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About the dimensioning of geosynthetic drainage systems in landfill covers

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ABSTRACT: A geosynthetic drainage system consists of a percolation layer, which absorbs the water vertically to its plane and passes it on in the plane, as well as at least one filter layer which protects the percolation layer against clogging. This paper presents a closer look at the functions to be fulfilled by the components of a geosynthetic drainage system in capping sealing systems of landfills.

1 INTRODUCITON

Sealing systems with several layers of geosynthetics are nothing unusual in landfill construction, particularly since additional waste volume is provided due to these relatively thin constructions -compared to mineral layers- (compare Saathoff & Keller 1996). In the USA the use of geosynthetic drainage sytems in base and capping sealing systems is a standard recommendation laid down in various guidelines.

Fig. 1 shows an exemplary construction. Geosynthetic drainage systems are used as a standard in capping sealing sytems to collect precipitation and to remove gas. In base sealing systems they serve, as a standard, as drainage layer for seepage water and as control layer between the two sealing layers of a double sealing system.

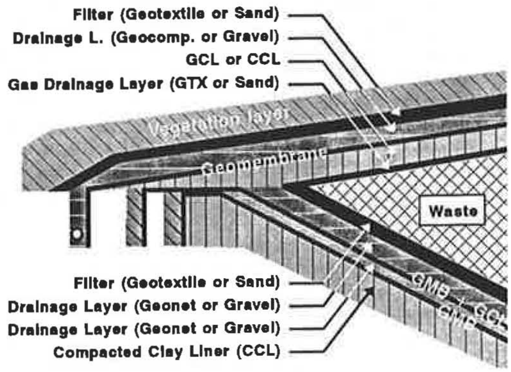

Fig. 1. Application of geosynthetic drainage systems in landfills in the USA (Koerner 1993)

2 SEALING SYSTEMS IN LANDFILL COVERS (CAPPING SEALING SYSTEMS)

Fig. 2 shows the capping sealing system for landfill class II as published by the TA Siedlungsabfall (1993) in Germany (landfill for residuals, formerly called landfill for household waste).

The Bundesrat (1993) made the following comments, prior to the publication of the final TA Siedlungsabfall, on the capping sealing system for landfill class II and inherited landfills for household waste:

- The technical solution for the capping sealing should only be shown in principle, the detailed realization should remain open. With respect to the settlements to be expected it should be possible to carry out provisional capping seals first and to install the final sealing when the settlements have stopped.
- It is left open whether the sealing system corresponds already to the state-of-the-art.

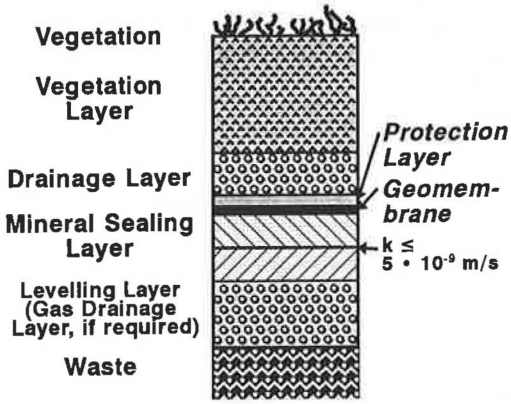

Fig. 2. Capping sealing system for landfill class II, recommended by TA Siedlungsabfall (1993)

- Other capping sealing systems should, however, not be compared to a system of which the suitability is not yet completely proven.
- For the allowed transition periods and for exceptions organic waste is still deposited for a fixed period on inherited landfills for household waste. In such landfills or landfill sections high settlements have to be expected which constantly damage an elaborate and costly capping sealing system.

The practice up to now clearly shows that, especially for capping sealing systems, the solution (Fig. 2) given by the TA Siedlungsabfall (1993) is often not selected (see Saathoff & Keller 1996). An example of an alternative capping sealing system is shown in Fig. 3.

The components of the upper geosynthetic drainage system are to be designed as follows (from top to bottom):

- upper nonwoven layer: filtering towards the vegetation layer and protection to UV radiation,
- geosynthetic drainage layer (for instance convoluting fibre layer): drainage of precipitaton and
- lower nonwoven layer respectively the complete geosynthetic drainage system: protection of the geomembrane to UV radiation and mechanical damage during construction and operation of the landfill.

The components of the lower geosynthetic drainage system have to be designed as follows (from top to bottom):

- upper nonwoven layer if only a mineral sealing layer is selected (for instance landfill class I) instead of a combinated sealing consisting of a GCL and a geomembrane: filtering towards the mineral sealing layer (supporting of self-healing effects),
- geosynthetic drainage layer (for instance convoluting fibre layer): gas drainage and
- lower nonwoven layer: separation towards the waste.

Furtheron the specific requirements for the landfill have to be considered. Apart from physical and biological stresses in landfill construction, especially chemical stresses (liquid and gaseous) are of high importance to the resistance of the raw materials used.

In capping sealing systems the following has to be taken into account:

- landfill gases and
- landfill gas condensate.

In addition it has to be considered that landfill gas is usually water saturated (Hoins 1989).

A geosynthetic drainage system which gets in contact with these aggressive mediums should be resistant to such stresses. This applies especially to the geosynthetic drainage system between sealing and waste as shown in Fig. 3 (placed at the bottom).

The raw material HDPE has the best "allround resistance". Therefore, it is logical and for the long-term resistance of landfill constructions advantageous to use geosynthetic drainage completely made of HDPE.

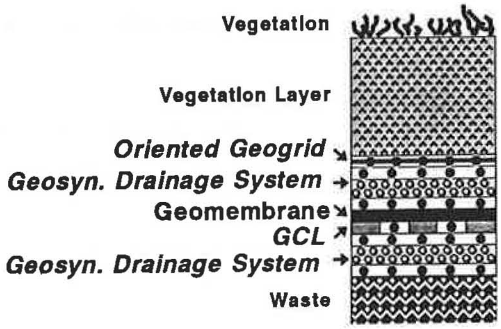

Fig. 3. Example of an alternative capping sealing system of landfill class II

3 EXAMINATION OF THE COMPONENTS OF A GEOSYNTHETIC DRAINAGE SYSTEM (GDS)

3.1 General remarks

Drainage is defined as follows: *"The collecting and transmitting of precipitation, ground water and/or other fluids and gases in the plane of a geotextile or geotextile-related product"* (comp. EN 30318).

A geosynthetic drainage system consists of a percolation layer which absorbs the water vertically to its plane and which passes it on in the plane, as well as a filter layer which protects the percolation layer (geosynthetic drainage layer) against clogging. Fig. 4 shows different geosynthetic drainage systems with filter layers applied on both sides.

The percolation layer can have different designs (coarse fibre layer or convoluting fibre layer or geogrid, in English usage also often referred to as *geonet*).

Following, the functions to be fulfilled by the components of a geosynthetic drainage system will be considered.

3.2 Component 'Geotextile Protection Layer'

The central task of geotextile protection layers is to protect a geomembrane against inadmissible stresses

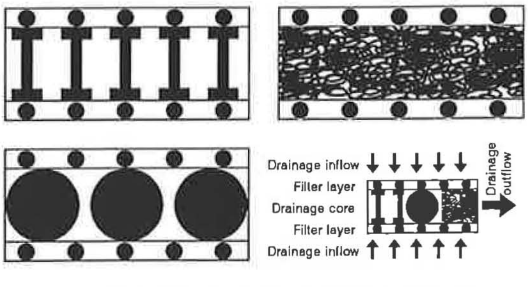

Fig. 4. Geosynthetic drainage systems (according to DVWK 1993)

which cause perforations, notches and deformations:
- in the short term against stresses resulting from installation, and
- in the long term against stresses resulting from constant loads.

The protective effect of a geotextile (resp. of the component 'geotextile protection layer' of a geosynthetic drainage system) can be determined by means of modified load bearing tests (Saathoff & Sehrbrock 1994).

For capping sealing systems it is generally assumed that a mechanically bonded nonwoven with a mass per unit area of 300 g/m^2 as lower layer of the geosynthetic drainage system gives sufficient protection towards the loads to be expected.

3.3 Component 'Geotextile Filter Layer'

The component 'geotextile filter layer' is being considered when a geosynthetic drainage system is used in contact with a soil layer (for instance mineral sealing or vegetation layer).

Filtering is defined as follows: *"The restraining of soil or other particles (also partially) subjected to hydrostatic and/or hydrodynamic forces while*

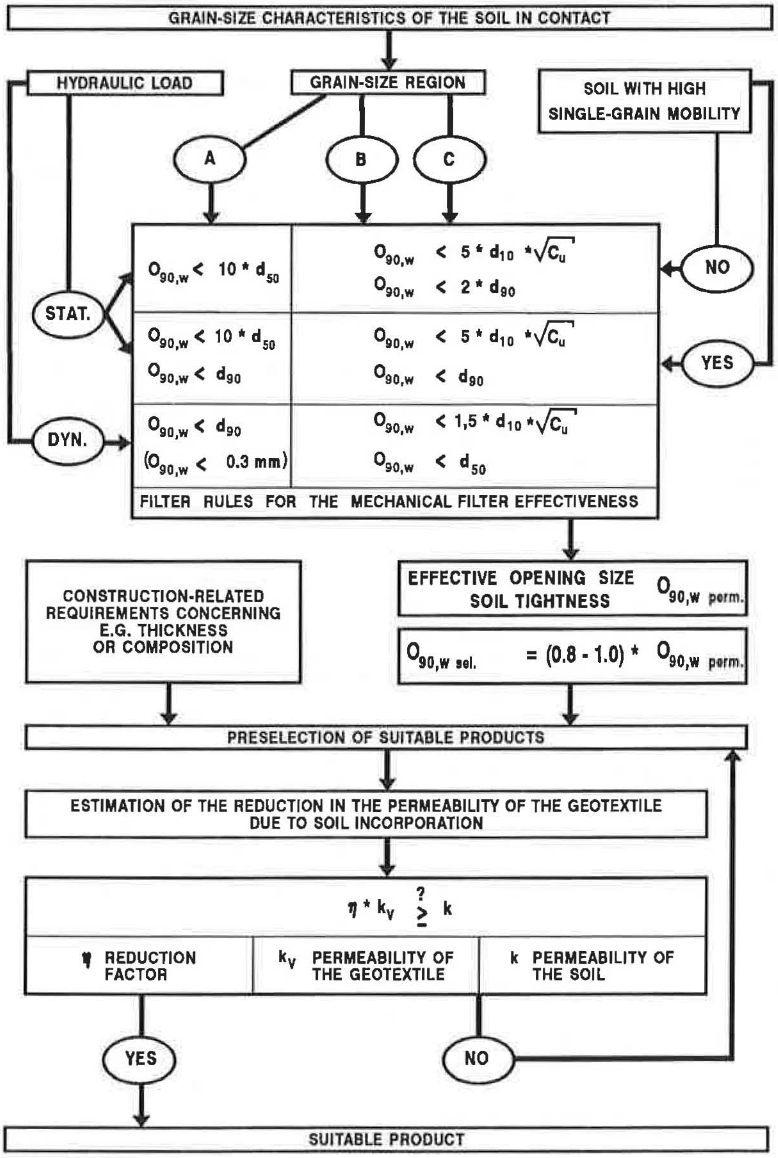

Fig. 5. Simplified flow diagram for the filter dimensioning (Saathoff 1995)

allowing the passage of fluids into or across a geotextile or a geotextile-related product" (comp. EN 30318).

The dimensioning is carried out in two steps. First, the so-called mechanical filter effectiveness (soil retention capacity) is proven. Then the hydraulic filtering effectiveness (water drainage with low pressure loss, i.e. small hydraulic gradients) for the selected product (with the product data) is examined.

In sealing systems of landfills geotextile filters can be dimensioned according to the DVWK guidelines (1993).

A simplified flow diagram for the filter dimensioning is shown in Fig. 5. For the filter dimensioning information is needed about the grain size of the soil in situ. The hydraulic load on a filter in the field of landfill construction is static.

The filter rules of the DVWK (1993) distinguish three grain-size regions:

- grain-size region A: $d_{40} \leq 0.06$ mm,
- grain-size region B: $d_{15} \geq 0.06$ mm,
- grain-size region C: $d_{15} < 0.06$ mm and $d_{40} > 0.06$ mm.

In the next step, it has to be examined whether it is a soil with a high single-grain mobility. Criteria for such a soil are:

- grain fraction < 0.06 mm with $c_U < 15$,
- 0.02 mm < d < 0.1 m > 50%, and
- plasticity index $I_P < 0.15$
  or as a substitute proportion of clay/silt < 0.5.

The result according to Fig. 5 is a permissible effective opening size $O_{90,w,permissible}$.

The pore structure of the geotextile should be selected as open as possible. The recommendation according to DVWK (1993) is:

$$O_{90,w,selected} = 0.8 \text{ to } 1.0 \bullet O_{90,w,\, permissble} \quad (1)$$

At least the following condition has to be observed:

$$O_{90,w,selected} \geq 0.2 \bullet O_{90,w,\, permissible} \quad (2)$$

A deep filtration (not a cake filtration) is desired, that means requirements are to be made on the filtration length resp. the thickness of the geotextile:

$$d_{min} > 25 \bullet O_{90,w,selected} \quad (3)$$

At this stage of the dimensioning the geotextile data are needed, that means a pre-selection has to be made.

The water permeability of a geotextile is reduced by the soil in situ. To read off the reduction factor a diagram of DVWK (1993) -based on the examinations of Heerten- is used (Fig. 6).

For the diagram the determination of an initial value with the pore fraction n (approx. 0.92) and the thickness d is needed:

$$k_v^2 / n \bullet d \bullet O_{90,w} \quad (4)$$

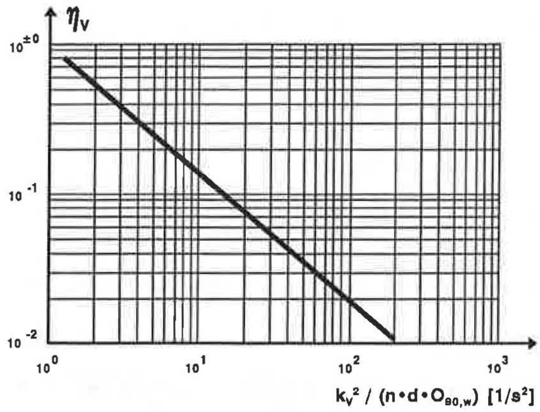

Fig. 6. Determination of the reduction factor η_V (DVWK 1993)

The value η_V results from Fig. 6. The reduced water permeability by the soil in situ must be higher than the water permeability of the soil:

$$\eta_V \bullet k_v > k \quad (5)$$

It applies to the grain-size spectrum that the mechanical filter effectiveness has to be proven for the left border of the grain-size spectrum and the hydraulic filter effectiveness for the right border of the grain-size spectrum.

Especially in capping sealing systems a safe filtering action has to be proven also after deformation if necessary. By the way, mechanically bonded staple fibre nonwovens keep their initial proportion of pores in stretched condition.

3.4 Component 'Geotextile Separation Layer'

The definition for separation is: *"The preventing from intermixing of adjacent dissimilar soils and/or fill materials by a geotextile or a geotextile-related product"* (comp. EN 30318). The soil retention capacity is thus the main criterion, that is the mechanical filter effectiveness has to be proven. Therefore, it can be assessed that "separation" is a subset of "filtering".

The lower layer of a geosynthetic gas drainage system used in capping sealing systems between the sealing and the waste (see Fig. 3) must be matched with the separation towards the waste body. As put down in section 2, questions of resistance have to be answered for this case.

3.5 Component 'Geotextile drainage/percolation layer'

For the dimensioning of drainage layers or better percolation layers the behaviour on long-term loading (with test periods of at least 1000 h) has to be considered in contact with the adjacent areas.

Often the imaginable discharge Q_A draining off the water (through the drainage core, percolation layer) and the anticipated quantity of drainage in-flow Q_E entering the percolation layer are compared:

$$Q_A > Q_E \tag{6}$$

The imaginable discharge Q_A is determined with the long-term transmissivity Θ_{long} of the drainage element (based on 1 m width) and the hydraulic gradient i in the drain resp. the slope inclination ß:

$$Q_A = \Theta_{long} \bullet i = \Theta_{long} \bullet \sin \beta \tag{7}$$

For the determination of the long-term transmissivity Θ_{long} the laboratory value Θ_{lab} is reduced. In this context it has to be considered that Θ_{lab} has been ascertained under typical normal stresses of landfill cappings of for instance $\sigma \approx 20$ kPa.

$$\Theta_{long} = \Theta_{lab} / \eta_S \tag{8}$$

Rüegger, Ammann & Jaecklin (1988) declare for single-layered nonwovens $\eta_S = 5$, for composites $\eta_S = 2$. According to GDA recommendations E 2-9 (1993) $\eta_S = 3$ shall be applied. In analogy to design procedures for Reinforced Soil the safety factor $\eta_S = 4$ could be chosen (Saathoff 1995). Jessberger, Neff & Gartung (1995) take a more differentiated view of the safety factor η_S following Koerner (1994):

$$\eta_S = \eta_{loc} \bullet \eta_{cr} \bullet \eta_{chem} \bullet \eta_{bac} \bullet \eta_\gamma \tag{9}$$

η_{loc} partical safety factor for local deformation (for long-term tests with soil contact $\eta_{loc} = 1.0$), according to Koerner: $\eta_{loc} = 1.0 - 1.5$,
η_{cr} partial safety factor for creep deformations of the synthetic material, according to Koerner: $\eta_{cr} = 1.2 - 1.4$,
η_{chem} partial safety factor for reduction of the drain cross section by chemical precipitation, according to Koerner: $\eta_{chem} = 1.0 - 1.2$,
η_{bac} partial safety factor for reduction of the drain cross section by biological influences (e.g. bacterial vegetation), according to Koerner: $\eta_{bac} = 1.2 - 1.5$ and
η_γ partial safety factor for general uncertainties of the system when experimentally ascertained data are transferred to field conditions, according to Koerner: $\eta_\gamma = 1.0 - 2.0$.

This approach also allows to vary the safey factor η_γ. Thus, for instance $\eta_\gamma = 1.75$ can be selected for normal cases (with a percolation flow-off which is based on the following $r_{15,n=1}$) and $\eta_\gamma = 1.0$ for a max. calculated percolation flow-off (or based on $r_{15,n=0.2}$).

The partial safety factors given by Koerner result in at least $\eta_{S,min} = 1.44$ and at the most $\eta_{S,max} = 7.56$. For geosynthetic drainage systems consisting of mechanically bonded nonwovens and a convoluting fibre layer the following value might be applicable:

$$\eta_{S,selected} = 1.0 \bullet 1.4 \bullet 1.0 \bullet 1.2 \bullet 1.75 \approx 3 \tag{10}$$

The safety factors given above, recommended by other authors, are also within this range. Without testing the marginal conditions, a safety factor of $\eta_S = 4$ should be on the safe side for most of the applications.

$$\eta_{S,selected} = 4.0 \tag{11}$$

The connection of the equations (6), (7), (8) and (11) results in the condition to be fulfilled:

$$\Theta_{lab} \bullet \sin \beta / 4.0 > Q_E \tag{12}$$

The in-flow water quantity Q_E will be considerably smaller compared with the precipitation, because a surface discharge will take place in the vegetation layer or water can be absorbed by roots. Furtheron, the water permeability coefficient of the vegetation layer plays a decisive role. Schäfer (1990) for instance states for the water quantity to be expected in the percolation layer of a capping sealing system 25 to 30% of the precipitation. His reflections show that only the k-value of the sealing layer, but not its thickness, is decisive for the good interaction of drainage and sealings systems. Computations can e.g. be carried out by means of the HELP program. In accordance with Schäfer (1990) the following equation often serves as basis for the in-flow water quantity Q_E to simplify the matter:

$$Q_E = 0.3 \bullet Q_R = 0.30 \bullet r_{15,n=1} \bullet \ell \tag{13}$$

Q_R rain discharge (precipitation)
$r_{15,n=1}$ 15 minute rainfall with the frequency 1 (1/a)
ℓ considered length / slope length

Assuming $r_{15,n=1} = 100$ l/s/ha $= 1 \bullet 10^{-5}$ m³/s/m², the result for the slope length of ℓ is:

$$Q_E = 0.3 \bullet 1 \bullet 10^{-5} \bullet \ell = \ell \bullet 3 \bullet 10^{-6} \text{ m}^3/\text{s}/\text{m}^2 \tag{14}$$

The in-flow water quantity Q_E is linearly dependent on the slope length. The consideration of the equations (12) and (14) results in:

$$\Theta_{lab} \bullet \sin \beta / 4.0 > \ell \bullet 3 \bullet 10^{-6} \text{ m}^3/\text{s}/\text{m}^2 \tag{15}$$

or

$$\Theta_{lab} \bullet \sin \beta / \ell > 1.2 \bullet 10^{-5} \text{ m/s} \tag{16}$$

In the case that the dimensioning according to equation (16) fails for a chosen construction task, it should be examined whether remedial measures can be taken by configuration of drainage possibilities (drain pipes) with a reduced slope length.

A geosynthetic gas drainage system, installed in capping sealing systems between sealing and waste, must be designed to the drainage of gas with its geosynthetic drainage core component (e.g. convoluting fibre layer). Koerner (1993) defines a safety factor η_G, which can be calculated as follows:

$$\eta_G > Q_{per.} / Q_{req.} \tag{17}$$

η_G safety factor
$Q_{per.}$ permissible gas drainage discharge
$Q_{req.}$ required gas drainage discharge

The permissible gas drainage discharge is calculated from the permeability to air resp. the air transmittivity depending on the normal stress resp. the compression. The required gas drainage discharge has to be regarded separately for each specific landfill. The proof of the resistance of the raw materials used should be to the fore.

4 SHEAR BEHAVIOUR

A sealing system is required to prevent sliding (caused by the own weight or by external load) in the system and to prevent that the geomembrane -also locally- provides a carrying function, that is tensile stresses should not be applied to the geomembrane (exceeding its tensile strength). It is required that the transmissible shear stress above the geomembrane must be (the same or) smaller than below the geomembrane, in order to transfer the additional tensions resulting from the load by (equal or) higher shear stresses to the bottom side of the geomembrane and to ensure for the geomembrane a position free of tension. If the values found out for the resistance to sliding are far above the permissible values, this demand can be dropped. Detailed knowledge is required about the shear planes given by the system, in order to guarantee a safe dimensioning of a sealing system.

If tensions have to be taken up systematically by elements of the sealing system, geosynthetic elements of high tensile strength like oriented geogrids are recommended (Scheu, Saathoff & Bishop 1994).

5 QUALITY MANAGEMENT

Prior to the manufacture of landfill sealing systems a quality assurance schedule has to be set up. This schedule shall lay down the specific elements of quality assurance, so that the mentioned quality characteristics are fulfilled.

All geosynthetic components should be subject to quality control, as for instance according to DIN 18200 -*"Überwachung (Güteüberwachung) von Baustoffen, Bauteilen und Bauarten"*-, which should already be required and laid down in the tender with internal and external monitoring to be proved by an authorized material testing institute. In addition, the manufacturer of a geosynthetic drainage systems should work according to the quality assurance system EN 29000 ff / ISO EN 9000 ff.

In order to ensure quality from the raw material to the finished product, *Naue Fasertechnik* uses for instances HDPE granules to produce HDPE staple fibres which are then -subject to external quality control according to DIN 18200- used for the production of staple fibre nonwovens (e.g. Depotex® 315), and these nonwovens are then applied for composites as e.g. Secudrän® 315-DS 805-315. Due to this uninterrupted, controllable chain from the raw material to the fibre and to the geosynthetic drainage system a steady, high quality can be guaranteed.

Landfill sealing systems demand an uninterrupted quality assurance of the components delivered and installed. These are:

- the dimensioning, carried out by an engineer, of the geotextile filter layer -among others- of a geosynthetic drainage system and the formulation of the technical requirements, if necessary to be proved by expert statements,
- the embodiment of all technical requirements in the tender and the inclusion of the requirements on quality control, identification of the geotextile (printing on the geotextile and label on each roll) and installation instructions into the technical preliminary remarks,
- the strong verification of the bids regarding task-orientated statements in the main offer,
- the securing of the quality control during production by uninterrupted internal and external monitoring carried out by an authorized material testing institute,
- the written confirmation of the authorized material testing institute, that the laboratory of the manufacturing company and the technical facilities of the production plant ensure a perfect observance of the requirements,
- the verification of the identifcation of the materials delivered to site by roll labels and prints on the material and consistent rejection of goods which are not properly marked,
- identity controls on site (at least mass per unit area and thickness, in special cases water permeability in the geotextile plane) and
- control of the professional installation under strict observance of the installation instructions stated in the tender.

A quality assurance schedule should include for geosynthetic drainage systems at least the following specifications (Saathoff 1995):

- proofs and test reports
  test reports from the factory according to EN 10204,
  test reports on water permeability in the plane for the used drainage core (percolation layer, geosynthetic drainage layer),
  examinations on compressive creep of the used drainage core,
  test reports on the effective opening size und thickness of the nonwovens used,
  proof of the filter stability of the used nonwovens,
  proof of the external monitoring according to DIN 18200, at least with regard to thickness and mass per unit area,

proof of the physical and mechanical data of the geosynthetic drainage system (raw material, thickness and mass per unit area of all components, maximum tensile strength longitudinal/transverse and elongation of the nonwoven components),
- description of the product (including raw material specification sheets),
- internal monitoring tests on the initial product (nonwovens), as for instance

thickness	1 x per 2 500 m^2
mass per unit area	1 x per 2 500 m^2
maximum tensile strength longitudinal/transverse	1 x per 10 000 m^2
maximum tensile elongation longitudinal/transverse	1 x per 10 000 m^2
effective opening size	1 x per 25 000 m^2

and
- internal monitoring tests on the geosynthetic drainage system, as for instance

thickness	1 x per 500 m^2
mass per unit area	1 x per 500 m^2

6 ADVANTAGES OF A GEOSYNTHETIC DRAINAGE SYSTEM

Geosynthetic drainage layers are rolled up on a core and delivered to site in a packaging protecting against moisture. They can be easily cutted with a knife or a pair of scissors.

The advantages of a geosynthetic drainage system are:
- low weight,
- therefore low load and easy handling,
- industrial manufacture, that means data are available as well,
- permanent quality controls according to DIN 18200,
- no test fields necessary,
- high safety on settlements in the landfill,
- light-weight installation equipment,
- easy installation, also at steep slopes,
- high installation performance,
- a complete system consisting of a percolation layer, a filter layer and a protection layer can be installed in one operation (no multiple installation),
- easy to repair (refers to cappings seals only),
- costs can be calculated more easily,
- less sensitive to settlements and
- low volume requirement,
- consequently additional volume for waste is gained.

Compared to mineral drainage systems, a geosynthetic drainage system ist not only advantageous for its low thickness and its easy installation, but also for static, economical and ecological reasons. Whereas a geosynthetic drainage system Secudrän® weighs on the subsoil with approx. 0.6 to 2.0 kg/m^2 depending on the mass per unit area, a for instance 30 cm thick gravel drainage layer applies a load of 600 kg/m^2. Furtheron, a 24 t truck has a capacity for approx. 40 m^2 of a mineral drainage material, a comparable truck could load at least 2000 m^2 Secudrän®. Moreover, the use of geosynthetic drainage systems saves the gravel deposits which are growing scarce.

Quite a number of examples for the application of geosynthetic drainage systems is shown by Saathoff (1995). A special example for a capping sealing system with, among others, Secudrän® made of HDPE as drainage system for the removal of gas below a geomembrane is the landfill Eckendorfer Straße; the construction is shown in the paper of Saathoff & Keller (1996) which is also comprised in the present Proceedings.

7 CONCLUSION

Especially at steep slopes it is difficult to place mineral drainage layers. In this case geosynthetic drainage systems are preferably used as a composite of filter and percolation layers in order to drain off the water.

The different fields of application for geosynthetic drainage systems in landfill constructions clearly show that a successful and at the same time safe design requires to examine the behaviour and the performance of the different components in detail.

Important tasks (functions) as protection, filtering or separation, drainage, but also reinforcement and sealing, are assigned to geosynthetics. The advantages of a construction method with geosynthetics in general can only take effect in case of a right choice, a suitable application and a professional installation. For most of the applications the selection of a suitable geosynthetic, the monitored installation and the long-term behaviour is of decisive importance for the life and safety of the complete construction.

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