional method and a mid range geosomposite drain.

Table 1. Flow rate results.

Parameter	GCD	Gravel 2
Q_{intro} (m^3/s)	2,20 x 10^{-4}	2,20 x 10^{-4}
Q_{out} (m^3/s)	1,10 x 10^{-5}	1,18 x 10^{-6}
Total (s)	1800	1800

From this test in these conditions, it was shown that the flow rate of extraction for the geocomposite was almost ten times faster than that of the traditional method.

3. Geocomposite for Drainage

Geocomposites for drainage are tested in accordance with mechanical and hydraulic test methods. Mechanical testing are requires to assure the survivability of the geocomposite during installation and under the soil pressure. Hydraulic testing highlights the performance of the geocomposite for drainage, permeability through the geotextile and most important the water flow (amount of water flowing in its plane). Geosynthetics are often assessed in short and long term due to their time related behaviour.

Short term properties refer to initial mechanical and hydraulic performances such as installation survivability, opening size of the geotextile, flow rate and compressibility behaviour. Usually short term properties are identified for construction stage properties.

Long term properties refer to post-construction properties, often at the end of the design life of the project. Geocomposite for drainage shall be assessed for clogging and flow rate. Clogging occurs on the geotextile filters while the flow rate reduces during time due to the viscous deformation occurring under constant loading. Its flow rate is also determined by its capacity to maintain the thickness of the core, thus compressive creep should be considered to understand the long-term thickness loss of the geocomposite.

Testing of geocomposites can be done according to EN and ISO may include:

- Short term flow rate test (EN ISO 12958);
- Compressive creep test with shear load applied (EN ISO 13432);
- Junction peel and junction shear tests for geocomposites (EN 13426-2);
- Direct shear test (EN ISO 12957-1);
- Inclined plane test (EN ISO 12957-2);

- Long term protection efficiency test (EN 13719); and
- Impact protection test (ENV 13428).

3.1 Type and characteristics of the draining core;

Depending on the type of draining core, all geocomposites will be subject more or less to short term compression and compressive creep under the applied loads and pressures. In general, an increase of load will lead to a reduction, gradual or sudden, in the thickness of the core It is possible to identify two types of behaviour of the draining cores under sustained compressive loads (Figure 3): compressible cores, without any defined point of collapse; collapsible cores, with to a well-defined point of collapse.

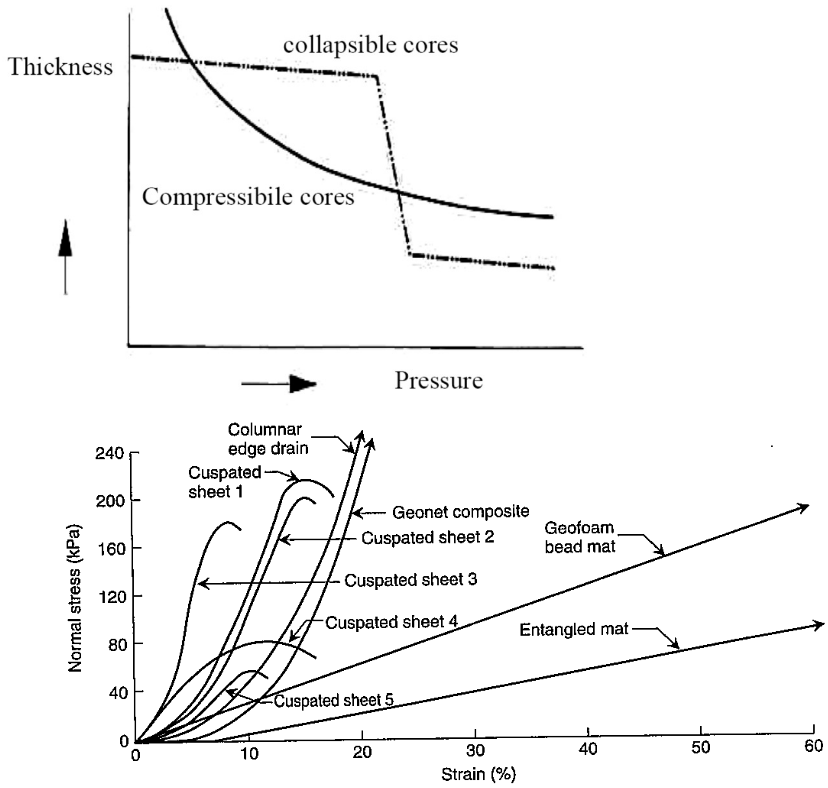

Figure 3. Compressibility behavior of selected geocomposite sheet drain materials (Koerner, 2005).

3.1.1. Type and characteristics of the filter geotextiles, and process of bonding to the draining core

The geocomposite is first required to fulfill the function of filtration is based on two contradictory conditions, permeability and retention. In most cases, a geotextile is used for filtration purposes, in which according to Heibaum et al. (2006), the primary goal of filters is to retain particles of a base soil without altering the drainage capacity of the system. Thus the opening of the geotextile should be wide enough to allow the passing of liquids but at the same time avoid the passing of the fine particles of the soil (Koerner, 2005). A commonly used empirical relationship between permeability coefficient and soil particle size is the following Equation (1):

$$k = Cd_{10}^{2} \quad (1)$$

In which k is the permeability coefficient (hydraulic conductivity) of the soil, C is the site specific constant and d_{10} the effective soil particle size at which 10% of the soil is finer
Furthermore the bonding of the drainage core to the geotextiles is very important especially in sloped applications such as landfill slope or a capping. On a slope the applied pressure given by the material at the top generate a shear component which might cause deformation between the interfaces. If the geotextile is not bonded to the drainage core (thermally or chemically) the chances of creating a failure plane between is very high. The ISO 13426-2: Geotextiles and geotextile-related products -- Strength of internal structural junctions -- Part 2: Geocomposites is often performed to assure the integrity of the geocomposite for drainage under shear loading.

3.1.2. Characteristics of the materials in contact with the two faces of the geocomposite

About the materials in contact with the two faces of the geocomposite, as above said a “soft” material will produce a more pronounced intrusion of the geotextiles into the draining core, while a “rigid” material will produce practically no intrusion of the geotextiles into the draining core.
Considering that the geocomposite has two faces, there are only three possible combinations:

- Rigid–Rigid contacts;
- Soft–Soft contacts;
- Rigid–Soft contacts.

Each application of geocomposites affords a typical contacts situation as shown in Table 2, hence for each application the flow rate shall be measured with the appropriate contacts. This is a preliminary guideline, anyway each project shall be properly evaluated:

Table 2. Application of geocomposites.

Rigid–Rigid contacts	Rigid–Soft contacts	Soft–Soft contacts
- GCD for leakage detection in landfills, between two geomembranes - GCD between shotcrete and structural arch in tunnels	- GCD behind retaining walls - GCD in a capping package or for leachate collection landfills, in contact with geomembrane at the bottom and soil on top - GCD for roof gardens or vegetated terraces	- GCD inside a draining trench - GCD under a road or railway embankment - GCD in parking areas - GCD behind a reinforced slope

Since the intrusion of the geotextile into the draining core occurs in a different way for each geocomposite and for each type of contact, it is fundamental that the water flow capacity is measured with an apparatus which can reproduce all the possible conditions of use:

- materials in contact with the two faces;
- applied pressure;
- hydraulic gradient.

Hereafter, it is reported the results of the tests run on the same material but in different conditions (Table 3). It’s evident that the performance of the material are highly affected by the boundary conditions and that the magnitude of the effects increase by increasing the applied load.

Table 3. Test results of drainage flow capacity.

Drainage Flow Capacity (l/s/m) measured with ISO 12958 test *(Test run in SKZ Laboratory)*									
Configuration	120 g/m² gtx + HDPE geonet + 120 g/m², Thickness at 2 kPa = 5,45 mm								
Contact	hard/hard			hard/soft			soft/soft		
Gradient	0.1	0.3	1	0.1	0.3	1	0.1	0.3	1
σ = 20 kPa capping	**0.241**	**0.520**	**1.026**	**0.116 RF=2.1**	**0.287 RF=1.8**	**0.653 RF=1.6**	-	-	**0.505 RF=2**
σ = 100 kPa Slope in New Landfill Hr = 20 m ; φ'_r = 25° ; dr =12 kN/m³	0.221	0.462	0.909	0.086 RF=2,6	0.204 RF=2,3	0.453 RF=2,0	-	-	-
σ = 200 kPa Slope in New Landfill Hr = 40 m ; φ'_r = 25° ; dr =12 kN/m³	0.198	0.400	0.839	0.045 RF=4,4	0.094 RF=4,3	0.259 RF=3,2	-	-	-

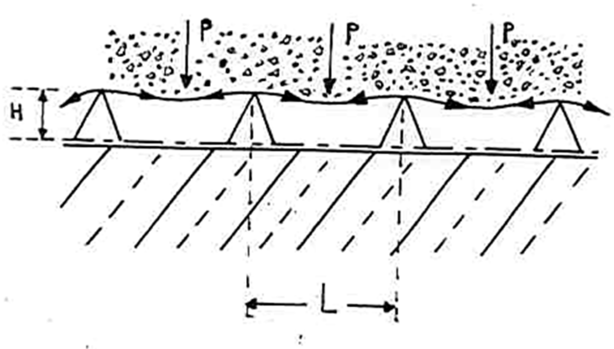

Figure 4. Decrease of draining cross-sectional area in a geocomposite in contact with a soft material (like soil or waste).

The influence in reduction of flow rate due to the intrusion of the geotextile in the core is evident from comparing flow rate testing on the core only and the geocomposite which highlight a reduction of about 50%.

geonet only	Geonet + geotextile
1.80	0.9

ISO 12958 at 1.0 hydraulic gradient and 100 kPa

3.2. Long Term Properties

For all applications, the available flow rate of the geocomposites shall be obtained by applying a set of Reduction Factors (Cancelli & Rimoldi, 1989; Koerner, 1994) using Equation 2 which take into account all the phenomena that may decrease the flow rate over the entire design life compared to the short term flow rate measured in the tests according to EN ISO 12958:2010 or ASTM D4716 - 08(2013) standard:

$$Q_a = \frac{\mathrm{Q_L}}{\mathrm{RF_{in} \cdot RF_{cr} \cdot Rf_{cc} \cdot RF_{bc}}} \tag{2}$$

where:

Q_a = Available long term flow rate for the geocomposite;
Q_L = Short term flow rate obtained from laboratory tests;
RF_{in} = Reduction Factor for the intrusion of filter geotextiles into the draining core;
RF_{cr} = Reduction Factor for the compressive creep of the geocomposite;

RF_{cc} = Reduction Factor for chemical clogging of the draining core
RF_{bc} = Reduction Factor for biological clogging of the draining core

Table 4 - Suggested range of values for the different RFs

Term	Description	Suggested range for Macdrain geocomposites
RF_{in}	Reduction Factor for intrusion of the filter geotextiles into the draining core	1,15 – 1,5
RF_{cr}	Reduction Factor for thickness change due to compressive creep of the core	1,2 – 1,5
RF_{cc}	Reduction Factor for pore/volume reduction due to chemical clogging **	1,0 – 1,3
RF_{bc}	Reduction Factor for pore/volume reduction due to biological clogging**	1,0 – 1,3
Π RF	**Product of all Reduction Factors for the site-specific conditions**	**1,38 – 4,0**
* values can change according to the type of the core and also according to the type of filtering geotextile used ** values are related to the type of liquid / fluid to be drained and to its nature (clean water, polluted water, leachate, etc)		

The Reduction Factors shown in Table 4 shall be set considering the specific conditions of each project, taking into consideration the experience and/or research on similar conditions of use.

The geotextile in a geocomposite drain needs to insure that sufficient water or liquid flows through in order to assure the functionality of the drain. Thus, it is essential that the geotextile filter resists the phenomena of clogging. The IGS defines closing as blocking of material pores by physical, biological and chemical process. In most cases, clogging occurs when the finer particles are trapped by the constrictions of the filter and therefore affecting the permeability and permittivity of the geotextile. Figure 5 illustrates constriction (i.e. passage between fibres) in a geotextile filter and spherical particle just passing through the constriction, which defines the constriction size (Giroud, 2010).

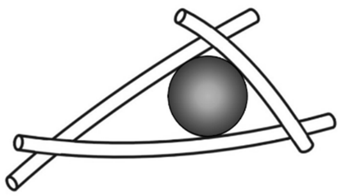

Figure 5. Constriction (Giroud, 2010).

As a consequence of this phenomena, insufficient amount of water will pass through the filter, therefore creating undesired hydraulic pressure that can affect the stability of the structure. Thus, it is essential that clogging resistance is verified.

3.3. Laboratory Test of Compressive Creep with Shear

The compressive creep behavior can significantly affect the long term draining performance of the drainage composite due to their variation of thickness at constant loads. To this end, laboratory testing can be performed using both the Stepped Isothermal Method (SIM) of time-temperature superposition (TTS) compressive creep tests and conventional isothermal compressive creep tests performed at room temperature. The testing method used were the ASTM D7361-07 (2012), Accelerated Compressive Creep of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method and the ISO 25619-1:2008, Geosynthetics - Determination of Compressive behavior - Part 1: Compressive Creep Properties.

Figure 6: Representative photo of a conventional Creep with Shear Testing Apparatus.

As shown by Figure 6, in addition, tests under normal and shear loads can be performed to simulate drainage on slopes, found in landfill capping. The flow rate of the geocomposites is obtained by applying a set of Reduction Factors which take into account all the phenomena that may decrease the flow rate over the entire design life compared to the short-term flow rate measured in EN ISO 12958:2010 or ASTM D4716-08 (2013) tests.
Testing should be done on the geocomposite as a whole (geotextile with drainage core) and not only the drainage core isolation. By assessing the system as a whole can provide a more accurate view on the performance of the geocomposite as a system.

4. Designing with geocomposites for Drainage

The design of a geocomposite drainage system will be carried out with the following procedure (Rimoldi, 2013)

1) Set all the design conditions, such as: type of project (landfill bottom or capping, vertical wall, etc.); types of soil involved (stones, gravel, clay, etc.) and their gradation curves; environment (aggressive for landfill bottom, medium for landfill capping, ordinary for walls or roof gardens, etc.); chemical – physical properties of the materials in contact with the geocomposite (pH, chemical and biological content, hardness, stiffness, etc.) and of the liquid to be drained (pH, chemical and biological content, density, viscosity, turbidity, etc.);
2) Set the boundary conditions, that is the type of materials in contact with the two faces of the geocomposite;
3) Calculate the maximum applied pressure, the hydraulic gradient and the design input flow rate for the geocomposite;
4) Select on or more geocomposites and for each of them calculate the available flow rate for the design conditions of materials in contact with the 2 faces, maximum applied pressure, and hydraulic gradient;
5) Compare the available flow rate with the design input flow rate, and consider only the geocomposites for which the former is larger than the latter;
6) Make the final selection of the geocomposite; and
7) Provide design specs and design details, in particular the method for fixing the geocomposites on the supporting surface and the connections / overlapping between

geocomposites rolls and between the geocomposites and other elements of the drainage system (manholes, perforated pipes, etc.).

5. Conclusions

It is discussed in this paper that geocomposites, for specifically drainage, have many applications and it indicates the benefits of using geocomposites to replace the traditional methods for drainage.

When designing and choosing a geocomposite, there are some short-term and long term properties that need to be considered:

- Characteristics of drainage core;
- Type and characteristics of the filter geotextiles, and process of bonding to the draining core;
- Characteristics of the materials in contact with the two faces of the geocomposite;
- Introduce reduction factors for design life;
- Consider phenomena of clogging.
- Long term performance can be significantly affected by compressive creep.
- Compressible and collapsible cores have different behavior to compression and should be considered in design.

It is important to understand the information given by a technical data sheet as these may only provide information regarding the short-term performance of a product. The designer should request all information of a products long term performance to assure the drainage system meets the requirements throughout the design life of the project.

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