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Protection Geotextiles for Geomembranes in Landfill Applications

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ABSTRACT

Geomembranes are often used in civil engineering applications to create a hydraulic barrier. With nearly all protection-layer systems, deformations occur in the geomembrane which need to be quantitatively assessed by reference to the indentations. The geomembranes 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. A protection geosynthetic needs to be designed in consideration of the specified geomembrane and its thickness as well as in consideration of the soil material (typically mineral drainage layer) and the surcharge placed above. Inappropriate selection of the protection geotextile can result in a failure, e.g. puncture of the lining material. Several methods of determining puncture protection are described in different standards. This paper will describe the design-related approach for protection layers and explain the concept of one specific test. Overall this paper will give a closer insight of this design-oriented test method.

INTRODUCTION

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

The basic function of a geomembrane 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 especially in a geomembrane and, in critical situations, could ultimately puncture it (Figure 1).

Figure 1. Deformation without protection layer.

A protection geosynthetic needs to be designed considering the specified geomembrane and its thickness as well as the soil material (typically mineral drainage layer) and the design confining stress.

The general and main purpose of the protective layer is to:

- minimize the risk of geomembrane damage or puncture during construction and during the subsequent operation (Figure 2),
- minimize the strains in the geomembrane 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 1).

Figure 2. Deformation with protection layer.

CYLINDER TEST ACCORDING TO EN 13719

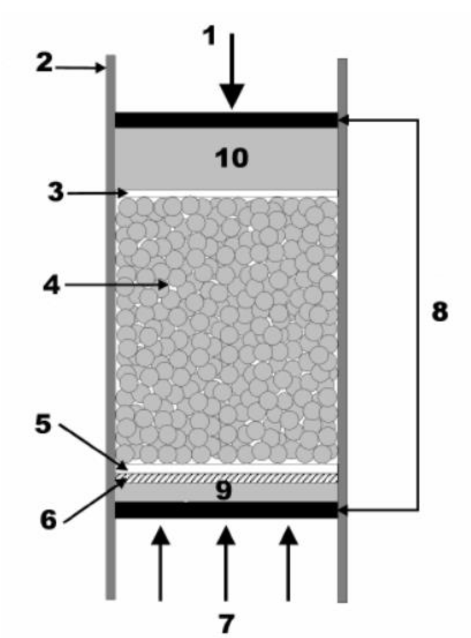
Related to various European (EN) application related standards, the protection efficiency of a geosynthetic over a geomembranes has to be tested following EN 13719.

The sealing system of a landfill has to work for a selected lifetime, e.g. ≥ 100 years in Germany. For this reason, the sealing system has to function reliable in the surrounding environment. As one of the sealing systems is typically a geomembrane, one requirement is that the geomembrane has to survive installation without being damaged. The second criteria is to survive under the specific environment, which includes the mechanical stress due to overburden pressure.

The European standard EN 13719 describes the determination of the long-term protection efficiency of geosynthetics in contact with geosynthetic barriers and is useful for determining the protection efficiency of lining systems in landfill applications but is not limited to landfill applications. This test is valid only for the purpose of measuring identification values and for comparison tests between different products and therefore is more an index test. However, the Annex B describes the test for site-related results as it includes the on-site material for a protection efficiency evaluation.

The index test of EN 13719 (see Figure 4) always requires running the test under 3 loads, 300 kN/m², 600 kN/m², 1200 kN/m². The load is applied on top of an standard "aggregate" (steel balls with a 20mm diameter) placed on the top of the geosynthetic specimen (Figure 3, left), which is supported on a simulated standard subgrade (lead sheet and dense rubber pad) for 100 or 1000 hours (Table 1). The local strain in the lower surface of the geomembrane is measured on the lead plate and used to determine the protection efficiency.

Figure 3. Cylinder test according to EN 13719 with steel balls (left) and according to Annex B with site-specific material (right)



1. applied load
2. cylinder
3. separation geotextile
4. 20mm steel balls (index test) or mineral drainage layer (Annex B)
5. protection geotextile 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

The Annex B of EN 13719 (Figure 3, right) describes the test procedure for site-specific conditions with site-specific drainage material and the applicable confining stress. This test is required because an aggregate with sharp edges can cause more severe damage than rounded shapes. The acting load therefore is concentrated at the sharp edge and likely creates higher local stresses. In an ideal case, the protective geosynthetic has to distribute these penetrating compressive stresses in such a manner that the compressive stress load on the geomembrane is homogeneously distributed over the surface without local peaks. In reality, 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 Figure 5, 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 stress relaxation in the geomembrane into account. 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). Narejo (1995) defined levels of protection against puncture for geomembranes under typical loading conditions:

- Level I is typically applied to liner systems for hazardous waste facilities. This level requires that the liner system be designed such that less than 0.25 per cent localized strain occurs in the geomembrane liner from the imposed loading.
- Level II (intermediate protection level) is for non-hazardous waste facilities. The 'intermediate protection level' lies between Level I protection and the yield of an HDPE geomembrane. The yield of HDPE geomembranes in the puncture mode is considered as failure of the level II protection. In other words, the liner system is allowed to have geomembrane strains greater than 0.25 per cent, but not resulting in yielding of an HDPE geomembrane liner.

  Wilson-Fahmy et al. (1996), Narejo et al. (1996), Koerner et al. (1996) and, more recently, Koerner et al. (2010) provide a basis for protection layer design consistent with this philosophy.

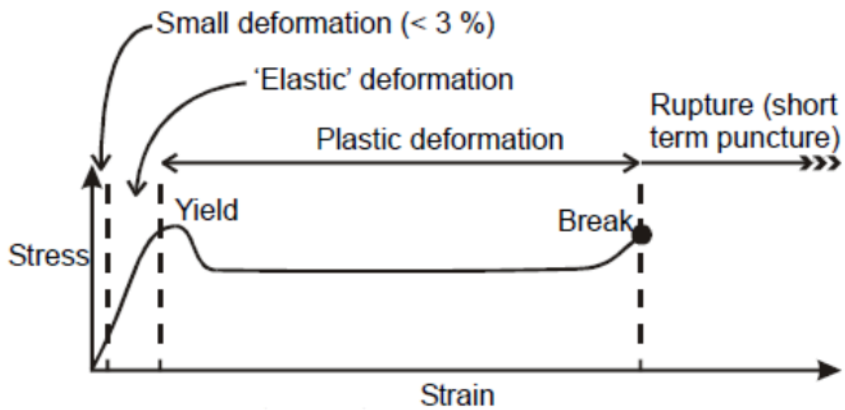


Figure 5. Stress/strain behavior of HDPE geomembranes

A maximum of 0.25 % local strain (ε_L) was set as the limiting value for local deformation (evaluation as described in the chapter “Deformation Evaluation by EN 13719” and shown in figure 7 and 8) in Germany and in many other European countries. This value was proposed by the German ‘Quo Vadis working group’ (Dixon, J.H., von Maubeuge, K. (1992)), explained by Seeger, S. and Müller, W. (1996 and 2003) and in Müller, W. (2001 and 2007). The critical strain limit of HDPE lies within the range of 3-5%. If these strains are exceeded damages develop in the microstructure and can develop stress cracks. This value of 3-5% has to be compared with the edge deformation (ε_B) of a local strain (ε_L). The outer part of the bent geomembrane is stretched and the inner part compressed due to the bending.

Figure 6 shows an example of an FEM calculation with a local strain (ε_L) of 0.25%. The figure shows in some parts edge or bent deformations (ε_B) of ≈ 4% (left side, lower part) and 1.0-3.6% (right side, upper part).

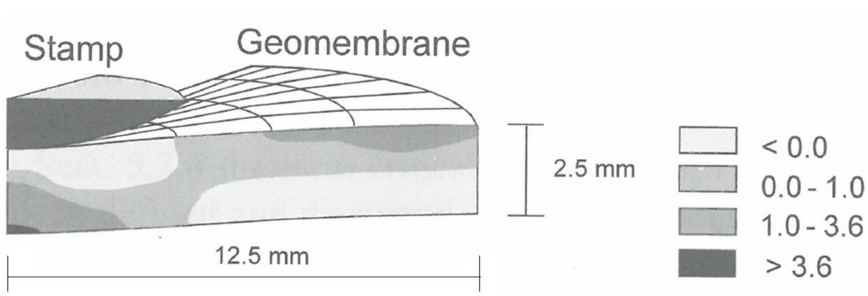


Figure 6. Elongation in the tangential plane ε_B (%) when ε_L = 0.25% (picture from Müller, W. 2007)

The upper limit for the local strain (ε_L) was set with 0.25% as it was shown that this value is similar to a bent deformation (ε_B) of 3%, what is a critical deformation value for HDPE.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.

TESTING EQUIPMENT AND PROCEDURE (EN 13719)

The test cylinder has a smooth surface on the inside and the internal diameter should be between 300mm and 500mm. The elastomer pad on which the test set-up is laid is 25mm ± 1mm thick, has a hardness of 50 ± 5 Shore A and a diameter similar to the inside test apparatus diameter. On top of the elastomer pad, a soft metal (lead) plate (1.3mm ± 0.1mm thick from a grade 3 lead, according to EN 12588) for the deformation measurement is placed, as well as the geomembrane and the protection layer, which should be investigated.

For the protection efficiency investigation a smooth 2.5mm thick HDPE geomembrane was used. To simulate the expected site conditions the test runs for 1000 hours at a temperature of 40°C with 1.5 times the expected confining stress on site. To enable shorter term testing at 20°C lab conditions, instead of realistic landfill conditions (40°C), the test procedure allows a reduction of the temperature (from 40°C to 20°C) and a shorter testing time (100 hours instead of 1000 hours) if the confining stress is increased by an additional factor of 2.25 or 2.5 (see Table 1). These factors are not only stated in EN 13719 Annex B but also in 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

Depending on the test requirements, two different methods can be tested and were used during the investigation:

- Index test (e.g. for CE marking): 20mm diameter steel balls with a minimum layer thickness of 150mm are placed on top of the protection layer.
- Annex B, application related test: on-site granular aggregate is installed with a thickness of ≥ 300mm.

DEFORMATION EVALUATION BY EN 13719

To evaluate the deformation in the geomembrane the soft metal plate is examined. The number of perforations, if any, is recorded and if visible any significant physical damage of the geomembrane.

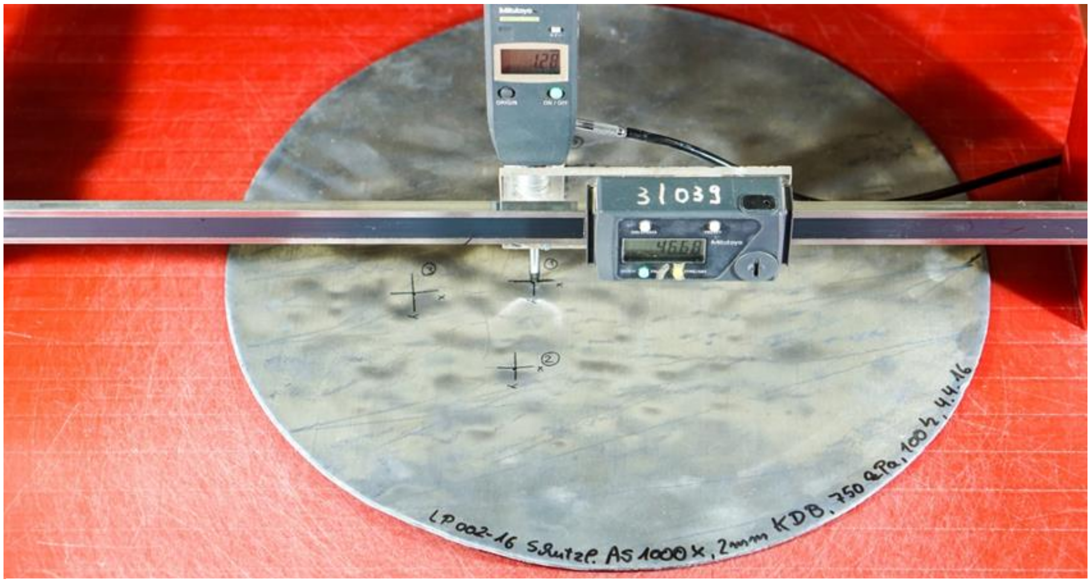


Figure 7. Selected deformations with the two axes and the depth measuring device

In the next step the five deformations with the greatest strains in the metal sheet are selected and marked. However, only deformations located more than 25mm from the edge are taken into account. For each single deformation two rectangular axes are drawn on the plate (see Figure 7) crossing through the deepest point.

With the help of a deformation-measuring device, the depth of the deformation is measured every 3mm ± 0.20mm (horizontal) over the entire line of the axis. The vertical deformation depth is measured with an accuracy of 0.01 mm at each horizontal interval from one side of the deformation to the other. The edge of the deformation is defined as the point where two consecutive readings (3mm apart) have a vertical height difference of less than or equal to 0.06mm. Then this procedure is repeated along the other axis. Deformation measurements should be completed within a 24 hour period after removal of the applied confining stress.

Alternatively, direct local strain measurements may be made using calibrated laser or optical scanning. From these depth measurements every 3mm the individual length lda is measured per section using the Pythagorean equation and summed up (Figure 8) over the entire elongated length ld. in “mm”.

[1] $l_d = \sum (l_{d1} \text{ to } l_{dn})$

To measure the local strain "ε" according to the arch approach the following equation is used:

[2] $\varepsilon = (l_d - l_u) / l_u$
[3] $l_u = n \cdot 3mm$

The local strain (deformation) is then calculated to 2 decimals.

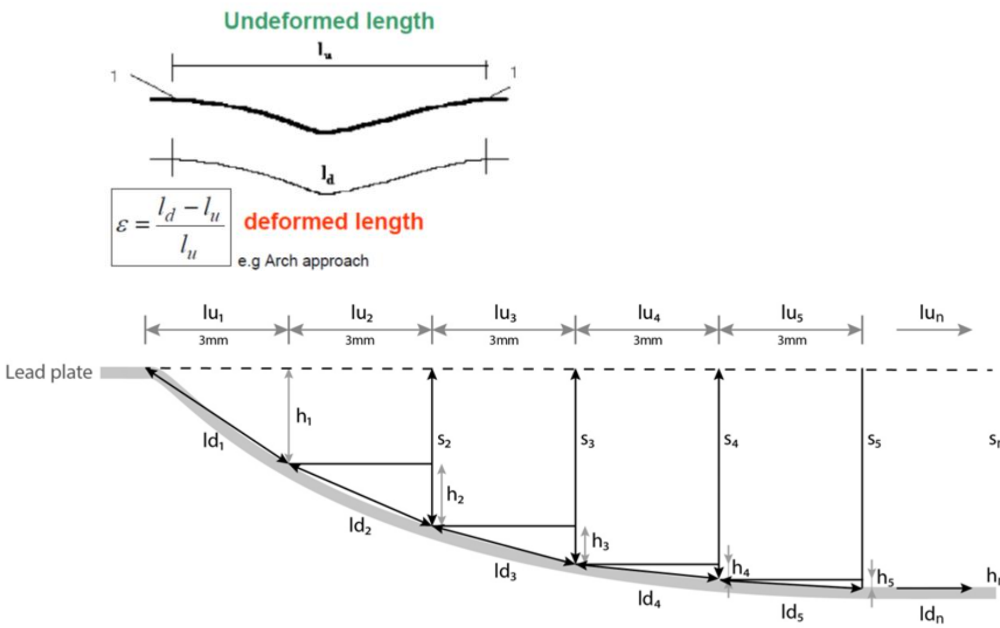


Figure 8. Measuring and calculation of local strain

Once this calculation is done on both axes of the deformation, the value is averaged and is considered as the true deformation of the selected spot. After determining the total deformation on all five selected spots, the highest three values are averaged again and represent the strain value under the tested conditions.

TYPICAL RESULTS FOR EN 13719 AND FOR EN 13719 ANNEX B

In the first test series three different nonwoven geotextiles according to Table 2 were tested. The masses per unit area of each group were selected with 300g/m², 600g/m² and 1200g/m².

Figure 9 shows a comparison of the results and indicates that a higher mass per unit area brings higher protection efficiency. This is rather logical and not surprising. More of interest is that the higher strength products with a lower thickness but same mass per unit area showed higher deformation strains.

Table 2. Geotextile nonwoven properties for products tested in Figure 9

	Low strength/modulus, high thickness	High strength/modulus, middle thickness	Very high strength/modulus, low thickness
300 g/m²	4.0 mm 0.2 kN/m @ 5% 0.3 kN/m @ 10%	3.0 mm 0.9 kN/m @ 5% 1.8 kN/m @ 10%	2.5 mm 6.0 kN/m @ 5% 12.0 kN/m @ 10%
600 g/m²	5.5 mm 0.4 kN/m @ 5% 1.0 kN/m @ 10%	4.5 mm 1.8 kN/m @ 5% 3.6 kN/m @ 10%	3.5 mm 6.0 kN/m @ 5% 12.0 kN/m @ 10%
1200 g/m²	10 mm 0.9 kN/m @ 5% 1.5 kN/m @ 10%	8.2 mm 2.2 kN/m @ 5% 4.0 kN/m @ 10%	7.0 mm 6.0 kN/m @ 5% 12.0 kN/m @ 10%

In the second test series under same conditions (steel ball index test approach), the same production technology was used for the protection nonwovens, to allow a direct comparison (see Table 3). Figure 9 on shows the influence of a higher mass per unit area on the protection efficiency. Logically a higher mass per unit area nonwoven geotextile and consequently a larger nonwoven thickness allows a better cushioning (bedding) effect for the steel balls. The elongation (deformation) in the soft steel plate decreases with a higher mass per unit area regardless if the confining stress tested was 300kPa or 1200kPa.

Table 3. Geotextile nonwoven properties for products tested in Figure 10

	Thickness	Tensile strength (md)
300 g/m²	3.0 mm	0.9 kN/m @ 5% 1.8 kN/m @ 10%
600 g/m²	4.5 mm	1.8 kN/m @ 5% 3.6 kN/m @ 10%
1200 g/m²	8.2 mm	2.2 kN/m @ 5% 4.0 kN/m @ 10%
2000 g/m²	11.0 mm	3.3 kN/m @ 5% 6.0 kN/m @ 10%

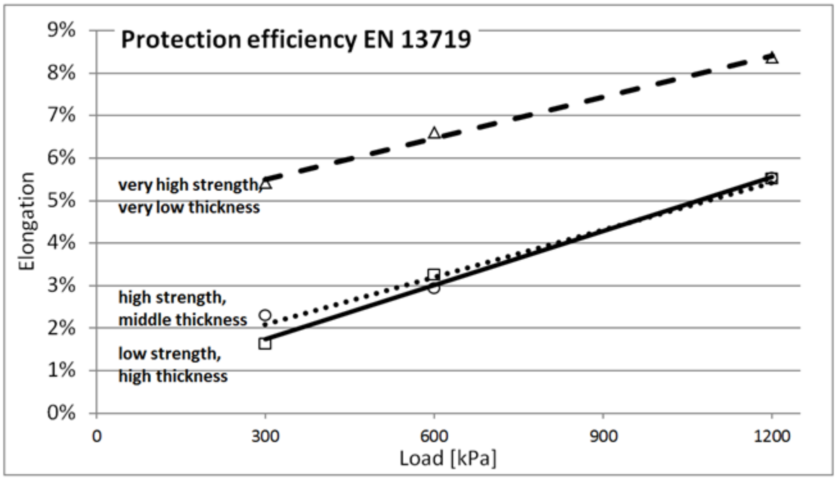


Figure 9. Average local strain with different 300g/m² protection layers

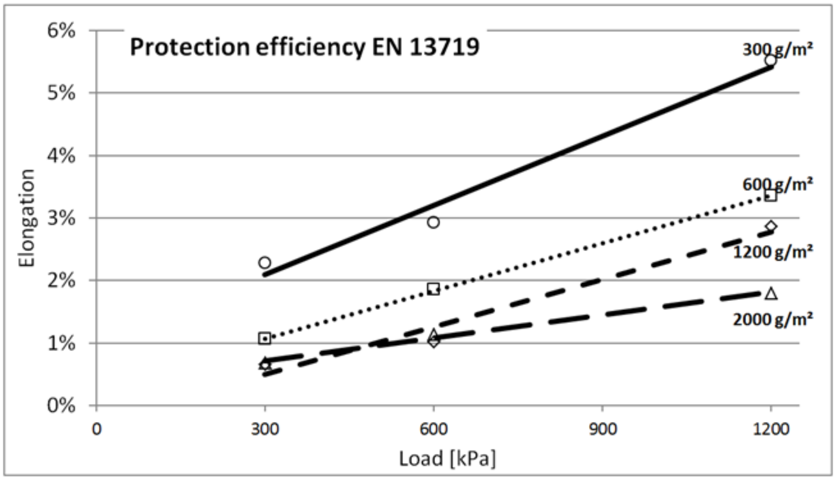


Figure 10. Average local strain with protection layers with different weights

The third series of testing are summarized in Figures 11 – 13. Ideally, designers would like to have a chart from which they can select a specific protection geotextile based on the waste height, the mineral drainage material and the deformation performance of the nonwoven geotextile. However, this is unrealistic and at the most can only be a guide as the mineral aggregate alone already has much variability: size of the drainage granular, hardness and sharpness of the drainage granular, and shape. All these have a major impact on the deformation results in the geomembrane.

In the following summary of various tests needle-punched nonwoven geotextiles from one manufacturer were used for a series of protection efficiency tests. The mass per unit area of the nonwoven materials ranged from 800g/m² to 3000g/m². The selected confining stresses were 450kPa, 600kPa and 900kPa and the mineral gravel used was rounded gravel.

The evaluation of the elongation in the geomembrane was carried out according to EN 13719 and represents the three worst indentations during the test. Figures 11 – 13 show the maximum and average elongation of the selected three indentations. The results are quite logical as they show that the geomembrane undergoes lower deformation if the protection layer has a higher mass per unit and it shows that there is no influence from the strength of the protection layer.

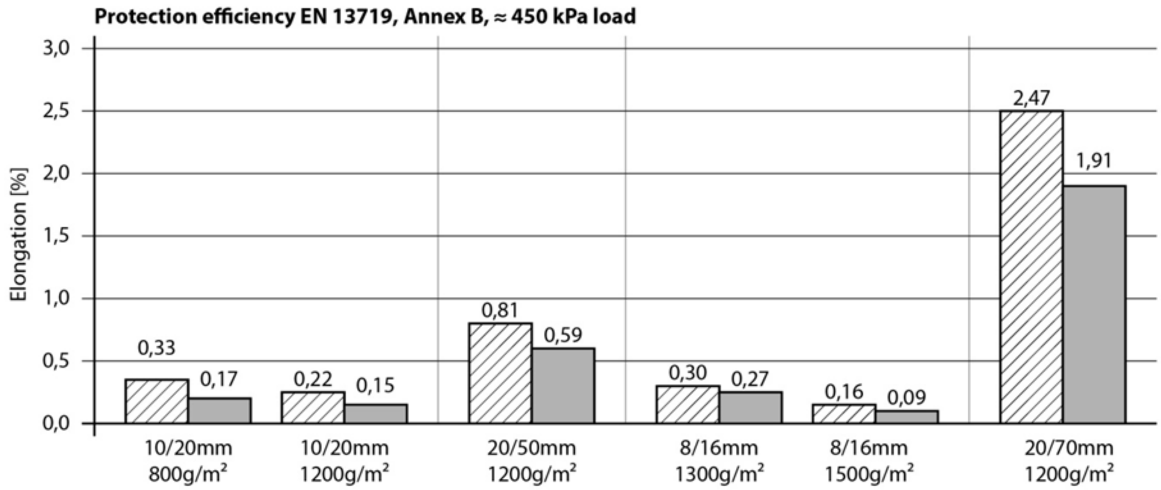


Figure 6. Average local strains under ≈ 450kPa (approx. 10 m waste height) with different grain sizes and different protection layers

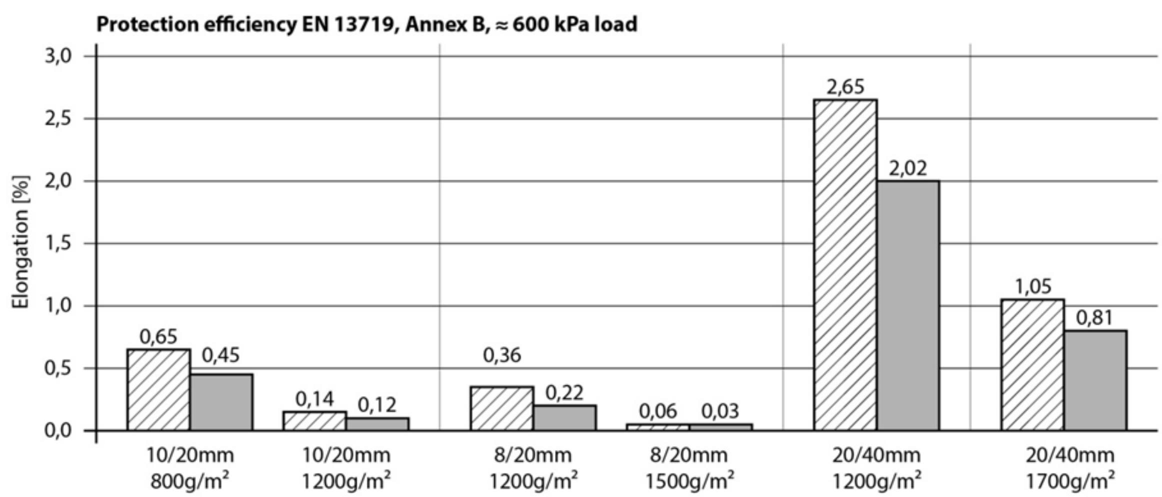


Figure 12. Average local strains under ≈ 600kPa (approx. 14 m waste height) with different

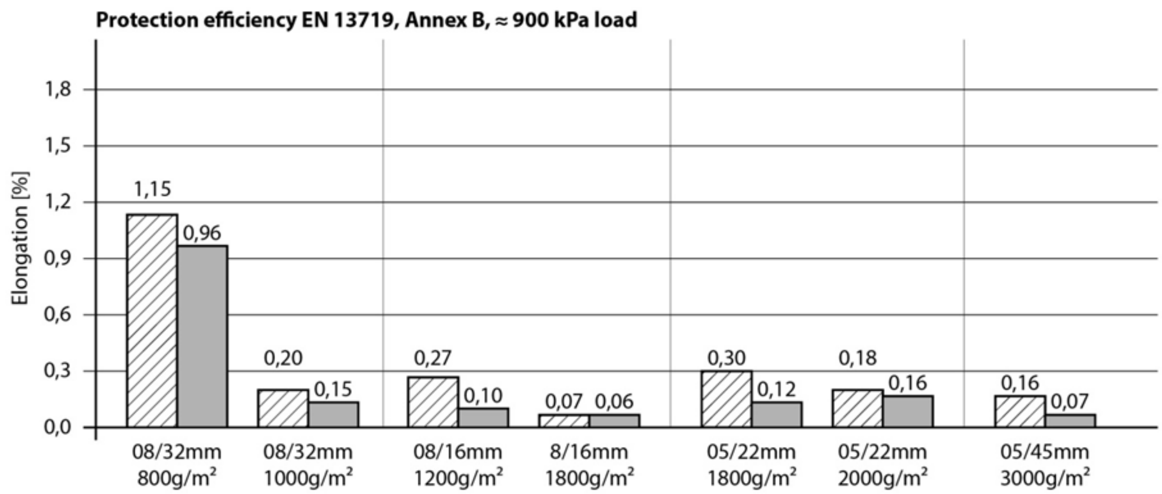


Figure 7. Average local strains under ≈ 900kPa (approx. 20 m waste height) with different grain sizes and different protection layers

Schlüter (2014) tried to find a correlation (see Figures 14 and 15) 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.

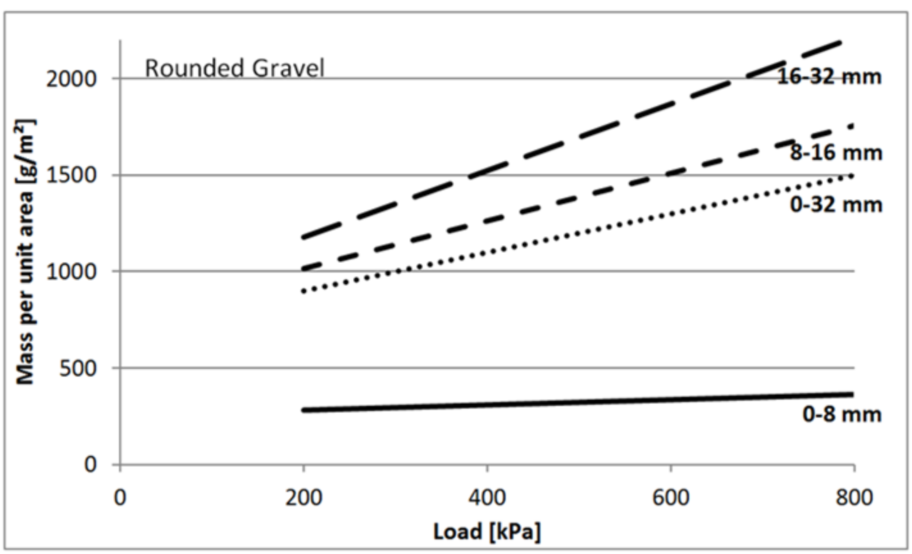


Figure 8. Estimated weight of the protection layer with rounded gravel depending on load (up to 800 kPa), Schlütter (2014)

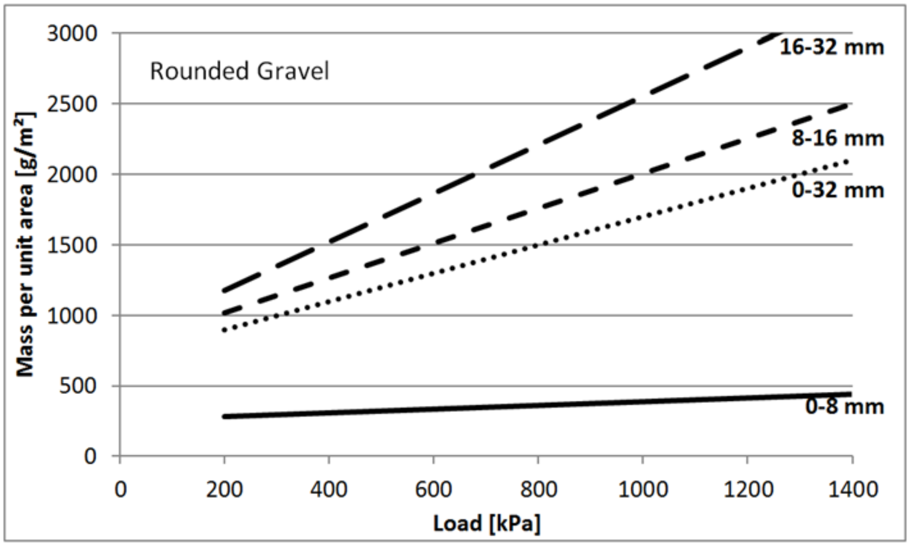


Figure 15. Estimated weight of the protection layer with rounded gravel depending on load (up to 1400 kPa), Schlütter (2014)

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 gives 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.) has a major influence on results. An evaluation without testing is nearly impossible and not recommended as site soils vary from project to project. Testing with “standard plates”, where gravel material is fixed in epoxy lead to wrong results as the gravel cannot move druring the test and could change their shape after every test..

To assure a long-term function of the geomembrane it is recommended to use site material as they are placed in field and allow a maximum elongation of equal or less than 0.25% local strain in the geomembrane (following EN 13719 Annex B). Meanwhile this concept is accepted in several countries.

To achieve a good protection function following EN 13719 Annex B, it seems that the protection geosynthetic should have a high mass per unit area and a high thickness to allow a good bedding effect for the gravel. The strength of the geosynthetic may have less influence for the protection efficiency.

REFERENCES

BAM, (2015) Guidelines for the Certification of Protection Layers for Geomembranes in Landfill Sealing Systems, Issued by Division 4.3 "Contaminant Transfer and Environmental Technologies"

Dixon, J.H., von Maubeuge, K. (1992) Geosynthetic protection layers for the lining systems of landfills. Ground Engineering

Ehrenberg, H., Stoltz, G. (2016) Testing of Protection Geosynthetics for Geomembranes in European Landfill Applications. Güler et al. (eurogeo6), Lubljana

Environment Protection Authority Victoria (2015) Siting, design, operation and rehabilitation of landfills, Publication 788.3

EN 13719 (2014) Geosynthetics - Determination of the long term protection efficiency of geotextiles in contact with geosynthetic barriers

EN 14574 (2015) Geosynthetics - Determination of the pyramid puncture resistance of supported geosynthetics

EN 14151 (2010) Geosynthetics - Determination of burst strength

GDA E-3 (2015) E 3-8 Reibungsverhalten von Geokunststoffen. www.gdaonline.de/empfehlung.html

ISO TC 221 WG6 (2015), Project Group 6 – Protection, unpublished internal working document, (2015)

Koch, R., Gaube, E., Hessel, J., Gondro, C. and Heil, H., (1988) Langzeitfestigkeit von Deponiedichtungsbahnen aus Polyethylen. Muell und Abfall, Heft 8, Erich Schmidt Verlag, Berlin

Müller, W. (2001) Handbuch der PE-HD Dichtungsbahnen in der Geotechnik. Birkhäuser Verlag Berlin

Müller, W. (2007) HDPE Geomembranes in Geotechnics. Springer Verlag Berlin

Schlüter, S., (2014) Analyse der Anforderungen an Schutzschichten für Dichtungsbahnen in Anlagen beim Umgang mit wassergefährdenden Stoffen. University of Applied Sciences, Münster

Seeger, S., Müller, W. (1996) Requirements and Testing of Protective Layer Systems for Geomenbranes. Geotextiles and Geomembranes 14, Elsevier Science Limited

Seeger, S., Müller, W. (2003) Theoretical approach to designing protection: Selecting a geomembrane strain criterion. 1st IGS UK Chapter, Dixon et al (Eds.), Nottingham

Stoltz, G., Croissant, D. and Touze-Foltz, N. (2013) Some geotextile properties useful for HDPE geomembrane puncture protection, Coupled phenomena in Environmental Geotechnics. Manassero et al. (Eds.), Torino