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Geosynthetic drain elements for landfill cappings: Long-term water flow capacity and long-term shear strength

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ABSTRACT: The German Federal Institute for Materials Research and Testing (BAM) has established a testing guideline for suitability proof of geosynthetic or geocomposite drain elements (GCD) for final landfill capping systems that is commensurate with the state of the art. The BAM guideline uses a uniform procedure for determining long-term water flow capacity. For this, it is necessary to produce data for creep behaviour developed under compressive and shear stresses. However, the extrapolation of creep curves is only then permissible when it can be shown that aging over the period being extrapolated does not invoke any relevant changes in the material due to aging. This is proven above all by the method of the long-term shear strength testing, which is described. The material's basic suitability, when assessed according to the guideline, does not supplant a careful design for each individual situation by an experienced professional. The design problem is discussed.

1 INTRODUCTION

The European Council Directive on the landfill of waste established requirements on the geological barrier and on the bottom and surface sealing. Since many landfills in Europe have neither an acceptable geological barrier nor a base liner, a capping will be of importance for the required protection against the potential hazards of landfills to ground water, soil and air. The Directive recommends a drainage layer with an extraordinary large thickness of at least 0.5 m, which had to be made of coarse gravel material. However, the regulations of the Member States and the competent local authorities are allowed to take into account thoroughly justified technical developments. Therefore, the question arises whether geosynthetic or geocomposite drain elements (GCDs), which have tremendous short term technical and economical advantages compared to coarse gravel drainage layers, are suitable for final landfill capping systems with respect to their long-term behaviour, especially considering long-term water flow capacity and long-term internal shear strength.

The European Organisation for Technical Approvals (EOTA) requires that the working life of a construction product has to correspond to the expected functional service-life of the construction itself, when the construction product is not repairable or replaceable "easily" or "with some effort". This is obviously the case for drainage layers in landfill capping systems and therefore a minimum service lifetime of at least 100 years is mandatory for GCDs. However, the requirements of the European standard EN 13252 with respect to durability only explicitly ensure a functional service-life of at least 25 years.

Against this background, BAM has tried to establish a testing guideline for suitability proof of GCDs for final landfill capping systems that is commensurate with the state of the art (www.bam.de). An overview of the approach is presented and discussed in this paper. According to BAM's experience GCDs currently on the market are generally not designed from the outset for the extremely long-term functional service life demanded by final landfill capping systems. Their selection of materials is based primarily on processing and commercial viewpoints. In this respect, the long-term shear strength test has proven its worth in finding "weak points", as was already the case in investigations of textured geomembranes and geosynthetic clay liners. The method of the long-term shear strength testing of GCDs is described.

The BAM guideline establishes a uniform procedure for determining long-term water flow capacity. For this, it is necessary to produce data for creep behaviour developed under compressive and shear stresses.

The material's basic suitability, when assessed according to the guideline, does not supplant a careful design for each individual situation by an experienced professional. Such a design consideration must prove the geosynthetic drain elements adequacy for water flow capacity, filter effectiveness and slope stability under the prevailing conditions in the individual case. However, the design equations strongly differ from paper to paper. Beyond this, it is not exactly specified just how design parameters are to be derived from the test results. In addition, these design problems are shortly discussed in the paper.

Other topics, like weather resistance of drain core, determination of filter parameters and filter performance, friction parameters and protection efficiency and Manufacture Quality Assurance (MQA) as well as Construction Quality Assurance (CQA) are dealt with in the guideline but cannot discussed here.

2 THE LONG-TERM IN-PLANE WATER FLOW CAPACITY

Drain cores made of plastics exhibit a more-or-less distinctly pronounced visco-elastic deformation behavior; under continuous effective compressive stress, the thickness of the drain core is reduced. Where there is also a shear force, this process can be substantially accelerated. A reduction in water flow rate within the plane of the GCD is generally affiliated with such a reduction in thickness. The in-plane water flow capacity q is defined as volumetric flow rate of water per unit width of specimen at a defined hydraulic gradient and compressive stress. In order to assess the residual water flow capacity after a long time q_{LT}, the amount of this creep deformation must be determined and an estimate made of its quantitative effect.

This so-called “creep” is a natural characteristic of an intact polymer material. However, over long periods of time the materials properties and its creep behaviour can change dramatically by its own aging. The considerations purported below are therefore only permissible when it can also be shown that aging processes throughout the extrapolation period of creep curves (10^6 hours, i.e. 114 years) do not have a repercussion on the materials properties (Mueller et al. 2003). The approach to elucidate long-term shear strength will therefore be discussed in the next section of this paper.

An estimate of long-term water flow capacity starts with the determination of creep curves for mechanical stresses, as they are typical for landfill capping systems. This is done by recording the thickness of the GCD under a prescribed compressive/shear stress over a period of time not less than 10^4 hours. The resulting curves are then extrapolated to estimate probable final thickness after 10^6 hours (= 114 years) at various given stress levels (Fig. 1, top left). The next step is

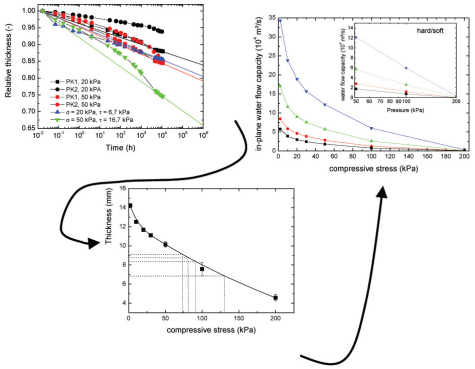

Figure 1. Illustration of the selected procedure for assessing the long-term water flow capacity under differing bedding conditions. One observes: the extrapolation of the creep curve is only then permissible when it can be shown that aging over the period being extrapolated does not invoke any relevant changes in the material due to aging.

to determine in-plane volumetric water flow rate per unit of width as a function of thickness. The thickness dependency can then be used to specify the water flow capacity q_{LT} that would still be present at a given extrapolated final thickness. Different amounts of compressive stress will be applied in the apparatus to produce the required thickness reduction. Therefore certain values of compressive stress might be attributed to the final thickness, too.

The composition of the layer beneath the GCD as well as the cover layer above it, i.e. the type of bedding, can have a significant influence on water flow capacity. Laboratory testing (EN 12958) therefore examines three different types of bedding. For hard/hard bedding the drain element is clamped between two stiff plates, e.g. steel plates or reinforced acrylic plastic plates; for soft/soft bedding two foam rubber plates are used instead. Finally, for hard/soft bedding, a stiff plate is placed on one side and a foam rubber plate on the opposing side. A well defined thickness, and thereby a creep curve as well as the thickness dependency of water flow capacity, can only be measured when the drain element is clamped between two stiff, flat plates whose spacing defines thickness. The above-described procedure for determining q_{LT} is therefore only applicable to hard/hard bedding.

However, to estimate long-term water flow capacity for bedding conditions hard/soft or soft/soft, one can use the dependency of water flow capacity on pressure stress. This approach begins with the compressive stresses that would be necessary to produce a final thickness for the hard/hard bedding condition (Fig. 1, bottom). The long-term water flow capacity for hard/soft and soft/soft bedding conditions is then that which is actually measured at this compressive stress when placed in the respective bedding conditions (Fig. 1, top right). A similar discussion for determining long-term water flow capacity and results from examining the procedure can be found in (Jarousseau and Gallo 2004).

3 THE LONG-TERM SHEAR TEST

Long-term shear tests were performed to clarify if aging processes impair internal shear strength, i.e. whether the results of short-term experiments (an experiment at room temperature extending over a period of one year is still definitely a short-term experiment) are actually applicable.

Long-term shear strength of geosynthetics are tested by so-called “long-term shear tests”, in which the product is subjected over an extended period of time to compressive and shear stress under elevated temperature in a liquid or gaseous test media (Fig. 2). The time until failure occurs, the so-called time-to-failure, is determined in conjunction with testing conditions. By varying test conditions, one obtains a functional relationship between time-to-failure and these conditions. These can then be extrapolated to obtain a functional service lifetime for application conditions. The determination of permissible long-term hoop stress for pressured plastic pipes is probably the most technically mature example for the application of such service life testing in the field of plastics. By analogy to such pipe service-life testing, shear test stands were conceived by BAM with the objective of investigating the long-term behaviour of geosynthetics subjected to shear stress (Müller et al. 2004; Seeger et al. 2000).

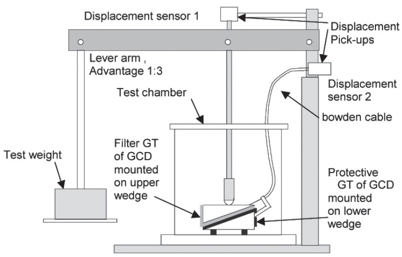

Figure 2. Schematic drawing of a test stand for determining long-term shear strength.

The tests of the GCD were carried out as follows: A rectangular segment of the drain element with a welding point in its centre (about 12 cm · 13 cm = 156 cm^2) was mounted between two steel wedges, each having an incline angle of 21.8° that corresponds to a slope gradient of 1:2.5. The fastening of the filter geotextile and the protective geotextile to respective wedges was accomplished by area entanglement in friction plates fixed-mounted to the face of both wedges. The friction plates were made of sheet metal with a crown rasp pattern.

With respect to normal surface lining conditions, a relatively large cover load of 50 kN/m^2 was exerted onto the area of the test specimen by way of force on the upper wedge from a lever mechanism. The cover load’s component of force parallel to the slope is exerted between the upper and lower layers of the geosynthetic composite. The assembly is immersed in a water bath that can be heated to a test temperature of T = 80°C. The vertical displacement of the upper wedge was automatically recorded over the entire duration of all tests via a high-precision displacement sensor ($\Delta s \leq 1/10$ mm).

For GCDs made of polyolefin materials, these long-term tests are monitored by measurements of oxidation-induction time (OIT). For rapid drops in OIT values, the influence of oxidising conditions must be clarified through air oven aging tests (Mueller et al. 2003).

4 CALCULATION OF DRAINAGE LENGTHS

Whether or not the hydraulic performance of a GCD is sufficient for landfill construction can be evaluated by virtue of the drainage lengths still permitted by typical landfill site conditions. A simplified postulate is made for this assessment, specifically, that long-term water flow capacity q_{LT} for a hydraulic gradient that corresponds directly to the embankment slope must be at least as great as the total seepage water inflow, i.e. the product of expected seepage water discharge q_S and required drainage length L. For the actual design one modifies q_{LT} with reduction factors for product characteristics (partial factors of safety for material resistance) and q_S with partial factors of safety for field stresses, expressing the stresses from construction site conditions. The general design equation for water flow capacity is:

$$\frac{q_{LT}}{\gamma_{R,1}\cdot\gamma_{R,2}\cdot\gamma_{R,3}\cdots} \geq (\gamma_{S,1}\cdot\gamma_{S,2}\cdot\gamma_{S,3}\ldots)\cdot L\cdot q_S \qquad (1)$$

q_{LT} is the long-term water flow capacity, defined in Sect. 1. One should carefully differentiate between reduction factors for product characteristics $\gamma_{R,i}$ (partial factors of safety for material resistance) whose clarification is up to the manufacturer and material testing institutes, and the partial factors of safety for field stresses $\gamma_{S,i}$, that are dependent on construction site conditions which, above all, must be clarified by field tests and field research.

Unfortunately, there is still a great deal of confusion about this in the various guidelines and recommendations They differ in partial factors of safety for materials resistance and for field stress or in general factors of safety for which different values or value ranges are specified. This is due to the fact that it is not precisely defined what a given factor should actually describe, and the assignment of values or value ranges is usually guessed and only founded in rare cases. To avoid this diversity, one should take the following into account:

The scatter for measurement values and extrapolation error may be included by introducing a reduction factor of 1.2. Additional local reduction in water flow capacity can occur where there are overlap areas, alongside-joints and end-joints. These can have an overall effect on hydraulic performance. However, when GCD rolls are correctly installed this effect should be minor. From laboratory tests a factor of 1.2 was recommended (Gartung and Zanzinger 1999). With these two reduction factors for material resistance one has for the long-term water flow capacity which enters into the left side of design Eq. 1: $q_{LT}/(1.2 \cdot 1.2)$.

In the next step the factors of safety for field stresses, i.e. the right side of Eq. 1, remain to be considered. Standard values of seepage water discharge are often used: e.g. in Germany 10 mm/d (typical value which is underrun on 99% of all days) and 25 mm/d (day peak value). However, they have to be controlled by site-specific measurements or simulation with the HELP model. Yet another lump-sum safety factor, e.g. of 1.1, intended to compensate for the uncertainty in determining seepage water discharge, should be applied.

Of all field stresses, those arising from construction site installation can cause the greatest damage. Quality assurance at the construction site should prevent such gross damage. In view of uncertainties with respect to construction site activities, it may be prudent to apply a strong factor of 1.5.

There is little that can be reliably said about other field stresses. This applies to the influence of chemical and biological clogging, colmation and also the penetration of roots. On the one hand, excavations after a number of years have shown that occurrences of these effects are generally very minor. On the other hand, the processes involved are extremely long-lived. Here one should actually pursue a program of preventative measures, i.e. avoiding these processes by an appropriate design of the re-cultivation layer with an special selection of soil and the structuring of the layer. Where there is indeed risk of such stresses, the formal manipulation of small factors of safety would appear to be more an attempt to fool oneself.

There is also no really clear answer about how accurately artificial beddings in laboratory experiments reflect actual bedding conditions in the field. This can only be properly answered with data that is apparently not yet available in sufficient quantity.

Due to this uncertainty in assessing field stresses as well as to account for general systematic errors, one may call for a partial factor of safety of 2. Overall then, this results in a partial factor of safety coefficient for field stresses amounting to $1.1 \cdot 2 \cdot 1.5 = 3.3$. Beyond factors for installation stress, general uncertainty in the assessment of field stresses, and perhaps also for uncertainties with regard to the assessment of seepage water discharge, a greater differentiation of partial factors of safety under the current state of expertise would not appear reasonable.

5 CONCLUSIONS

The consequences of creep and bedding on water flow capacity should no longer be expressed by factors of safety but rather must be investigated by measuring and be calculated on the basis of the extrapolations constructed from these measurements, as was done here in Section 1. The so-derived long-term water flow capacity q_{LT} forms the starting point for calculating the drainage length L. In principle, aging effects must not be accounted for with factors of safety as well (Müller et al. 2004). Therefore it must be shown explicitly that the product, whose hydraulic performance is being evaluated, is sufficiently stable over the required functional service life on the basis of appropriate material investigations.

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