# Testing of Protection Geosynthetics for Geomembranes in European Landfill Applications

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ABSTRACT: Geomembranes are often used in civil engineering applications to create a hydraulic barrier. Their basic function is to remain impervious over the entire design life of the project. However, mechanical stresses induced by confined materials could produce a deformation of the membrane and in critical situations, could ultimately puncture it. This paper will describe the design-related approach for protection layers and explain the concept of the test. Results will be presented, where different geotextile types were tested and the testing conditions were changed. Overall this paper will give a closer insight of this design-oriented test method.
*Keywords: protection geosynthetic, protection efficiency, EN 13719, Landfill Application*

## 1 INTRODUCTION

Geomembranes are often used in civil engineering applications to create a hydraulic barrier. With nearly all barrier systems, deformations occur in the geomembrane layer and need to be quantitatively assessed.

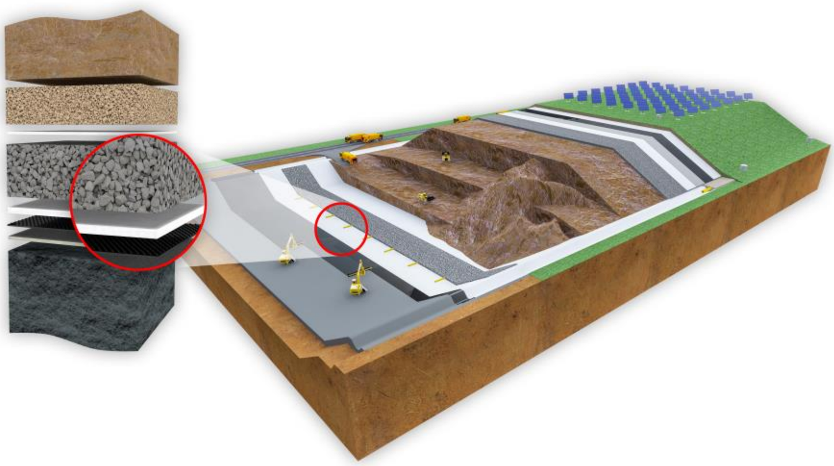


Figure 1: Typical construction of a landfill with base and cap sealing

The basic function of a geosynthetic lining system is to remain impervious over the entire design life of the project. However, mechanical stresses induced by confined materials could produce a deformation of the membrane and, in critical situations, could ultimately puncture it.

Figure 2: Deformation without protection layer

A protection geosynthetic needs to be designed in consideration of the planned geomembrane and their thickness as well as in consideration of the soil material (typically mineral drainage layer) and the surcharge placed above.
The purpose of the protective layer is to:

- minimize the risk of barrier damage or puncture during construction and during the subsequent operation,
- minimize the strains in the barrier and, hence, the risk for future punctures forming, due to, for example, environmental stress cracking

Inappropriate selection of protection geotextiles can result in a failure of the lining material.

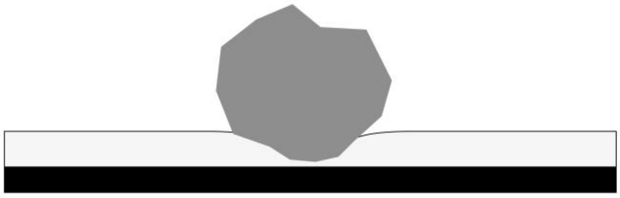


Figure 3: Deformation with protection layer

## 2 CYLINDER TEST ACCORDING TO EN 13719 FOR CE CERTIFICATION

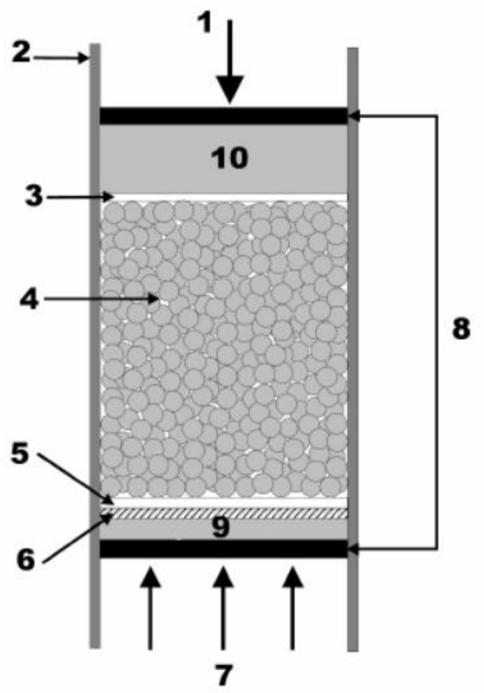
Related to the EN application standards, the protection efficiency of a geosynthetic on geomembranes has to be tested, relevant to specific conditions of use, for the following applications:

- EN 13254, Characteristics required for the use in the construction of reservoirs and dams; tested by 13719 and 14574
- EN 13255, Characteristics required for use in the construction of canals tested by 13719 and 14574
- EN 13256, Characteristics required for the use in tunnels and underground structures tested by 14574
- EN 13257, Characteristics required for use in solid waste disposals tested by 13719 and 14574
- EN 13265, Characteristics required for use in liquid waste containment projects tested by 13719 and 14574

The EN 13719 describes the determination of the long-term protection efficiency of geotextiles in contact with geosynthetic barriers and might be useful for protection in applications like landfills.
This test is valid only for the purpose of measuring identification values and for comparison tests between different products, but not for achieving site-related results. For site-related results, Annex B of this standard has to be used.
The EN 14574 describes the determination of the pyramid puncture resistance of supported geosynthetics and might be useful for protection in applications like tunneling.
The EN 13719 always requires tests with three loads, such as 300 kN/m², 600 kN/m², 1200 kN/m². The load is applied using a simulated standard aggregate (steel balls with a 20mm diameter) placed on the top of the geosynthetic specimen, which is supported on a simulated standard subgrade (lead sheet and dense rubber pad) for a standard time (see Fig. 4).
The local strain in the lower surface of the geomembrane is measured at the lead plate and used to determine the protection efficiency.
The EN 14574 can be useful for applications where no drainage gravel is used but where the protection geosynthetic is used against concrete (e.g., in tunnels).

## 2.1 *Test equipment by EN 13719*

A smooth-sided steel cylinder having an internal diameter between 300mm and 500mm is used. For details, see Fig. 4.
The elastomer plate is a 25 ± 1 mm thick rubber pad having a diameter similar to the lower steel plate and a hardness of 50 ± 5 Shore A has to be used. On top of the elastomer, a lead plate (1.3 ± 0.1 mm thick from a grade 3 lead, according to EN 12588) is placed.
As simulated, standard aggregate 20 mm diameter steel balls with a minimum depth of 150 mm have to be placed on top of the protection layer.




1. applied load
2. cylinder
3. separation geotextile
4. mineral drainage layer (in-situ soil) or 20mm steel balls
5. protection geotextile *(material to be tested)* and geomembrane
6. soft metal plate
7. load cells
8. top and bottom plate
9. elastomer pad as base
10. sand

Figure 4: Cylinder test according to EN 13719 and EN 13719 Annex B

### 2.2 *Test procedure*

Assemble the apparatus and build up the layers as shown in Fig. 4. The simulated aggregate should be placed on the specimen. Placing the pieces of the simulated aggregate individually is not permitted. Gradually apply increasing stress over a maximum period of 1h up to 300 kN/m², as registered by the load cells or pressure gauges beneath the lower steel plate. Maintain the stress for 100 hrs. Then, dismantle the apparatus and carefully recover the geosynthetic and the lead sheet.
Using a new specimen and a new lead sheet, repeat steps above but with a stress of 600 kN/m².
Using a new specimen and a new lead sheet, repeat steps above but with a stress of 1200 kN/m².

### 2.3 *Evaluation*

Examine the geosynthetic and record the number of perforations, if any, through the geosynthetic, together with any significant physical damage.
Examine the lead sheet and select the three deformations with the greatest strains. Do not select any deformation with any part closer than 25 mm to the edge of the sheet. For each deformation, select two axes at right angles and on each axis mark the limit of the deformation. Defining the limit of the deformation should be done accurately because the difference between the deformed axis length and the non-deformed axis length is small.
Using the deformation measuring device, start at one edge of the deformation and work along one of the axes. Determine the vertical displacement with an accuracy of 0.01 mm at 3.0 ± 0.20 mm horizontal intervals to the edge of the deformation. The edge of the deformation is defined as the point where two consecutive readings 3 mm apart have a vertical height difference of less than or equal to 0.06 mm. Repeat the measuring procedure along the other axis.
Alternatively, direct local strain measurements may be made using calibrated laser or optical scanning.
Deformation measurement should be completed within 24 hrs of removing the test load. From the measurements, calculate the non-deformed length "$l_u$" and the deformed length "$l_d$" using a series of Pythagorean calculations.
For each axis, calculate to 0.01 the local strain, as defined above, i.e. $\{(l_d - l_u)/l_u\}$ (see Fig. 5).

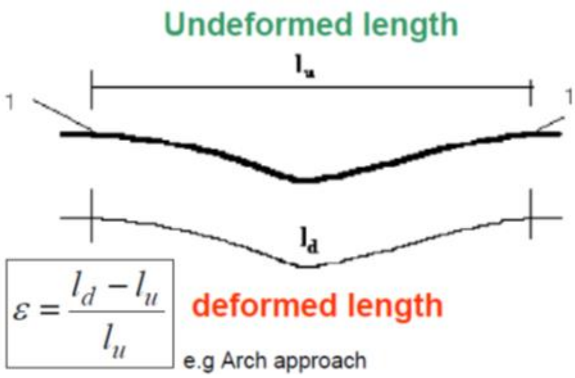



Figure 5: Measuring and calculation of local strain

Calculate the arithmetic mean of the six local strains (two from each depression) determined for each lead plate and give an average value of these six local strains for each load.

## 3 CYLINDER TEST FOR LANDFILL APPLICATION

The sealing system of a landfill has to work for a long time, e.g. ≥ 100 years. For that reason, the sealing has to work reliable. The geomembrane has to be installed in such a way that the sealing element can work without any damage.
Annex B of EN 13719 describes site-specific testing (see Fig. 4) with granular used at site and the load applicable to a site.
An object with sharp edges and points initially has only a small contact area on the protection layer. The acting load therefore creates a more or less local compressive stress. In an ideal case, the protective layer has to distribute these perforating compressive stresses in such a manner that the compressive stress load on the geomembrane is homogeneously distributed over the surface without local peaks. In real life, the protective effect of a protection layer is sufficient if the load distribution in the protection layer is dispersed to such an extent that only slight indentations arise in the geomembrane. Critical limiting strain of geomembranes means that damage in the microstructure of the partially crystalline material develops when strains exceed this limit, which might then develop into macroscopic stress cracks. Conversely, stress crack formation is impossible when deformations stay below this limiting strain, regardless of the stresses imposed. The critical limiting strain of HDPE materials lies within the range of 3 % (see Fig. 6, small deformation).
Such a limiting value for the permissible deformation can also be derived in another way. Koch et al. (1988) suggested that tensile stresses are considered which arise from different deformation events, taking into account stress relaxation in the geomembrane. These stresses are then compared with the stress level that the HDPE material can tolerate over the long term without stress crack formation (long-term pipe pressure test).
A maximum 0.25 % local strain was set as the limiting value for local deformation in Germany and in many other European countries.

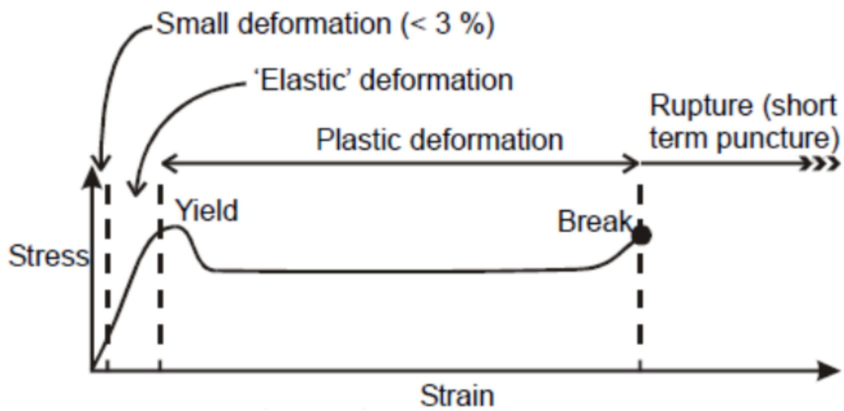



Figure 6: Stress/strain behavior of HDPE geomembranes

This value was proposed by the German 'Quo Vadis working group' (Dixon, J.H., von Maubeuge, K. (1992)) and was arrived by taking the maximum total allowable strain to be 6 %, based on results from HDPE gas line pipe testing studies, and applying a factor of safety of 2. This gives a total permissible strain of 3 %. Because of possible settlements in the underground during and after the construction phase a safety factor must be taken into account of the requirement. Furthermore, due to chemical and thermic attack, the geomembrane can be stressed more on site.

This strain can therefore be used as criterion for the design of protective layers: protective layers must be designed in such a way that the local strains resulting from indentations by objects with edges and points do not exceed the limiting strain.
Thus a 0.25 % local strain was set as the limiting value for local deformation in Germany and in many other European countries.

### 3.1 *Cylinder Test based on EN 13719 Annex B and based on GDA E3-9*

In Germany, the mechanical protection efficiency is tested since more than 25 years with the Cylinder Test as described according to EN 13719. Originally, it was described on the occasion of a Quo Vadis work shop in the late ‘90s. Later on, details for this test method were defined in GDA E3-9 (GDA = Geotechnik der Deponien und Altlasten = Geotechnics of Landfills and Contaminated Sites). The principles are described in EN 13719 Annex B.

#### 3.1.1 *Test equipment*

The test equipment is exactly the same as described in 2.1 with one exception: instead of using ≥ 150 mm height 20 mm steel balls, granular material as it is intended to be used at a site has to be used in a height of ≥ 300mm. As geomembrane a 2.5 mm smooth/smooth geomembrane has to be used, even when a structured geomembrane will be installed at site (see Fig. 4).

#### 3.1.2 *Factors for long-term behavior depending on testing time and temperature*

To ensure representative test results and for extrapolation of the short-term test in comparison to long-term performance in-situ, the surcharge has to be multiplied with an additional load increase factor (see Table 1). This load increase factor is based on several influences relating to the test conditions (e.g. standard test period and temperature) and is defined in the German BAM specifications.

Table 1. Factors for long-term behavior and testing load

| Test Temperature | Test Duration | Test Load |
|---|---|---|
| 40°C | 1000 hours | 1.50 x Design Load |
| 20°C | 1000 hours | 2.25 x Design Load |
| 20°C | 100 hours | 2.50 x Design Load |

#### 3.1.3 *Test procedure*

Assemble the apparatus and build up the layers as shown in Fig. 4. The granular from site should be placed on the specimen. Placing pieces of the aggregate individually is not permitted. Gradually apply increasing stress over a maximum period of 1h up to the calculated test load following the principle described in 3.1.2. Keep the stress constant for the defined testing time, following the principle in 3.1.2. Then, dismantle the apparatus and carefully recover the geosynthetic and the lead sheet.

#### 3.1.4 *Evaluation*

After completion of the test, the geomembrane is inspected for damages of its upper surface (cracks or nicks), sharp-angled deformation, and maximum permissible local strain using the metallic plate. With the use of this soft metal plate, deformations in the geomembrane can be measured after the test procedure.
The average longitudinal strain in the geomembrane is obtained by fitting a circular segment to the indentations in the lead sheet, selecting the most crucial segment, and calculating the arch elongation. This has to be done at a minimum at the three damage points with the visually highest deformations. At each deformation, two directions are measured due to the defor-

mation. Determine the vertical displacement with an accuracy of 0.01 mm at 3.0 ± 0.20 mm intervals with sizes of the drainage gravel up to 32 mm and in intervals of 1.5 mm for sizes of the drainage gravel up to 16 mm.
The allowable deformation for the average of the six aches (three deformations) is less or equal 0.25 %.

# 4 TYPICAL RESULTS FOR EN 13719 AND EN 13719 ANNEX B

## 4.1 *Examples for EN 13719 / CE*

Fig. 7 shows a comparison of three different 300g/m² geosynthetics tested following the procedure for the CE declaration. The difference in the results shows that with higher thickness the best protection efficiency is achieved. A higher strength on the other hand has no positive influence on the protection efficiency.
Fig. 8 on the other hand shows the influence of a higher weight with similar production technology. With higher weight and higher thickness a better bedding effect for the drainage granular/steel balls is achieved and consequently the average local strain decreases.

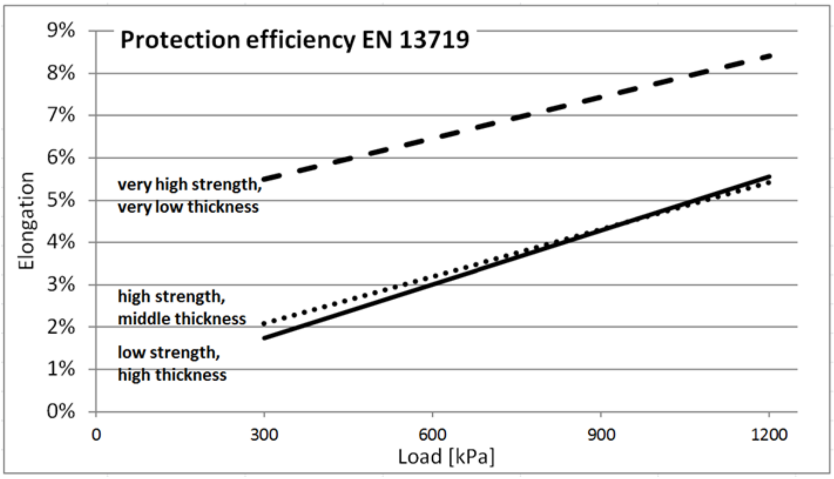



Figure 7: Average local strain with different 300g/m² protection layers

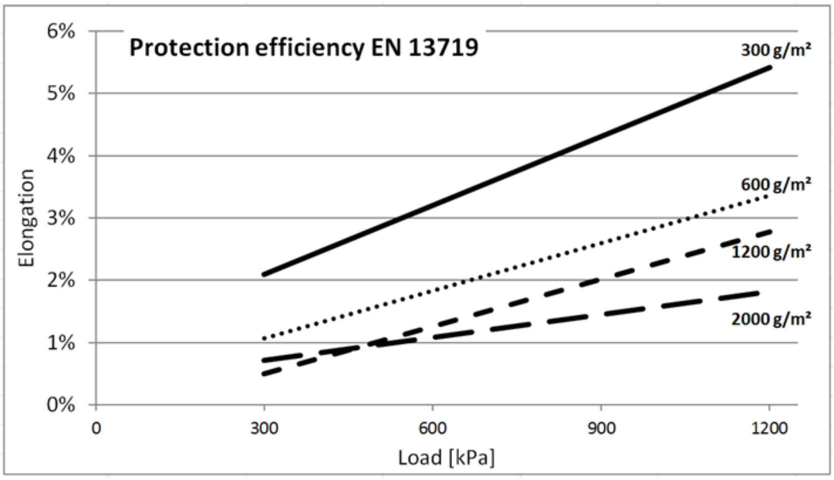


Figure 8: Average local strain with protection layers with different weights

### 4.2 *Examples for EN 13719 Annex B*

A general recommendation for a protection layer corresponding to a drainage material used at site and corresponding to the load at site is really critical. There are always variations in waste load, size of the drainage granular, hardness and sharpness of the drainage granular, and all this has a major effect on the required protection layer. Fig. 9, 10 and 11 show some results at loads of approximately 450 kPa, 600 kPa and 900 kPa, mainly with rounded gravel. The elongations are the max. (dark color) and the average local strains (light color) measured.

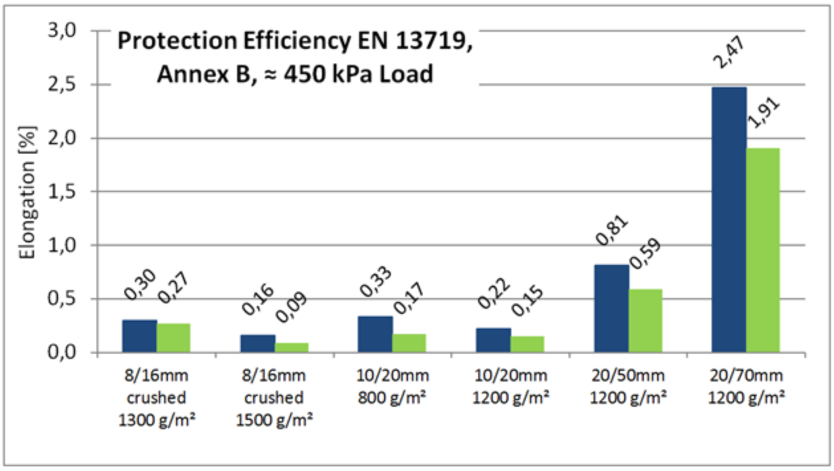



Figure 9: Average local strains under ≈ 450kPa with different grain sizes and different protection layers

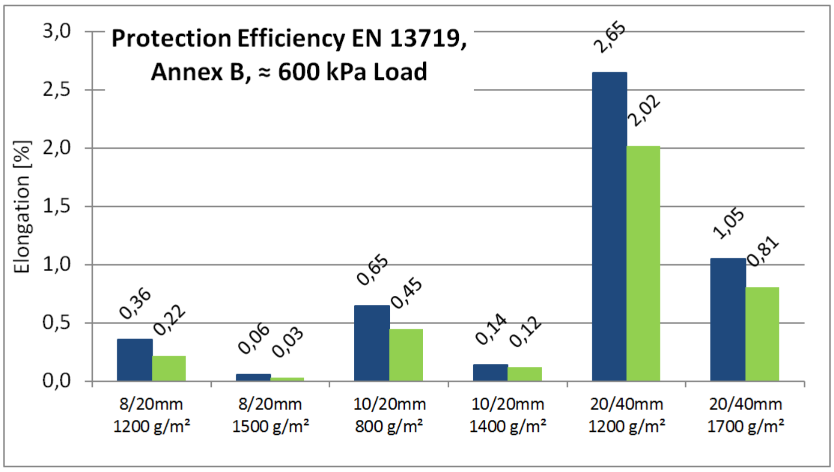



Figure 10: Average local strains under ≈ 600kPa with different grain sizes and different protection layers

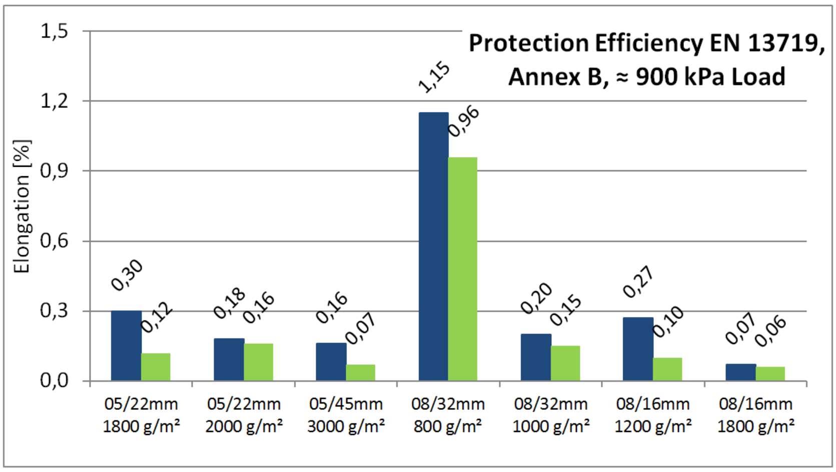



Figure 11: Average local strains under ≈ 900kPa with different grain sizes and different protection layers

Schlüter (2014) tried to find a correlation (see Fig. 12 and 13) in which a first identification of useful protection layers is given based on hundreds of tests. Depending on the load and drainage layer - rounded gravel only - the weight of a protection layer can be estimated. This estimation must be confirmed with site-specific tests.

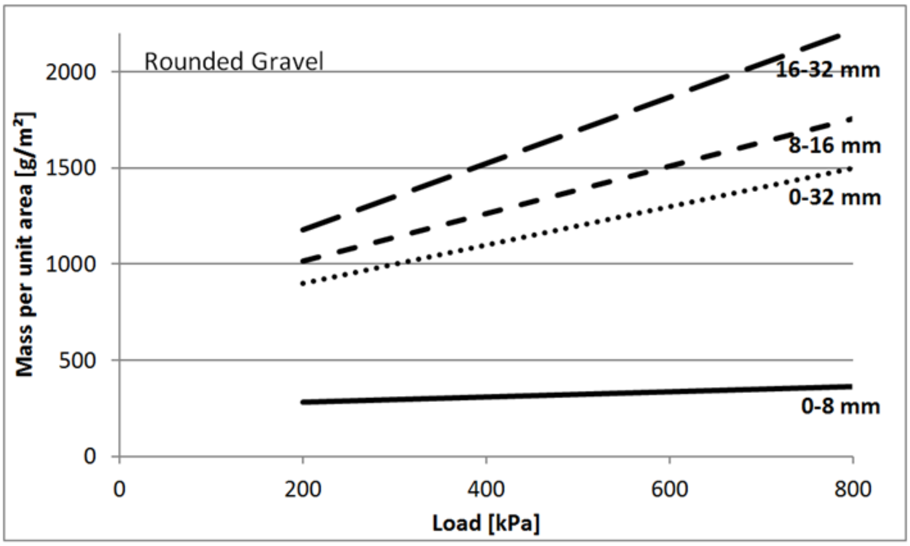



Figure 12: Estimated weight of the protection layer with rounded gravel depending on load (up to 800 kPa)

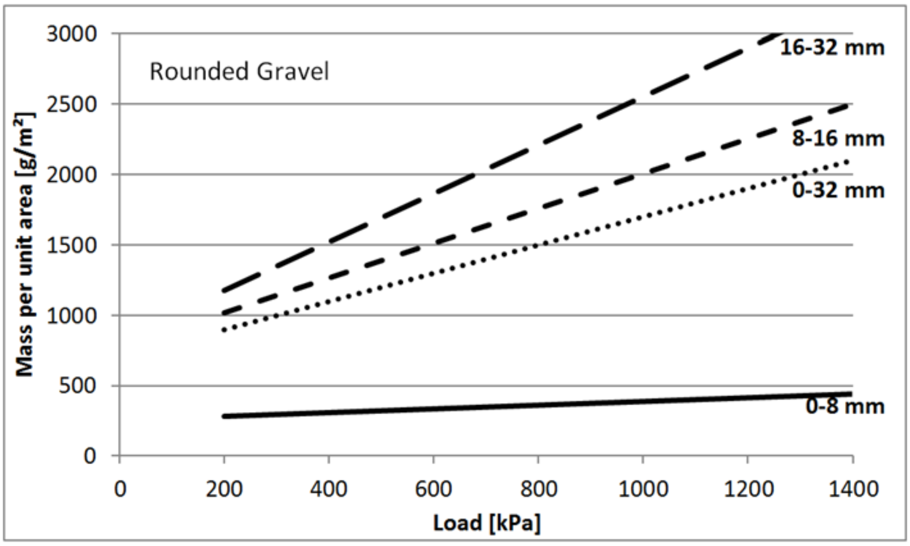



Figure 13: Estimated weight of the protection layer with rounded gravel depending on load (up to 1400 kPa)

## 5 PROTECTION EFFICIENCY TESTING AND RESULTS IN FRANCE

### 5.1 *Approach*

The European regulation on waste stipulates that in addition to a geological barrier, a leachate collection and sealing system must be added. This includes an artificial sealing system (geomembrane) and a drainage layer.
The regulation of waste landfilling is currently evolving in France. It will be allowed to replace a part of the gravel layer at the bottom of landfills by a drainage geocomposite, provid-

ed that the hydraulic equivalence can be demonstrated. Concerning puncture actions on the geomembrane, two questions arise:

- Is the geocomposite able to ensure geomembrane puncture protection from the gravel layer and limit the stress development in the geomembrane?
- Conversely, may the geocomposite induce indentation and/or deformation on the geomembrane?

Stoltz et al. (2013) developed a methodology to assess the efficiency of protective materials by a performance test. This performance test, described below, included a visual inspection on the geomembrane specimen following by a burst test on the same specimen. The visual inspection consisted of detecting any damage on the geomembrane as suggested by the French Chapter of the International Geosynthetics Society (IGS). A detailed analysis was made on the geomembrane to notice any damage. If an unacceptable damage was identified on a geomembrane specimen (indentation, severe deformation, or hole), the geotextile that was used to protect was considered as non-efficient. In any case, this designation was confirmed by a burst test on the geomembrane specimen (useless in case of a hole). This test was performed on geomembrane specimens following EN 14151. It consists in applying a pressure under the specimen with a circular shape, which deforms the geomembrane and, in the specimen center, induces an isotropic stress in the tangent plane of the geomembrane. The property considered for the burst test analysis is the strain at failure since it permits a better distinction of the damage effects for HDPE geomembranes.
Using this performance puncture test, Stoltz et al. (2013) presented and compared results obtained with 11 nonwoven needle-punched geotextiles having an average mass per unit area of 1000 g/m², protecting a 2mm-thick HDPE geomembrane used with a granular layer composed of either 20/40 mm angular or 20/40 mm rounded particles. Some results of the following are derived from this study.
Other tests were also performed on drainage geocomposites, for which the geotextile had a mass per unit area greater than or equal to 1000g/m$^2$. Various types of drainage geocomposites were included containing different drainage cores. In some cases, it was noticed that indentations to the geomembrane were observed due to the drainage core, additionally to indentations due to gravel. Results are too scarce at the moment to allow conclusions, but it is the authors' belief that this point deserves further research.

## 5.2 *Testing procedure*

Tests are performed in a metric-scale experimental device (Fig. 14) that permits to reproduce the liner system with a good representativeness.
The regulation on waste landfilling in Europe states that the substratum of a liner system in a landfill has to be a compacted clay layer. To reproduce this layer, a dense 0.95 m diameter rubber pad 25 mm thick was used. This material has a hardness of 50 Shore A and was chosen as proposed in the standard EN 13719.
Constant vertical load (design load) is applied during a basic duration of 1000 hours (long-term test) at a temperature of 40°C. As indicated in the EN 13719 standard, it is possible to reduce the test duration at 100 hours and the temperature at 20°C with a load increase factor of 1.67.

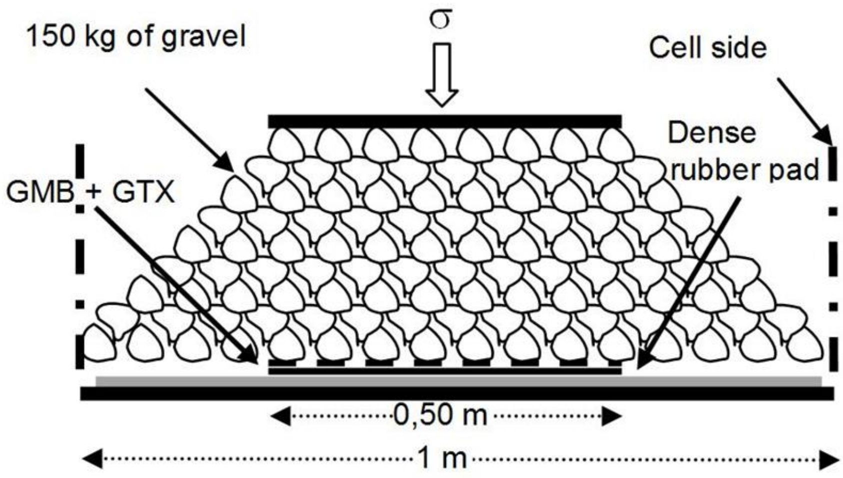



Figure 14: Schematic of the experimental device for the static puncture tests.

After carrying out the static puncture test in the large-scale device, the analysis of the protection efficiency of the geotextiles were both based on a visual inspection and on a burst test performed on the geomembrane. In any case, the major criterion that determined whether the protection was efficient or not was the burst test.

The visual inspection consisted in detecting any damage on the geomembrane. Five type of damage scenarios were evaluated:

- “Scratch” with no reduction of the geomembrane thickness
- “Notch” with low reduction of the geomembrane thickness
- “Indentation”: significant reduction of the geomembrane thickness but without any hole
- “Deformation” with no reduction of the geomembrane thickness
- “Hole” or “opening”

The burst test was performed on the tested geomembrane specimens in the static puncture tests following EN 14151. It consisted of applying a pressure under the specimen with a circular shape, which deforms the geomembrane and, in the specimen center, induces an isotropic stress in the tangent plane of the geomembrane.

During this test, the bending strain at the center of the specimen is measured. During the duration of the burst tests the vessel pressure and the permissible bending strain determine the stress and strain of the geomembrane, based on a hypothesis that considers the strain as spherical and homogeneous, as well as the incompressibility of the geomembrane and a constant thickness of the geomembrane.

For each geomembrane specimen subjected to a static puncture test, a spherical piece with a 0.3 m diameter was sampled. As far as possible, the geomembrane specimen for the burst test was centered on the most noticeable damage.

The properties considered for the burst test analysis are the maximal stress (yield stress), the strain at maximal stress, and strain at failure (burst). To assess the performance of a protective geosynthetic, current research seeks to evaluate which level of residual mechanical characteristics is adapted for HDPE geomembrane.

### 5.3 *Typical results*

Typical results (Fig. 15) presented in Stoltz at al. (2013) show the performance of 11 protective geotextiles protecting a 2mm-thick HDPE geomembrane with the puncturing damage of a 20/40 mm angular granular material loading at 300 kPa.

The big columns correspond to the geotextile mass per unit area while the small columns correspond to the thickness. The columns are green when the protective performances of geotextile are assumed as "satisfactory"; whereas, they are red when the protective performances of geotextile are assumed as "unsatisfactory".
It is observed that the protection function brought by the geotextile was not sufficient when the thickness was smaller than 6.5 mm. For higher thicknesses, the geotextiles consisted of long fibers assembly or only made with recycled fibers did not bring satisfactory protection.

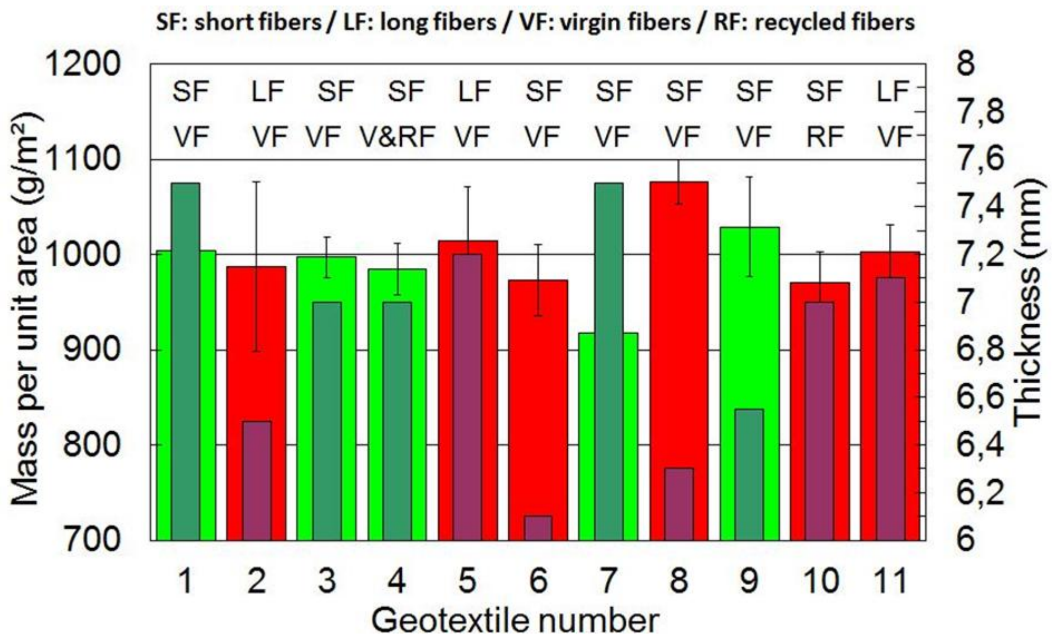



Figure 15: Mass per unit area (big rectangles) and thickness (small rectangles) of protective geotextiles tested with an 20/40 mm angular granular material; the rectangles are green when the protective performance of geotextile are assumed as "satisfactory" unlike the red rectangle indicates an "unsatisfactory" protective performance.

## 6 CONCLUSION

Tests following EN 13719 B show a good approach to simulate the protection behavior achieved with different protection materials under site-specific conditions. EN 13719 give guidance on how to calculate the testing load based on site-specific load and temperature conditions with reference to testing durations.
Results following this test method show that the gravel material (grain size and distribution, sharpness, hardness, load, etc.) have a major influence on results. An evaluation without testing is nearly impossible. Also, testing with "standard plates" therefore could lead in a wrong direction in comparison with tests following EN 13719 Annex B.
To assure a long-term function of the geomembrane, an elongation of equal or less 0.25% at the geomembrane after testing is established (following EN 13719 Annex B) in many countries.
For achieving a good protection function following EN 13719 Annex B, the main parts of the protection geosynthetic are a high mass per unit area and a high thickness to get a good bedding effect for the gravel. The goal is to ensure a more or less similar pressure at the whole surface of the geomembrane. The strength of the geosynthethic has a lower influence at this result, but for installation issues it is needed.

The influence of short and long fibres or recycled materials cannot be seen by results of EN 13719 Annex B; but, it may be that more results from the new French approach could offer guidance.

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