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Assessment of the resistance of (geotextiles + geomembrane) lining and cover systems against localised mechanical damage

Olivier Artieres
Bidim Geosynthetics, Bezons, France

Christian Duquennoi
Cemagref, Antony, France

ABSTRACT : A new approach is proposed to design geotextiles + geomembrane lining systems in order to prevent localised mechanical damage, including puncture. The approach is based on the analysis of the elementary sollicitations and damage mechanisms of the geosynthetics. Some existing tests are presented in respect to the elemental sollicitations they represent, and are classified as either characterisation tests or empirical tests. An example of lining system design is given, according to correlation between characterisation and empirical tests.

1 INTRODUCTION

The « resistance to puncture » is a characteristic often requested before choosing and installing a lining or a cover system. A lot of information is available on this topic, but the relationships between all the data provided are not always very clear. Confusion often occurs, and designers or end users find more new questions than answers to their problems :

- Is it a characteristic of the geomembrane alone, or of the geotextile for protection alone, or of both products together ?
- What are the differences between all the tests available ?
- Is a test conducted with natural material more representative than a test conducted with artificial aggressive material, such as pyramids, cones, and cylinders ?
- What are the main parameters used in the design ?

The aim of this paper is to clarify these previous points and to propose a method to approach this important problem.

It will be underlined that the common expression « resistance to puncture » covers in fact different physical mechanisms including real static puncturing. All these mechanisms are included in the more general expression « localised mechanical damage ».

2 CIRCUMSTANCES OF LOCALISED MECHANICAL DAMAGE ON A LINING SYSTEM

The expression "localised mechanical damage" is prefered to the word "puncturing" which is commonly used. It is a general expression that groups several types of elementary actions on the lining system, including in particular, puncturing.

Localised mechanical damage can be divided into the following elementary actions (Figure 1) :

2.1 Static circumstances

These conditions correspond to 2 cases :

2.1.1. Static puncturing

This risk of puncture begins during installation as soon as an aggressive material (gravel, tools, roots,..) is in contact with the lining system under a static normal stress.

At short term, this stress is mainly due to traffic on the drainage and lining systems. At long term, the stress corresponds to the weight of the upper layers (waste or soil).

The main parameters that control this action are :

1. the shape of the puncturing material;
2. the normal force on the puncturing material;
3. the stiffness of the support.

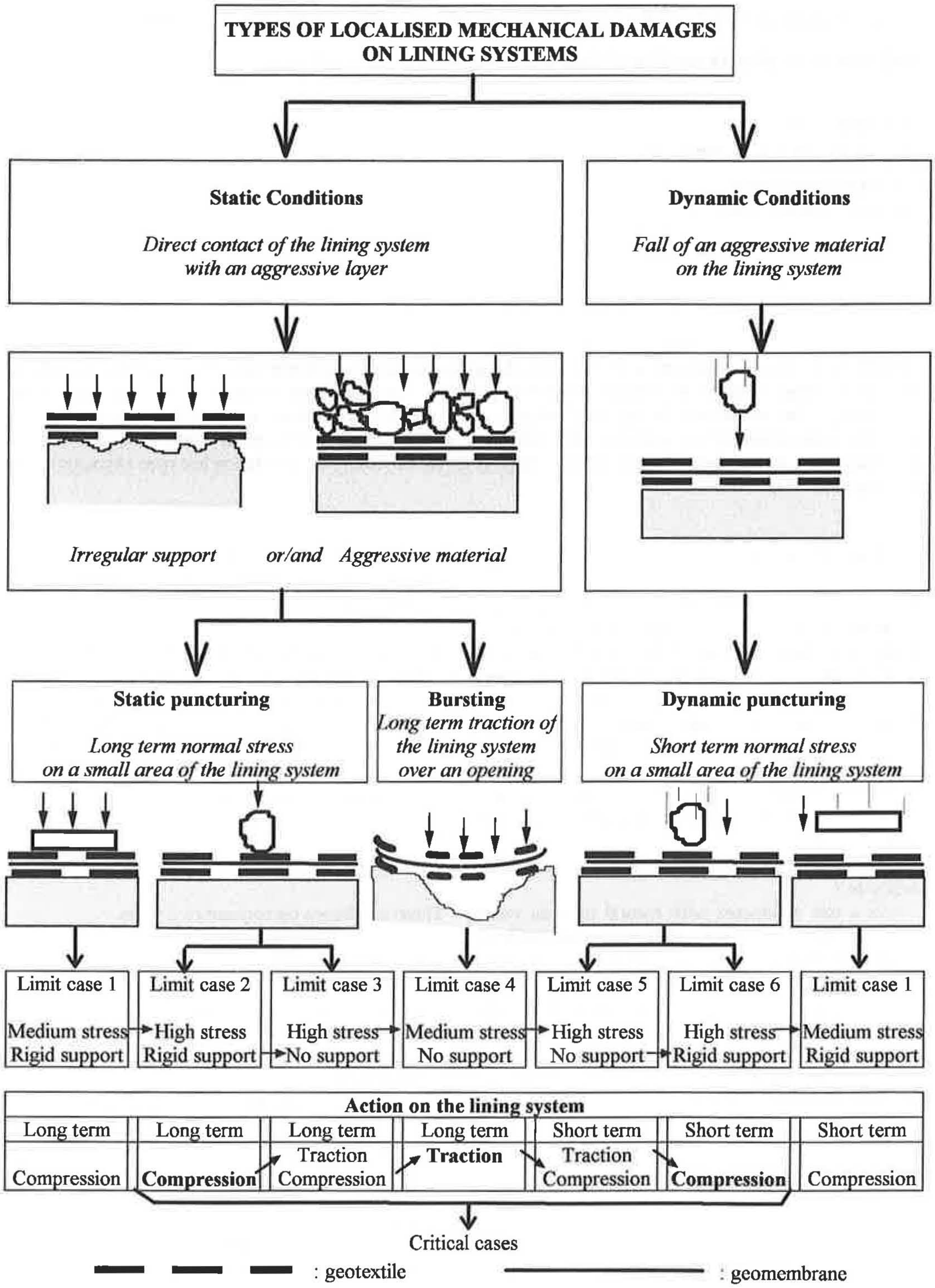

Figure 1 : Circumtances of localised mechanical damage on lining or cover systems and corresponding actions

The result of this action is the local compression of the lining system. Depending on the stiffness of the support, traction also occurs. But there is always a part of compression, even in the limit case of a static puncturing without support.

2.1.2 Bursting

The lining system bridges an opening of the support layer (between 2 aggregates, or due to local differential settlement), and it is pushed into the opening by the normal stress.

It is usually a short term effect.

The main parameters that control this action are:

1. the size of the opening;
2. the normal stress on the lining system

The result of this action is traction of the lining system.

2.2 Dynamic circumstances: dynamic puncturing

These conditions correspond to dynamic puncturing due to the fall of stones, gravel, or tools. The risk of puncture occurs during the installation stage of lining and drainage systems.

It is a short term effect.

The main parameters that control this action are:

1. the shape of the puncturing material;
2. the fall energy (weight x height);
3. the stiffness of the support.

The result of this action is the local compression of the lining system. Depending on the stiffness of the support, traction also occurs. Traction is maximum for the limit case "without support".

2.3 Actions on the lining system

For each elementary localised mechanical damage described in figure 1, the resulting action on the lining system is always a combination of a part of traction and a part of compression. Two limit cases define the variation range of the traction component:

- rigid support: no traction, high compression
- no support: high traction, medium compression.

Between these two limit cases, support stiffness varies from smooth to hard. The corresponding action on the lining system can be interpolated by varying the respective parts of traction and compression.

2.4. Combination of elementary actions

More complex situations can be divided into some of the previous elementary mechanical actions.

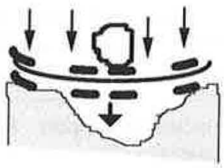

Figure 2: Combination of 2 elementary actions: bursting and static puncturing.

We can for instance imagine the case described in figure 2. It corresponds to the conjunction of bursting and static puncturing without support (limit case 3 + limit case 4). In this case, the resulting action on the lining system is a large part of traction and a small part of local compression.

3 TESTS AVAILABLE TO ASSESS THE RESISTANCE OF A LINING SYSTEM AGAINST LOCALISED MECHANICAL DAMAGE.

The evaluation of the resistance of a given lining system against localised mechanical damage is not easy.

The method often used is to carry out large scale tests that exactly *reproduce* the superposition of each layer of geosynthetic or of soil, and to apply on it a given compressive stress or a given traffic. These *empirical tests* can be done in the laboratory with performance tests or directly in the field. Such tests are long and expensive, and they cannot be repeated many times to fit the design and to find the best technical and economical association of geotextile and geomembrane for a given condition (Table 1).

The interpretation of the empirical tests is sometimes difficult. For example, the pressure plate test has the purpose of measuring the resulting deformation of the geomembrane after contact of a granular layer under a given normal stress. Deformations are measured by means of mechanical scanning along lines randomly selected along the sample with a resolution of about 5 mm. Werner et al. (1995) observed that when increasing the scanning resolution, the maximum measured deformation also increases: on a specimen, these authors found that a maximum deformation of 0,27% measured with a scanning resolution of 5mm corresponds in fact to a maximum deformation of 3% when measured with a scanning resolution of 0.5mm. It is therefore difficult to accept such tests as a basis for design or to specify products.

Table 1 : Some empirical tests assessing the resistance of lining systems against localised mechanical damage.

Test method or standard	Puncturing material	Support	Result
Pressure plate ÖN S2076 BAM (D)	Steel balls or gravel 16/32	20mm elastom.	Geomembrane deformation at a given stress
Perforation by gravel NF G84510	Gravel 10/20	Steel plate	Normal stress before perforation
Hydraulical puncturing Cemagref (F)	Natural gravel	Water	Waterpressure at break

Another way of testing consists in assessing the properties of the lining system, and also of each layer separately (geomembranes or geotextiles) with *characterisation tests* in the lab (index tests). These tests are developped to *simulate* each elementary action and to measure the behaviour of the lining system for each of them. The testing parameters are well defined (shape of the puncturing material, stiffness of the support) and the measurement of forces, stresses and strains applied on the product is accurate. Such tests are therefore repeatable, of low cost and fast. Figure 3 gives a list of some tests simulating limit cases of elementary actions.

Werner et Pühringer (1995), and Artières et Delmas (1995), give both a description and an analysis of the static and dynamic puncturing tests. The efficiency of the geotextiles for geomembrane protection is clearly shown. The latter has especially observed that in case of soil supports, even

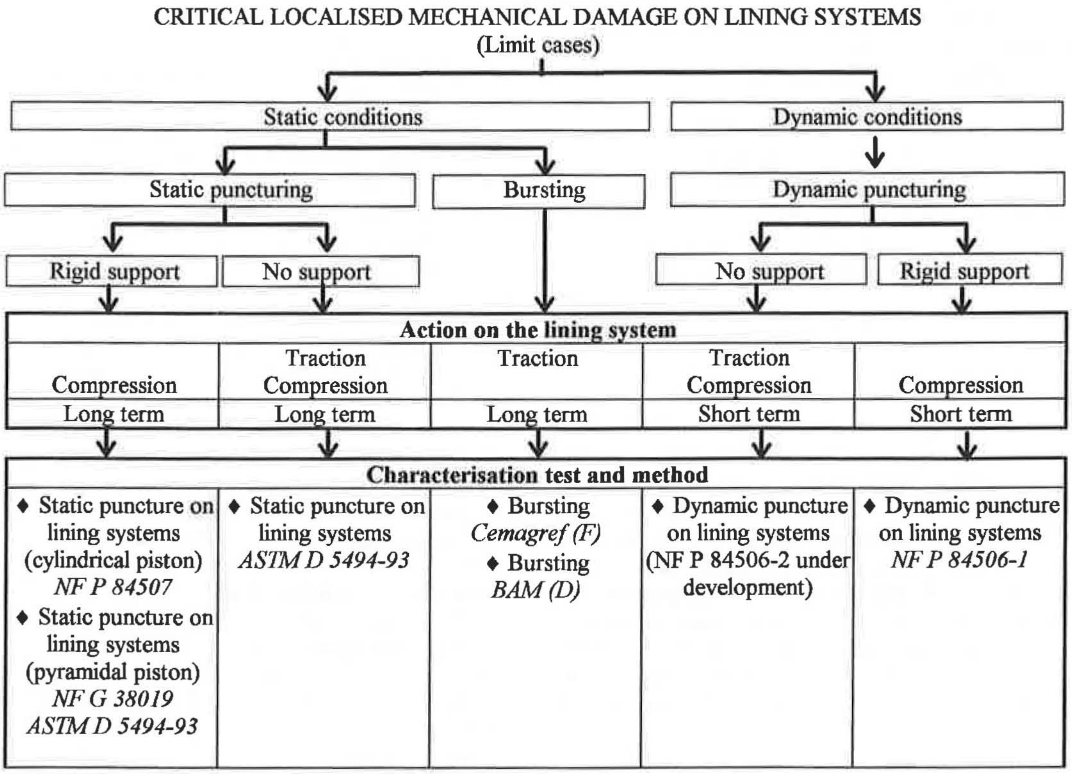

Figure 3 : Elementary actions of localised mechanical damage on lining systems and some corresponding characterisation tests.

compacted, the lining systems always elongate and the mechanical properties of the geotextiles and the geomembrane in the lining system are very important.

4 NEW DESIGN APPROACHES TO PREVENT LOCALISED MECHANICAL DAMAGE OF A LINING SYSTEM

From the type of tests used to choose a lining system, two design approches can be considered (figure 4) :

1. The *black box* design : Lining systems are only chosen from empirical tests. With this method, it is possible to determine whether a lining system fails under given testing conditions or not, but the reasons why are unknown. It is therefore difficult to improve or to adjust the products inside the lining system.

This *conformist design* cannot take into account all the new possibilities offered by the geosynthetics market.

2. To be *innovative*, a design must be based on reliable knowledge of the behaviour of the products under given elementary actions. With characterisation tests, the influence of the design parameters (normal stress, stiffness of the support,...) on each product can be assessed. They help the designer to make a first choice among all the possibilities of associations between geotextiles and geomembranes. With this method, empirical tests are more suitable to validate one or two associations of the materials which were preselected with characterisation tests.

5 EXAMPLE OF LINING SYSTEM SELECTION WITH CHARACTERISATION TESTS

The geomembrane and the protection inside a lining system are interdependent. The characterisation static puncture tests show clearly that in case of a deformable support such as a soil layer, the product with the highest puncturing modulus (puncturing force divided by piston displacement) governs the mechanical behaviour of the whole system.

In fact, the geomembrane has often the highest modulus inside the system. If the modulus of the geotextile is much smaller than that of the geomembrane, only a small part of its mechanical properties will be used to avoid the deformation of the geomembrane and to protect it.

From this, it is possible to compute the resistance to static puncturing of a lining system from the resistance of each product separately.

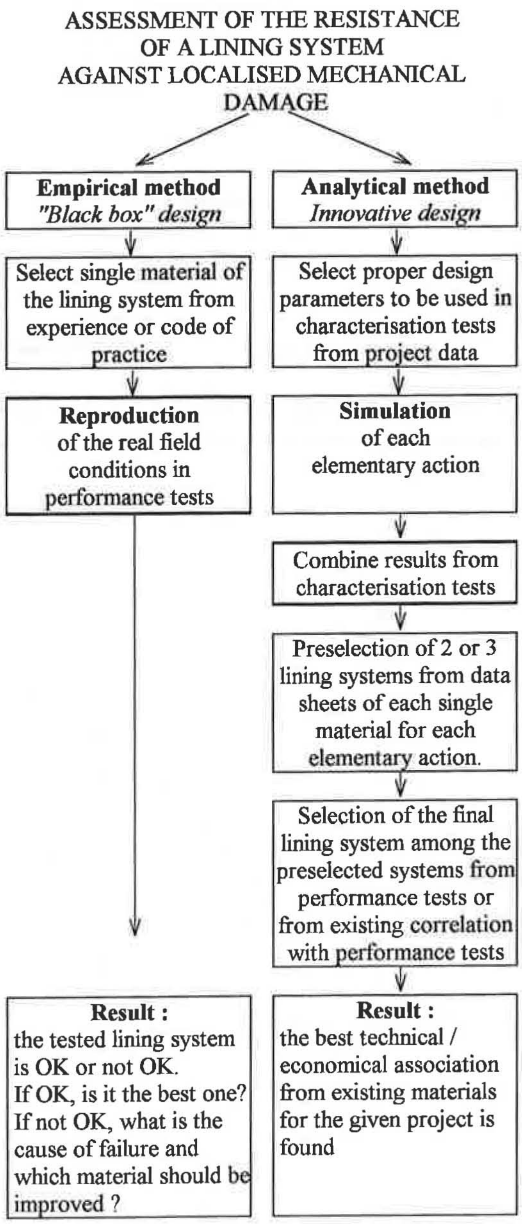

Figure 4 : comparison of two methods for lining system selection.

The maximum resistance of the system corresponds to the sum of the resistances of each individual product for the piston displacement corresponding to the maximum puncturing force of the product having the highest puncture modulus (figure 5), and not the sum of the maximum resistance of each product considered separately.

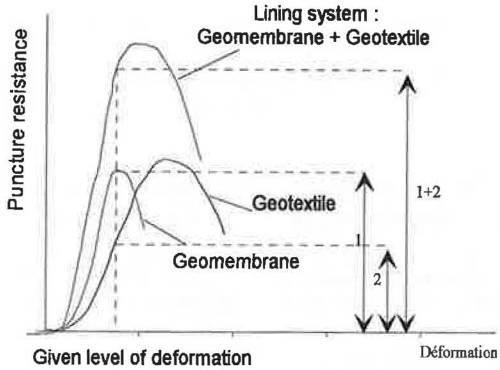

Figure 5 : Principle of addition of the static puncturing resistance of 2 components of a lining system.

It is thus possible for this elementary action to compare several lining systems or several geotextile-geomembrane associations for a given mechanical resistance to static puncture. Table 2 gives an example of equivalency between 2 lining systems.

6 EXAMPLE OF LINING SYSTEM DESIGN COMBINING CHARACTERISATION TESTS AND EMPIRICAL TESTS

A further step of lining system selection consists in correlating characterisation tests with empirical tests.

Figure 6 is an example of correlation between empirical tests on the one hand and characterisation tests on the other hand.

Empirical tests used to plot the data points are:

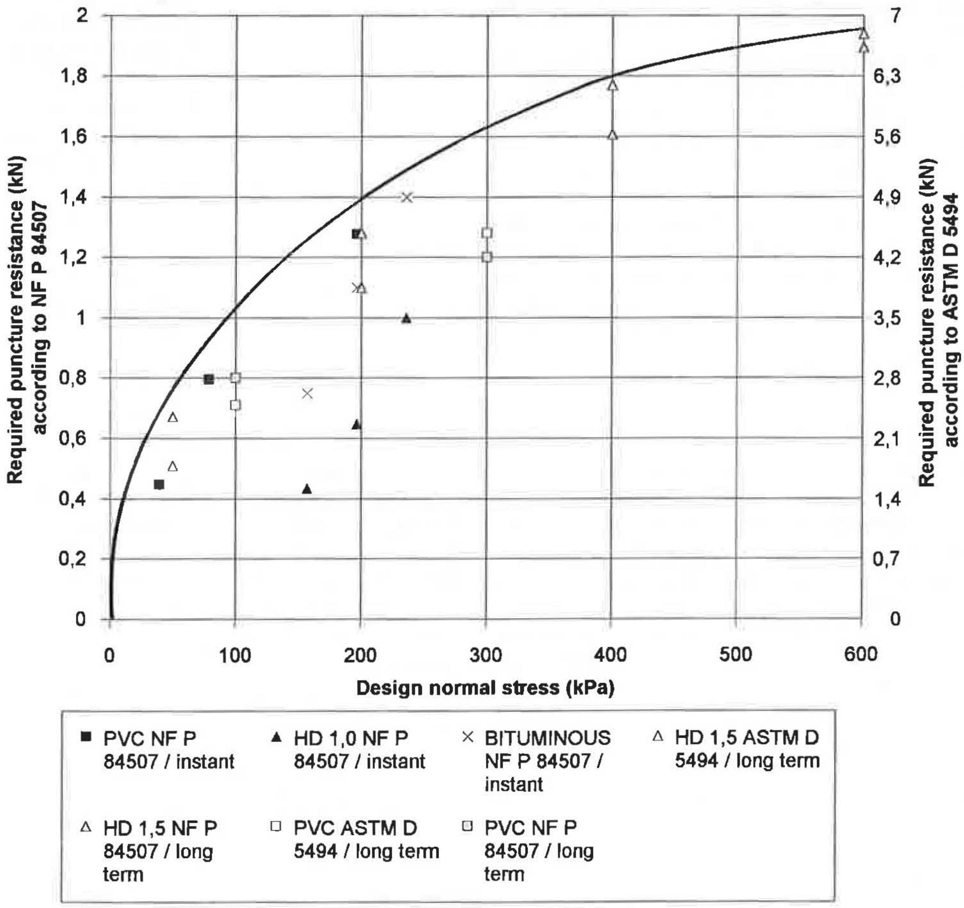

Figure 6 : Example of possible design curve obtained from empirical puncturing tests with crushed gravels on a rigid support, and static puncturing tests on lining systems.

- long term puncturing on a rigid surface with 20/40 crushed gravel; the following rule is used: after puncturing, the lining system performs well if the residual functional thickness of the geomembrane exceeds 1 mm. It has to be remembered that in France, geosynthetic liners are considered as geomembranes if their functional thickness is above 1 mm. The products used in the tests are 1,5 mm thick HDPE and PVC geomembranes, and polypropylene non-woven needle-punched continuous filaments geotextiles.

- modified french standard NF P 84510: instantaneous puncturing on a rigid surface with 10/20 crushed gravel; the following rule is used: after puncturing, the lining system performs well if less than 3 leaks are detected among 10 tested liner samples. 1mm thick HDPE and PVC, and 4mm thick bituminous geomembranes were used, associated with polypropylene non-woven needle-punched continuous filaments geotextiles. A factor of safety of 20 is applied to the result of the test, namely the maximum normal stress the lining system can sustain while performing. This factor of safety is believed to be necessary to account for the uncertainties related to the applied rule of 3 leaks in 10 samples. As the limit state considered here is complete failure of the lining system, a high factor of safety is deliberately chosen.

Characerisation tests are :

- french standard NF P 84507 static puncturing characterisation test,

Table 2 : Example of resistance to static puncture according to characterisation tests of 2 lining systems and of their separate products.

Lining system 1 : ♦ 2.5 mm HDPE geomembrane

Lining system 2 : ♦ PP nonwoven needle-punched protection geotextile
♦ 1.5 mm HDPE geomembrane

	Stactic puncturing resistance		
Test	NF P84507	NF G38019	ASTM D5494
Piston	cylinder	pyramid	pyramid
Support	no	no	rigid
Lining system 1	1.0 kN	3.2 kN	1.5 kN
Lining system 2	1.1 kN	3.9 kN	1.7 kN
Separate products :			
Geotextile	0.5 kN	1.9 kN	0.3 kN
1.5 mm HDPE GM	0.7 kN	1.5 kN	0.7 kN
2.5 mm HDPE GM	1.0 kN	3.2 kN	1.5 kN

- US standard ASTM D 5494-93 static puncturing characterisation test.

With this type of correlation, the designer can easily specify the static puncturing resistance of a lining system according to the type of aggressive material, the type of support and the normal stress. For a given puncturing resistance, a lot of lining systems can thus be proposed.

For example, a designer has to specify a lining system for a landfill. The drainage system consists in 50 cm of 20/40 crushed gravels. The maximum height of wastes is 20 m, corresponding to a total normal stress of about 300 kPa. According to figure 6, the minimum resistance to static puncture of the lining system must be 1.6 kN according to NF P 84507 or 5.6 kN according to ASTM D 5494. If the geomembrane is not specified, geosynthetics producers and installers can offer many confgurations of lining systems. If the geomembrane is specified, they have to propose a geotextile that meets the previous requirements.

These curves are only examples to present the design method. A lot of other comparative tests have to be carried out to plot proper design curves.

7 CONCLUSION

Whereas numerous tests and analyses still have to be conducted, the present study shows that some questions can yet be answered :

- Resistance to localised mechanical damage is a characteristic of the whole lining system. One cannot consider the protection properties of a geotextile without the knowledge of the geomembrane it will protect. On the other hand, a geomembrane cannot be designed against localised mechanical damage without considering the characteristics of its protection geotextile(s).
- Empirical tests are no sufficient to optimise a geomembrane-geotextiles lining system according to its resistance to localised mechanical damage. This type of test will undoubtedly conduct to oversizing the system in some cases, and to undersizing it in other cases.
- Empirical and characterisation tests are complementary at the present stage of knowledge, because they are necessary to plot design curves. It is expected that, in the future, only characterisation tests will be needed.
- The main parameters that have to be used in the design of geotextile-geomembrane lining systems are mechanical properties of the geosynthetics, such as resistance to puncture and tensile characteristics.

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