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LARGE SCALE TESTS ON GEOMEMBRANE PROTECTION LAYERS

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Abstract

Geomembrane liners at the base of solid waste landfills must be protected from stones and other sharp objects to properly act as liquid barriers. In Germany, a special protection efficiency test was developed for the assessment of the anticipated performance of protective layers.

At the LGA-Geotechnical Institute, the efficiency of six different geosynthetic protective layers was studied by large scale performance tests. The basal liner system, consisting of a compacted clay liner, a 2.5 mm thick HDPE-geomembrane, the protective layers and 0.3 m drainage stone of 16 to 32 mm were submitted to a uniformly distributed load increased step-wise up to 800 kPa. After more than nine months loading, the geomembrane was exhumed and the deformations were examined by laser-measuring technique. The six protective layers lead to different results. All systems tested functioned successfully.

A comparison of the observed and the anticipated performance allows conclusions concerning the German protection efficiency test. The paper will briefly introduce the German protection efficiency test, describe the large scale tests and discuss the results.

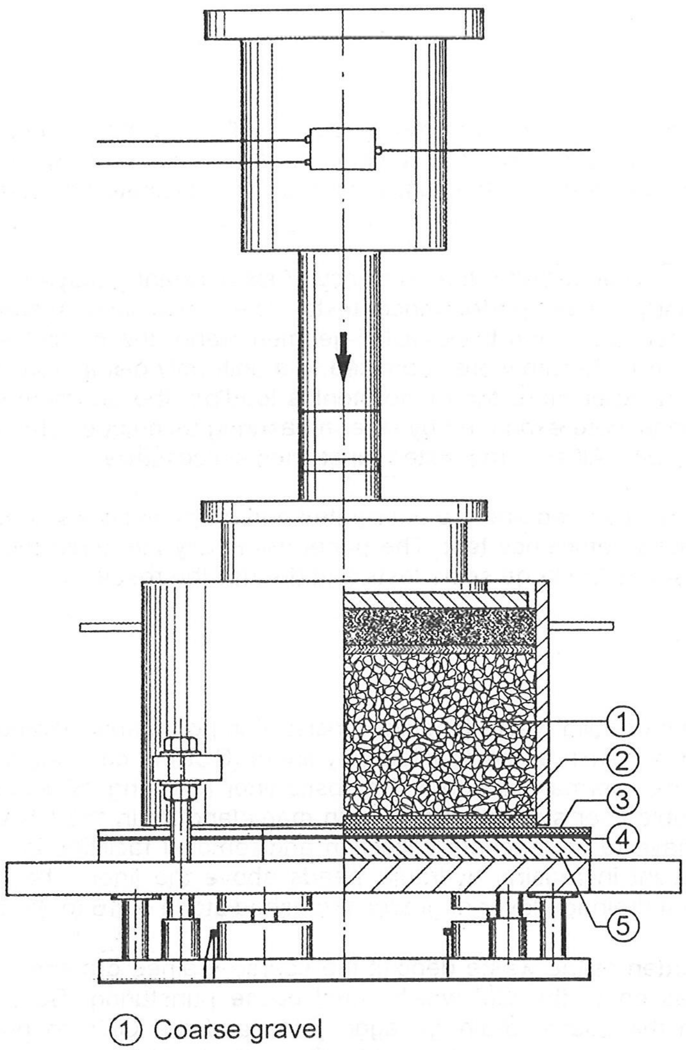
1. Introduction

Basal liner systems of solid waste landfills consist of impermeable geomembranes (GM) and mineral sealing layers such as compacted clay liners (CCL) in combination. There may be a single GM like in the German standard composite liner (Gartung 1996) or there may be two GMs, e.g. the double liner system employed in many landfills in the USA (Koerner 1994). In any case, there have to be leachate collection and removal facilities immediately above the basal seal to prevent increasing hydraulic heads above the liner. The dewatering systems typically comprise a drainage layer of gravel or crushed stone of 16 to 32 mm diameter.

Below the overburden of the waste deposit the coarse grained drainage material exerts very high local stresses on to the GM which could cause puncturing. So protection layers are installed between the coarse drainage aggregates and the GMs to prevent failure of the polymeric seal. The requirements to be met by the protection layers have been established on the basis of engineering judgment, and they have been supported by theoretical models. For the protection of the primary GM liner in the USA, Wilson-Fahmy, Narejo and Koerner (1994) carried out extensive studies. In Germany, where only one HDPE-GM of at least 2.5 mm thickness is used as a component of the composite basal liner, theoretical arguments for the criteria required for adequate long-term performance of protection layers have been presented by Seeger and Mueller (1996). In either country laboratory tests are performed for the evaluation of the suitability of protection layers. These tests which differ in both countries are modeling the function of the protection layer under simplified boundary conditions. The adequacy of such „index"-tests is not known, because there is no real long-term field experience with the performance of protectors. As a contribution to the discussion of GM protection issues, results are presented here of some large scale model tests which were carried out at the LGA Geotechnical Institute at Nuremberg in Germany.

2. Standard Protection Efficiency Tests

In the German standard test for the evaluation of the efficiency of protection layers, samples of the protector together with the GM of at least 300 mm, in our case 500 mm diameter, are submitted to loads in a device shown on Figure 1.



① Coarse gravel
② Protection layer
③ GM
④ Ductil metal sheet
⑤ Elastomer layer

Figure 1. German standard test device for puncture protection efficiency tests

The coarse drainage aggregate above the protector consisted of natural river gravel 16 to 32 mm in the case reported here, and there was a 20 mm thick elastomer layer of 50 Shore hardness below the loaded test sample as specified in the GDA-Recommendations (1997). A vertical stress of 1,350 kPa at a temperature of 20°C was applied for 100 hours, and the resulting deformations at the lower surface of the GM were recorded by means of thin soft metal sheets. The deformed shape of the ductile metal sheets was transferred to plaster and after hardening, the micro-topography of the gypsum block was surveyed by laser to be evaluated with respect to the deduction of strains that occurred in the GM below the protecting geocomposite by data analysis. The results of the standard tests on the different products for protective layers reported here are presented on Table 2.

3. Geosynthetics For Protection

The cushioning effect of protectors for GMs can be achieved by mineral layers such as sand, by geosynthetic sheets or by combinations of these two types of materials. Out of the great number of different products available, 6 geosynthetic protection layers were selected for the study reported here. They are listed on Table 1.

The geocomposite product no. 1 consists of rubber tire chips enveloped by geotextiles. No. 2 is a geocomposite routinely installed in many civil and environmental applications for drainage purposes, it was tested as a double layer protector. The geocomposites no. 3 and no. 4 are essentially mattresses filled with sand at the construction site. They are tailored to the needs of the particular landfill site and prefabricated. Protectors no. 5 and no. 6 are very robust mechanically bonded nonwovens. They are applied as single or double layers at the base of landfills, depending on the amount of overburden; in the study reported here, the efficiency of single and double layers was tested. The protection geocomposite on test fields no. 7 and no. 8 contains sand. The sand is filled into prefabricated geosynthetic sheets at the construction site.

Table 1. Protection layer systems tested for this study

System No.	Type of geosynthetic	Polymer	Mass per unit area (g/m²)	Thickness at 2 kPa (mm)
1	geocomposite (geotextile/geomat/rubber)	PET/PA/rubber	6,646	12.2
2	geocomposite* (geotextile/geonet/geotextile)	HDPE and PP	2,025	12.9
3	geocontainer** (woven geotextiles linked with spacer threads)	HDPE and sand 0.1 to 1.0	≈70,000	≈50
4	geocontainer** (woven geotextiles linked with spacer threads)	HDPE and sand 0.1 to 1.0	≈56,000	≈40
5	geotextile*, nonwoven needlepunched	PP	4,274	26.8
6	geotextile, nonwoven needlepunched	PP	2,137	13.4
7 = 8	geocomposite** (geotextile/geomat/sand 0.1 to 1.0 /woven+nonwoven geotextile)	PP/sand 0.1 to 1.0/HDPE	≈48,000	≈26

* double layer ** filled with sand on site

4. Large Scale Tests

At the LGA Geotechnical Institute large scale model tests were carried out, primarily for the determination of the soil-structure interaction of HDPE drainage geopipes and the surrounding soil (Zanzinger and Gartung 1998). The model was 5.4 m long, 4.4 m wide and 2.0 meters high. At the base it consisted of a composite liner, CCL of 0.6 m and HDPE GM of 2.5 mm thickness. The GM was protected against puncturing by a layer of geosynthetic protectors. The total area of 24 m^2 was subdivided into 8 test fields covered with 6 different products. In two cases two test fields were provided with identical protectors. The drainage layer was composed of natural river gravel 16 to 32 mm, above which a mixture of sand-wood shavings was placed as a waste material substitute. The entire model was encapsulated with concrete slabs and tied together with high strength steel tension rods. So a uniformly distributed vertical stress representative of the overburden of 60 m of solid waste could be applied via hydraulic flat jacks. Details of the loading procedure and the stress distribution within the model are given elsewhere (Zanzinger 1996).

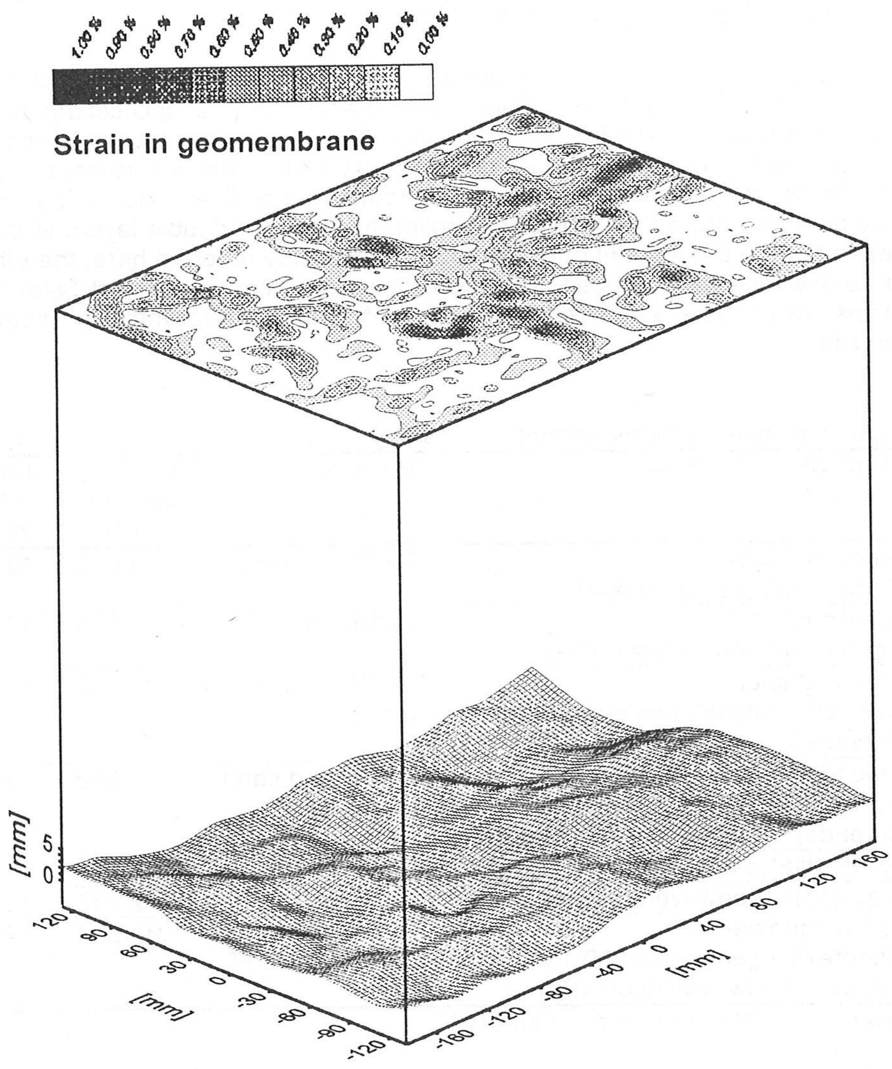


Figure 2. Image of the deformed GM and measured strain distribution

Table 2. Comparison of results of different protection layer systems from laboratory and large scale tests

System No.	Protection efficiency tests (according to GDA-recommendation E 3-9)		Large scale tests	
	Average strain (%)	Peak strain ε (%)	Average strain (%)	Peak strain ε (%)
1	0.04	0.21	0.08	0.41
2	0.02	0.07	0.08	0.66
3	0.34	0.99	0.11	0.75
4	0.02*	0.19*	0.05	0.46
5	0.06	0.17	0.09	0.58
6	0.09	0.26	0.10	0.92
7	0.07	0.62	0.07	0.79
8 = 7	-	-	0.05	0.78

* sample taken from a landfill construction site, tested at σ = 1,350 kPa, ϑ = 40° C, t = 1,000 h

For the quantitative determination of the performance of the protectors each test field was equipped with a 520 mm x 520 mm sheet of soft ductile metal at the lower surface of the GM in the zone of maximum vertical stresses below the foot of the structural arch which developed in the gravel adjacent to the geopipe. The recording procedure for the deformation measurement of the GM was the same as in the standard laboratory test. The metal sheet follows the deformation of the GM without any resistance, so also without developing any stress. After exhuming, the metal sheets depict the exact shape of the deformed GM. The microtopography is then recorded by a plaster imprint which is surveyed with excellent precision by laser-measurements at 3 mm centers in two directions. As a result, a three dimensional image of the deformed GM is obtained. An example of the measured micro-topography is shown on the lower part of Figure 2. Applying a detailed geometrical analysis to the deformation data, the distribution of strains in the GM is determined and plotted as shown on the upper part of Figure 2.

5. Test Results

Table 2 summarizes the most significant test results. It can be seen, that the average strains as well as the maximum strains determined in the standard laboratory test under a vertical stress of 1,350 kPa applied for 100 hours are somewhat smaller than the strains determined by the large scale test under a load representative of 60 m of waste overburden applied for 6,500 hours (9 months). At test fields no. 7 and 8 where the protection is mainly achieved by about 20 mm of sand and the geotextiles are merely used as containers, hardly any differences between the two testing methods occurred.

Perhaps the most significant difference between the standard laboratory tests and the large scale test is their duration. The load was applied 65 times longer in the large scale test than in the smaller lab tests. So it is conceivable that the larger deformations of the GM in the large scale test indicate the time dependent behavior of the polymeric geocomposites. But since there are also some other differences in the testing procedures, such as the stiffness of the base material: elastomer in one case, compacted clay in the other case and since the stress acting on the geomembrane in the large scale test is not exactly known, some other factors may also have contributed to the differences in the test results.

The performance of the sand filled geotextiles, test fields no. 3 and 4 and no. 7 and 8 is somewhat surprising. These systems which can certainly be considered suitable and durable because they employ mineral constituents, exhibit the largest values of maximum strains.

In case of the composite of test fields no. 3 and 4, the sand filled mattress with the greatest thickness and mass per unit area, the reason for the behavior can be assigned to the high degree of sand filling in the large scale test. The mattress transmits the vertical load along parallel lines. So the surface of the GM and below it the surface of the mineral sealing layer as well appear undulated. If the mattress is filled with less sand, this undulation can be minimized or avoided. This becomes evident, when the much smaller strains measured under conditions in the field (see Table 2, system no. 4: sample from a landfill side) are taken into account.

The protector no. 7 and 8 is thinner than the one of no. 3 / no. 4. The lower geotextile layer of the geocomposite is connected by welding points, and these welding points are stiffer than the surrounding elastic sections as matter of fact, the deformation of the GM is not caused by the drainage material above the protector but rather by the protector itself. So in the local region of the welding points there is an arching effect and the geomembrane is moving upwards.

These strains of the GM below sand filled protectors have to be regarded differently than those which are measured below pure geosynthetic protectors, because they are initiated by the structure of the protector. They are certainly tolerable at the recorded order of magnitude.

6. Conclusions

There is a difference in the maximum strains measured by standard protection efficiency tests and large scale field tests. If the large scale field tests are considered closer to actual field conditions, it turns out that the standard laboratory test underestimates the local maximum strains of the GM. So the lab test should be regarded as an index test rather than a performance test.

The local maximum strains of the geomembrane protected by geocomposites containing sand were greater than those of the tested geocomposites without mineral components. In all cases the maximum strains measured in the large scale test were less than 1 %. In the authors opinion all geosynthetic protection layers tested in the study presented here, performed successfully and are suitable for use at the base of solid waste landfills.

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