Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Performance of GCL and drainage geocomposite in a landfill cover system.

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ABSTRACT: The performance of a landfill capping system including a geosynthetic clay liner (GCL) and a drainage geocomposite was studied in a long-term field test. The test field was constructed as large-scale lysimeter, in which the relevant water fluxes are collected and measured. The water balance of the 3-years monitoring period shows, that evaporation accounts for almost 70% of the water output. 30% drain off laterally in the drainage geocomposite, and only 0.5% seep through the GCL. The drainage geocomposite and the GCL proved to be effective elements within the landfill cover system.

1 INTRODUCTION

The surface cover of a landfill serves as long-lasting barrier between the waste body and the atmosphere and biosphere. The EC-directive on the landfill of waste (1999) gives, in annex I, recommendations for the surface sealing of landfills. The EC-landfill directive states, that for landfills for non-hazardous waste (like municipal solid waste) a surface cover system may be prescribed, which is recommended to contain the following elements:

– Soil cover > 1 m
– Drainage layer > 0.5 m
– Impermeable mineral sealing layer.

Further more specific requirements are given in the technical regulations of individual member states. In Germany, for example, a compacted clay liner of > 0.5 m with $k < 5 \times 10^{-9}$ is prescribed as standard mineral sealing layer. Alternative sealing layers may also be permitted, if their functional equivalency to the standard system has been proven.

Field tests conducted at the Hamburg-Georgswerder landfill (Melchior, 1996) demonstrated rapid failure of GCL, when the design of the landfill cover system is inappropriate (in this case: insufficient thickness of restoration profile). These findings stressed the importance of testing and evaluating landfill covers as complete systems in addition to testing all individual elements.

The suitability of a drainage geocomposite in a surface cover system is often calculated on the basis of hydraulic modeling, e.g. the HELP-model (Schroeder et al., 1994). The performance of GCL is often tested by excavations after a certain time span. Excavations provide only a snap-shot-view of the conditions of the GCL. A more comprehensive study of the water balance of a landfill cover system in which the performance of a drainage geocomposite and a GCL can be examined is possible through large-scale lysimeter test fields. Such a lysimeter test field was set up at the landfill of Aurach in Bavaria in 1998. Results of the 3-years monitoring period of this test field are presented in this paper.

2 TEST FIELD

A test field for studying the water balance and the performance of a surface cover system including a GCL and a drainage geocomposite was installed at the landfill of Aurach in 1998. The test site is located some 60 km southwest of Nuremberg in a gently hilly region at an elevation of 500 m above sea level. The test field of 520 m² was constructed on the southern slope (inclination: 20%) of the landfill as a large-scale lysimeter.

A cross section of the cover system in the test field is shown in Figure 1. It consists of the following layers:

– Recultivation layer; topsoil: loamy sand (0.2 m)
– Recultivation layer; subsoil: slightly loamy sand (0.8 m)
– Drainage geocomposite
– GCL
– Regulating layer (loamy sand)

Seepage collection system (drainage geocomposite and HDPE-geomembrane)

A Ca-bentonite GCL was used in the test field in order to avoid changes in material properties due to ion-exchange effects, which are known to occur in Na-bentonite GCL (e.g. Egloffstein, 2000). The lower swelling capacity and higher hydraulic conductivity of Ca-GCL compared to Na-GCL is accounted for by higher mass per unit area for the Ca-bentonite GCL. The product which was used in the test field has a mass per unit area of 9500 g/m² and a permittivity Ψ of 8.3×10^{-9} s^{-1}.

A drainage geocomposite was used as drainage layer above the GCL. Under a load of 20 kPa it has a thickness of 11 mm and a horizontal water diversion capacity of q_{20} = 0,7 l/(s x m) at i = 0.1.

The major task of the restoration profile is to protect the mineral sealing layer from adverse effects such as desiccation, penetration of roots or freezing. Therefore a loamy sand with a high water retention capacity was chosen as top soil, and as subsoil a sand which is poor in clay content.

The main objective of measurements was the precise determination of the relevant water fluxes (see Figure 1):

Surface runoff (Q_S),
Drainage flow (Q_D),
Seepage flow through the GCL (Q_L).

The water fluxes are continuously measured at high precision in a measuring container. In addition soil moisture measurements by tensiometers and FDR-probes are carried out in the restoration profile. The relevant meteorological data (precipitation, temperature, relative humidity etc.) are measured in a meteorological station nearby. Readings of all measuring devices are taken automatically with the data stored on a PC. All data are readily available at the LGA-Geotechnical Institute via GSM-transmittance.

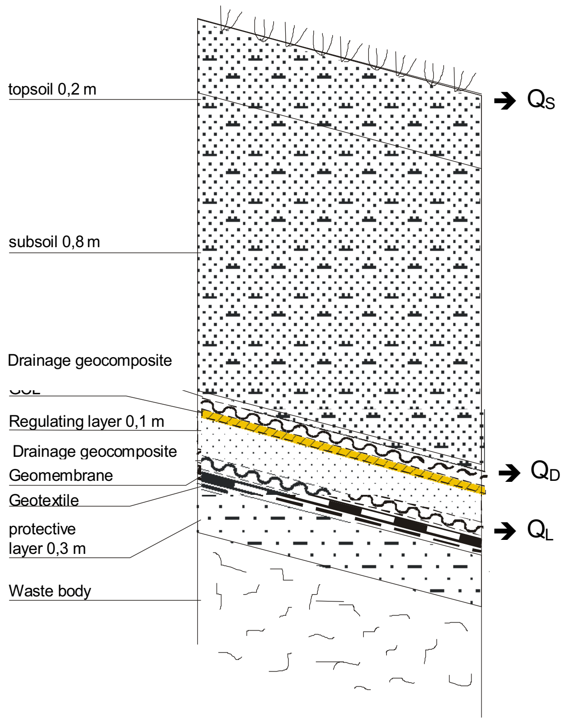

Figure 1. Cross section of the test field.

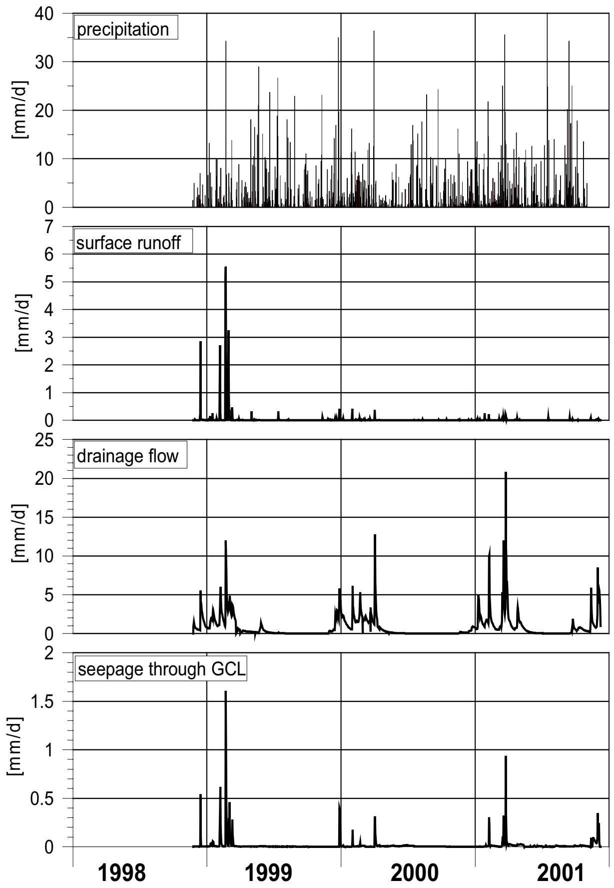

Figure 2. Daily values of precipitation and water flows in the test field

3 RESULTS

3.1 *Precipitation and surface runoff*

Measurements in the test field started in November of 1998. The results of the precipitation and discharge measurements are shown in Figure 2 as daily values in mm/d. The precipitation shows a pattern typical for cool temperate, humid conditions, which prevail in Bavaria. At the location of the landfill, average annual precipitation is about 750 mm. During the observation period precipitation was about 20% higher. Precipitation is almost evenly distributed over the years, without prominent wet or dry seasons. Peak daily precipitation reaches 40 mm.

Noteworthy surface runoff occurred only in the first winter season, while the vegetation on the recultivation layer was still sparse. After this initial period only minimal surface runoff is recorded, which is restricted to a few events in winter times.

3.2 *Drainage flow*

Drainage flow shows a systematic pattern of seasonal variability: Substantial drainage flow is recorded in winter, during the months of November through April. During the summer half year from May to October there is only little drainage flow. In summer, even heavy rainfall associated to thunder storms does not result in drainage flow.

The maximum daily drainage flow which occurred during the observation period was 21 mm/d in the generally wet month of March 2001. Daily values of > 5 mm/d occur a couple of times each winter. Peaks in drainage flow occur simultaneous to precipitation events. Following a flow event drainage flow rapidly decreases again to values below 1 mm/d.

Drainage flow is recorded by high resolution measurements. The drainage flow reached a maximum short-time value of 3.1 l/(s x ha).

3.3 *Seepage flow through GCL*

Seepage flow through the GCL is shown in the lowermost graph of figure 2. Note that the y-axis of this graph is expanded, compared to the other y-axes. Seepage flow occurs only on a few days during the observation period. It is not, as might be expected, proportional to the drainage flow, but it is restricted to a few events per year. Noticeable seepage flow only occurs, when the drainage flow exceeds 5 mm/d. Then the seepage flow reaches daily values of 0.2 to 1.6 mm/d. On the following day it drops to zero again.

Semi-annual sums of precipitation and fluxes in the test field are given in table 1. On the average 30% of precipitation account for drainage flow, surface flow is 1% and only 0.5% seep through the GTD. The remaining 68% of precipitation leave the surface cover system by evapotranspiration.

Table 1. Semi-annual sums of precipitation and discharge measurements in the test field.

	Precipitation mm	surface flow mm	drainage flow mm	seepage flow mm
Winter 98/99*	305.5	25.2	239.6	7.0
Summer 1999	537.7	1.2	23.7	0.3
Winter 99/00	525.3	3.2	228.0	1.8
Summer 2000	354.8	0.4	45.8	1.5
Winter 00/01	538.3	2.4	243.9	3.0
Summer 2001	565.1	0.7	65.9	1.2
Sum 11/98-9/01	2884.4	33.1	862.9	15.1
Sum in % of Precipitation		1.1%	29.9%	0.5%

*) note: measurement in winter 1998 started at the end of November.

3.4 *Measurements of soil moisture in the restoration profile*

Four FDR-probes are installed in the restoration profile for continuous monitoring of the soil water content. After proper calibration FDR-probes measure the volumetric water content of the soil. The FDR-probes are installed in a vertical measuring profile within the test field at 0.2 m spacing between 0.2 m (FDR-probe # 4) and 0.8 m (FDR-probe # 1).

The results of the measurements of volumetric soil water content by means of the FDR-probes is shown in Figure 3. All 4 FDR-probes display the same overall pattern of higher water content in winter and lower water content in summer. Water content in the topsoil (FDR-probe # 4) fluctuates between 15 Vol.-% in summer and 30-35 Vol.-% in winter. In the subsoil, which is poor in fine fraction, water content varies between 10-14 Vol.-% in summer and 15-20 Vol.-% in winter.

During winter season the curves exhibit several sharp maxima of water content. These peaks correspond to maxima in precipitation. In spring and early summer soil water content decreases. At closer inspection of the curves it can be noticed, that the onset of decrease in water content first starts in the uppermost FDR-probe (# 4) and is then consecutively recorded in the deeper FDR-probes.

During summer the water content in the subsoil reaches low values and shows little variation until the beginning of the next wet winter season. Rainfall events during summer are obviously intercepted in the topsoil and do not noticeably penetrate into the subsoil.

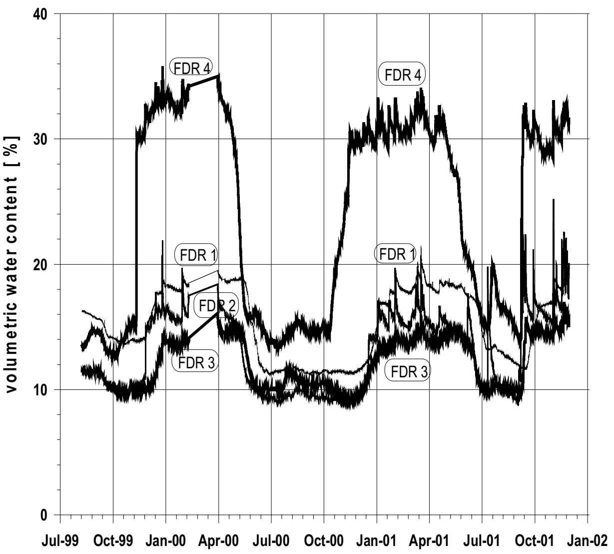

Figure 3.Continuous measurements of volumetric soil water content in the restoration profile between 0.2 m depth (FDR 4) and 0.8 m (FDR 1).

4 DISCUSSION

4.1 *Water balance of the recultivation layer*

The observations made in the test field give insights into the water balance of a landfill cover system with a GCL as sealing layer. Under middle-European climatic conditions the water balance at most locations shows distinct seasonal differences: During summer months evapotranspiration exceeds the amount of rainfall. In addition soil water is extracted and evapotranspirated. During winter season precipitation is higher than evapotranspiration. The soil water reservoir is replenished. When the field capacity of the soil is reached, additional precipitation percolates down into deeper layers. This process, which in natural soils leads to groundwater recharge, has repeatedly been observed in lysimeter test fields on landfills as drainage flow and seepage flow (Henken-Mellies et al., 2001; Breh & Hötzl, 2000; Siegmund et al., 2001).

The layers above the GCL have important functions with respect to the water balance: The recultivation layer has the task to keep desiccation stress away from the GCL in summer time. Soil water extraction due to evapotranspiration should not reach down to the base of the recultivation zone. In the test field the 1 m thick recultivation layer does not sufficiently fulfill this task: The FDR-measurements in different depths of the recultivation layer indicate, that the soil reaches a low and constant water content in summer and autumn. This low water content can be interpreted as the permanent wilting point of the soil.

4.2 *Performance of the drainage geocomposite*

The main task of the drainage layer within the surface cover system is to drain the water, which percolates through the recultivation layer and thereby to minimize the hydrostatic pressure on the mineral sealing layer.

Information about the potential quantity of water percolating through the recultivation layer is necessary in order to appropriately design the drainage layer. Recommendations in this respect are given for application in Germany in the "Technical Recommendation for Geotechnics of Landfills and Contaminated Land" (DGGT 1997). According to these recommendations peak daily values for percolation of 25 mm/d should be taken in account in case of sandy recultivation layers. In 99% of all days percolation rates of less than 10 mm/d are to be expected.

These values, which are recommended for design calculations in Germany have been verified by the observations in the test field (see Figure 2): Here the maximum percolation rate was 21 mm/d, and in 99% of all days it was below 6 mm/d.

Percolation through the recultivation layer and drainage flow is mainly restricted to the winter half year, when the soil moisture has reached field capacity. Heavy precipitation during summer does not penetrate down to the base of a 1 m thick recultivation layer and hence does not cause drainage flow.

The maximum short-time flow in the drainage composite was measured to be 0.006 l/(s x m) at the base of the 20 m slope of the test field. This value measured in the field is two orders of magnitude lower than the horizontal water diversion capacity of the drainage geocomposite of q_{20} = 0.7 l/(s x m) as measured in the laboratory.

4.3 *Performance of the GCL*

Seepage flow through the GCL is in the order of a few millimeters per year or 0.5% of the precipitation. In the first winter after construction of the test field seepage flow was somewhat higher; since then it remains as low as 0.3% of the annual precipitation. Up to the present time there is no tendency towards increasing seepage flows with time.

The process of seepage through the GCL is obviously not a low and constant flow, but a sporadic flow, which is triggered by high drainage flow (see figure 2). It can be assumed that during times of high drainage flow (> 5 mm/d) a hydraulic head builds up temporarily in the drainage layer, which then causes seepage flow. During most of the time the drainage layer effectively keeps the hydraulic head at about zero, and consequently no seepage flow occurs.

The seepage flow through the GCL in the test field reported here is in the same range as in test fields elsewhere: Siegmund et al. (2001) made long-term observations at a test field in Thuringia. In the profile of the test field they placed a sandy buffering layer between the drainage layer and the GCL, in order to reduce the risk of desiccation of the GCL. Here seepage flow occurred on numerous days during winter season with flow on individual days ranging from 0.05 to 0.25 mm/d.

5 CONCLUSIONS

The performance of a drainage geocomposite and a GCL within the surface cover system of a landfill is being tested by means of a large scale lysimeter. The water balance of the 3-years monitoring period shows, that evaporation accounts for almost 70% of the water output. 30% drain off laterally in the drainage geocomposite, and only 0.5% seep through the GCL. The results emphasize the importance of a properly designed and sufficiently thick recultivation layer in order to regulate the water balance of the surface cover system. The drainage geocomposite and the GCL proved to be effective elements within the landfill cover system.

6 ACKNOWLEDGEMENTS

The research work presented here has been carried out on behalf of and with financial support from the Bavarian State Ministry for Regional Development and Environmental Affairs.

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