doi:10.1088/1757-899X/1260/1/012018

Evaluation of the performance of a drainage geocomposite in a simple cover system based on 10 year measurements

E Birle[1], **M Melsbach**[1], **D Heyer**[1]

[1] Zentrum Geotechnik, TU Munich, Baumbachstr. 7, 81245 Munich
Email: e.birle@tum.de

Abstract. In the course of the geotechnical investigations for a new runway at Munich Airport the hydro-mechanical behaviour of organogenic clays was studied. With the aim of an efficient use of materials the organogenic clay shall be used for noise and view barriers. As the organogenic clays have increased arsenic contents the percolation of such structures should be minimized. For the detailed investigation of the hydro-mechanical behaviour and for the determination of seepage quantities, a large scale, 5 m high, 30 m long and 25 m wide test fill was constructed. Due to the low permeability of the organogenic clays in compacted condition a cover design with a drainage mat and a top layer without an additional sealing layer was chosen. Measurements of the water balance were collected since the installation in 2008. The results show very low leachate quantities, although humid climatic conditions with average annual precipitation of approx. 745 mm were present. The low leachate rates can be mainly attributed to the capillary-breaking effect of the drainage geocomposite and the high water retention capacity of the topsoil. Based on the results the presented simple cover system can be considered an efficient and effective solution for minimizing infiltration water into core materials of embankments and noise barriers in road-way design.

1. Introduction

In the course of the geotechnical investigations for a new runway at Munich Airport the hydro-mechanical behaviour of organogenic clays was studied. The organogenic clays, which form the topsoil in the area of the Munich Airport, have geogenically increased arsenic contents. For the planned expansion of Munich Airport (amongst others, the construction of a new runway is planned) large amounts of these topsoils will have to be removed.

With respect to material recovery, the organogenic clay shall be used for noise and view barriers. For reasons of groundwater protection, the barriers have to be designed with the aim of minimizing the elution of arsenic from the clays. This can principally be achieved by covering the organogenic clays with sealing layers, e.g. clay liners or geomembranes. However, due to the low permeability of the organogenic clays in compacted condition, a cover design with a drainage mat and a top layer without an additional sealing layer was chosen.

For the detailed investigation of the hydro-mechanical behaviour and for the determination of seepage quantities, a large scale, 5 m high, 30 m long and 25 m wide test fill was constructed. Extensive monitoring systems were installed for the determination of the water balance of the fill, including seepage flow through the compacted organogenic clay. Data of the water balance were collected since the installation in 2008. Results of the measurements were reported by Birle et al. [1] and Birle and

Heyer [2][3]. In the following the design of the fill and the measuring instrumentation is briefly described. Thereafter, the seepage flow through the simple cover system, which consists of the topsoil and a drainage geocomposite only is analysed and the hydraulic interaction between the topsoil and the geotextile is described.

2. Materials and design of the test fill

2.1. Core Material

For the construction of the test fill, topsoil was excavated from a site near Munich Airport. According to DIN 18196 and the Unified Soil Classification System (USCS), this soil is classified as an organogenic clay (OH) with a liquid limit in the range of 94 % to 133 % (average value of approx. 124 %) and a plastic limit in the range of 55 % to 87 % (average value of approx. 44 %). The organic content determined by the ignition method is between 25 % and 30 %. The compaction behaviour was studied by Standard Proctor tests. Other than in mineral soils, for the organogenic clay no distinct Proctor Optimum could be determined. A maximum dry density of approximately 0.8 g/cm^3 with corresponding water contents, ranging between 55 % und 75 %, was noted. For the determination of the water permeability laboratory tests were performed. According to the results, the coefficient of permeability depends strongly on the compaction water content: for a water content of 55 % a coefficient of permeability of $5 \cdot 10^{-8}$ m/s and for a higher water content of 75 % a lower value of $5 \cdot 10^{-9}$ m/s was determined [4]. To distinguish this soil from the material which was used for the top layer, it is also referred to as the “core material” in the following.

2.2. Drainage mat

For the drainage mat, which was placed between the core material and the top layer, a drainage geocomposite consisting of a wave-extruded monofilament drainage core and nonwoven geotextiles on the top and bottom for filtration and separation was used. According to the product specifications the effective opening width of the nonwoven layers was determined in line with DIN EN ISO 12956 and is 0.12 mm. The lateral drainage capacity is $1.5 \cdot 10^0$ L/(m·s) for a hydraulic gradient of 1 under vertical stresses of 20 kN/m^2 (determined according to DIN EN ISO 12958).

2.3. Topsoil

Another organogenic clay, which was also taken from a site near Munich Airport, was used as topsoil of the test fill. With average values of the liquid limit of 93 %, the plastic limit of 56 % and the organic content (determined by the ignition method) of 25 %, this organogenic clay is similar to the core material. The topsoil was placed with an excavator shovel and lightly pressed on, but not compacted with a roller. The dry density of the topsoil was determined directly after placement to approx. 0.77 g/cm^3. But only one year later due to consolidation effects a significantly higher dry density of 1.09 g/cm^3 was measured. Based on permeability tests, an average value of the coefficient of permeability of $5 \cdot 10^{-8}$ m/s can be assumed for the topsoil [5].

2.4. Design of the test fill

The design of the fill is shown in figure 1. The test fill is 5 m high, 30 m long and 25 m wide with a slope inclination of 1:2. The compacted organogenic clay is covered by a drainage mat and the 0.6 m thick topsoil layer. As the hydraulic properties of the organogenic clay depend strongly on the compaction water content, the fill was divided in two parts. In the western side the soil was compacted with an initial water content of approximately 55 % (“dry” compacted) and in the eastern side with an initial water content of approx. 75 % (“wet” compacted). The compaction was performed by means of a heavy roller (25 tons) with polygonal drums. Like that, dry densities of the dry and wet compacted material between 0.75 g/cm^3 and 0.85 g/cm^3 were achieved. After the compaction of the organogenic clay the drainage mat was installed. Finally the topsoil layer was spread with a thickness of approx. 60 cm and grass was sown.

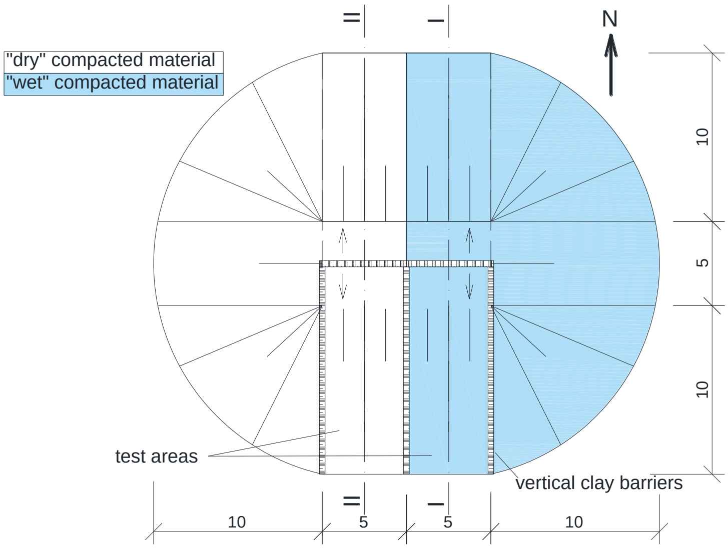

Figure 1. Plan view of the test embankment

2.5. Monitoring system

Two areas of 5 m width and 12.5 m length were separated from the remaining part of the fill by vertical clay barriers of very low permeability in the southern area of the fill (see Figure 1). For the assessment of the water balance extensive measuring systems were installed in these test areas, in which two-dimensional flow conditions can be assumed. Leachate is collected at the base by a drainage mat on top of a geomembrane. A tube connected to the geomembrane discharges the water to a gauge well situated on the south side of the fill, where the leachate discharge is measured by electronic tipping buckets. The interflow in the drainage mat between core and topsoil is collected at the bottom of the test areas and quantified similarly. The flow of water in the compacted organic soil can be derived from variations of suction and water content, measured by tensiometers and TDR-probes. The positions of these sensors after installation are shown in Figure 2.

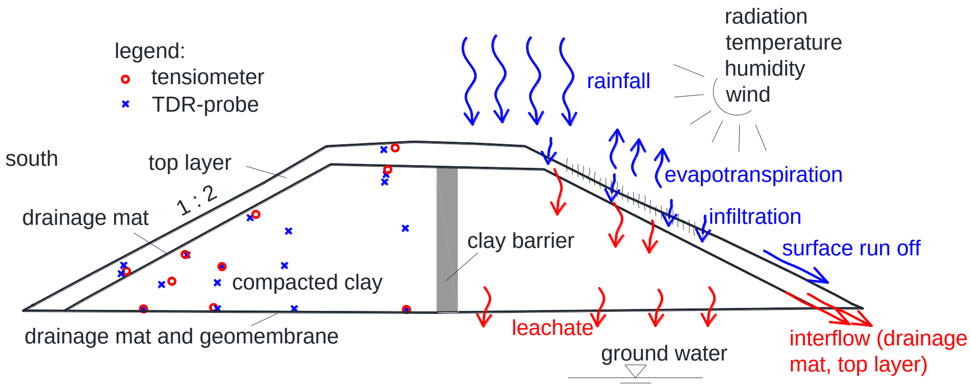

Figure 2. Cross section II-II of the fill with the final arrangement of the tensiometers and the TDR-probes (left section) and the description of the water balance (right section)

For the determination of the volumetric water content by means of the signals of the TDR-probes, a calibration of the TDR-probes had been performed. For the simulation of the water balance of the fill the climate conditions have to be known. The climate is measured by a meteorological station close to the fill. It consists of several sensors measuring the air temperature and humidity, the effective radiation, the wind velocity and direction as well as the amount of precipitation. The water balance of the fill is shown schematically in Figure 2 (right section).

3. Measurements

3.1. Precipitation

The precipitation recorded at the fill between November 2008 and November 2018 is shown in figure 3. The data presented refer mainly to the values measured directly on the test fill, unless no data were available due to problems with the local measuring device. In this case, the precipitation values from the German Meteorological Service (DWD) for Munich Airport were used.

The annual precipitation pattern is typical for the south of Germany showing a maximum in the summer months. This is caused by the accumulating effect of the Alps that is particularly significant during the summer months. The accumulated precipitation reaches 7475 mm, which corresponds to an average annual precipitation of 747 mm. Especially, the years 2013, 2014, 2015 and 2016 were slightly drier and the years 2010 and 2012 significantly wetter than the average long-time annual precipitation of approx. 750 mm given by the German Meteorological Service for Munich Airport.

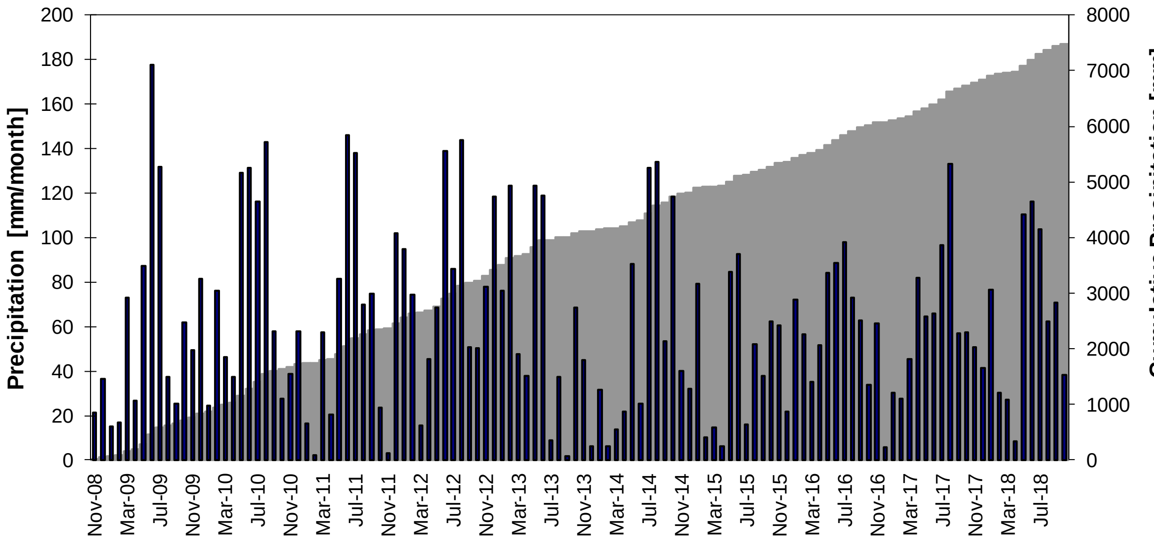

Figure 3. Precipitation measured at the test fill or taken from the German Meteorological Service (DWD) for Munich Airport

3.2. Leachate and interflow in the top drainage geocomposite

Figure 4 shows cumulative data of precipitation, leachate at the base and interflow from the top drainage mat, which were measured for the “wet” and “dry” side of the test fill. For the wet side 99 mm were collected at the base of the test area in the entire observation period and 112 mm from the drainage mat placed above the compacted organic clay. In comparison to the total precipitation of 7475 mm these are very small fluxes (approx. 1.3 % and 1.5 %). For the dry compacted clay even smaller fluxes for the leachate at the base (45 mm) as well as for the drainage mat (58 mm) were recorded. This is caused by the low water content of the “dry” compacted clay leading to the main portion of seepage water being retained by it.

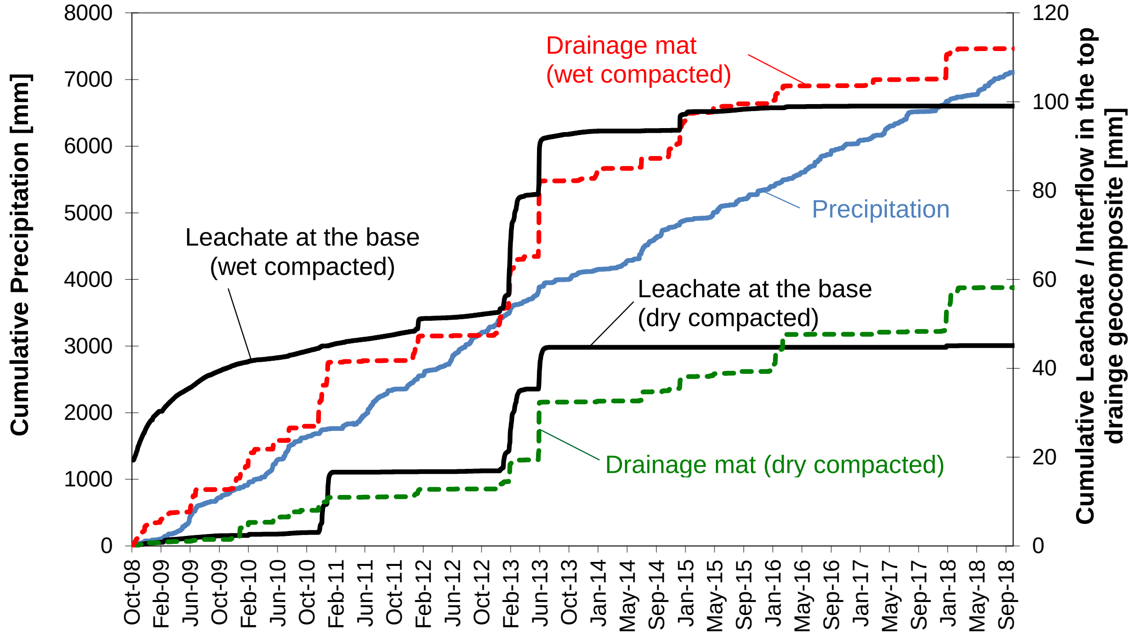

Figure 4. Cumulative fluxes of precipitation, leachate and interflow in the top drainage mat for the wet and dry compacted part of the test fill

Measurements of the TDR-probes located in the topsoil (Figure 5a), show that the maximum water contents are usually reached in the winter months. This is reasonable as the transpiration by the vegetation is low during this time. The interflows from the drainage mats are shown in figure 5b. A comparison of the water content measurements with the interflows indicates that significant discharge from the drainage mats only occurs when the topsoil has reached values of the volumetric water content in the range of 45 % to 55 %, which means that the topsoil is almost saturated. This occurs usually in winter, when no evapotranspiration takes place or in summer after a wet period with high precipitation (e.g. in summer 2013). As the wet compacted clay was almost saturated after compaction, less water is absorbed by the core material and a slightly higher discharge from the drainage mat is noticeable in comparison to the dry compacted core material. However, similar to the dry side, an interflow in the drainage mat takes place only occasionally, when the topsoil has reached water contents above the water content at field capacity and thus infiltrating water cannot be retained further by the topsoil.

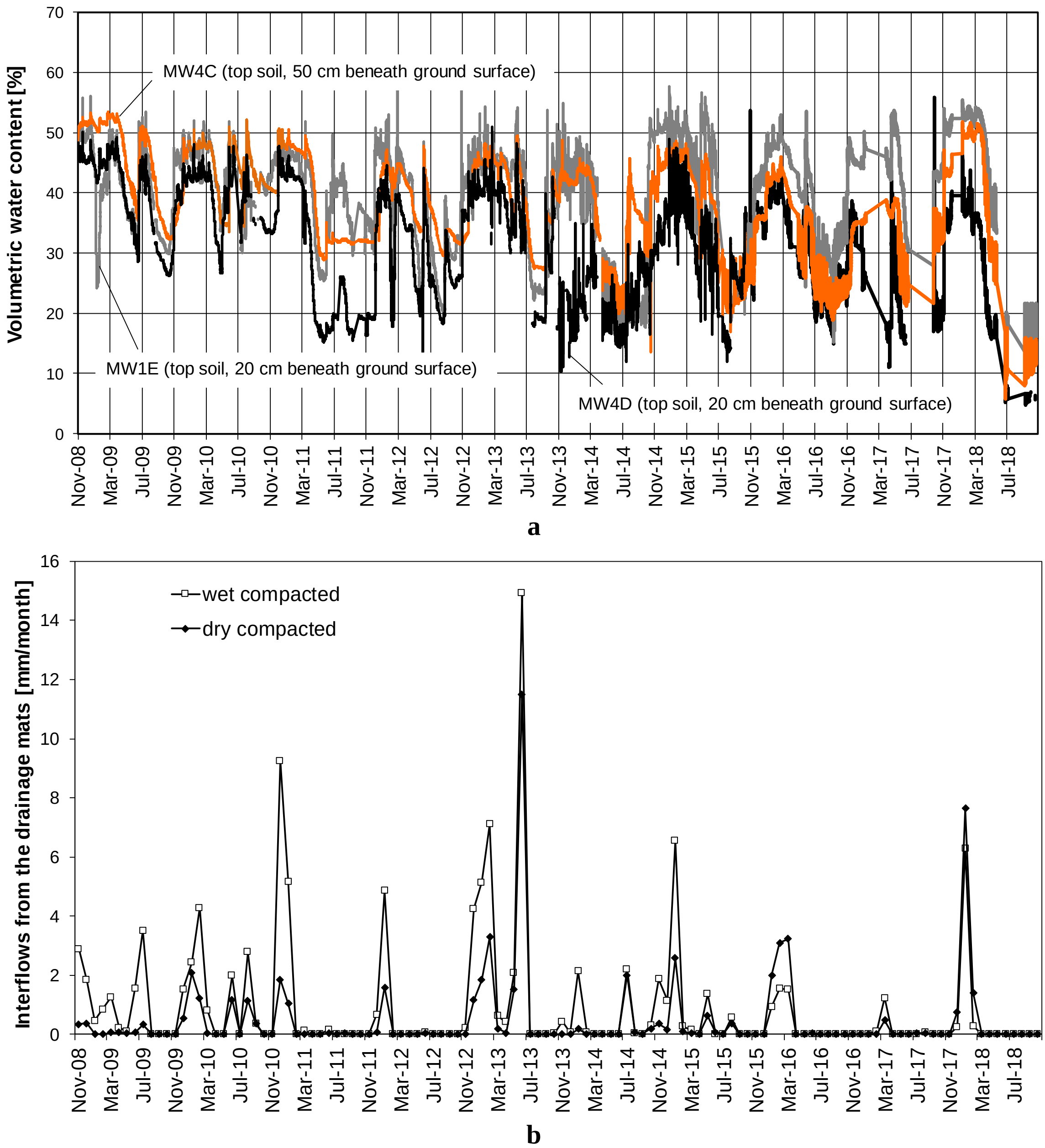

Figure 5. Volumetric water contents measured in the topsoil **a** and interflows from the top drainage mats **b**

4. Analysis of the water balance

According to the water balance equation the precipitation (N) must be equal to the sum of evapotranspiration (ET), surface runoff (SR), seepage flow (seepage at the base S_B and interflow from the top drainage mat S_I) and storage (W):

$$N = ET + SR + S_B + S_I + W \quad (1)$$

For the wet compacted clay Birle&Heyer [3] concluded based on the measurements of the water content sensors which were installed in the wet compacted core material that it was almost saturated after compaction and that no significant storage had occurred since 2008. For the dry compacted material in contrast, Birle&Heyer [3] described that it has the potential to retain a significant portion of the infiltrating water and thus the seepage at the base of the dry compacted organogenic clay and the interflow from the drainage mat of the dry compacted clay is only half of that collected from the wet compacted clay.

The actual evapotranspiration was analysed by Birle&Heyer [3] for the period between November 2008 and June 2014. Based on the climate data, they determined the potential evapotranspiration by the Penman-Monteith equation as described by Allen et al. [6]. To get the actual evapotranspiration they used the approach of Disse [7] referring to the measured data of the water content in the topsoil. With this approach, they determined an actual evaporation rate of 84% based on precipitation. Assuming that the evaporation rate did not change significantly since 2014 the actual evapotranspiration for the period between 2008 and 2018 is calculated to 6279 mm.

As the water storage can be neglected for the wet compacted organic clay, equation (1) can be reformulated and the surface runoff, which is not measured directly, can be calculated from the precipitation, the evapotranspiration and the seepage flow as follows:

$$SR = N - ET - S_B - S_I \tag{2}$$

Considering the cumulative fluxes of the leachate at the base and interflow from the drainage mat for the wet part as shown in figure 4 the accumulated surface runoff between 2008 and 2018 is determined to 985 mm, which corresponds to 13 % of the precipitation. As the same material was used for the topsoil above the wet and the dry compacted part, a similar surface runoff is expected for the dry part. Accordingly, for the dry part, the stored water quantity can be determined from the water balance equation (1). Table 1 summarizes the components of the water balance of the dry and wet compacted part.

Table 1. Components of the water balance for the period from November 2008 to November 2018. Percentages in brackets are related to the cumulative precipitation of 7475 mm

	Evapotranspiration ET [mm]	Surface runoff SR [mm]	Seepage at the base S_B [mm]	Interflow from the drainage mat S_I [mm]	Water storage W [mm]
Wet compacted part	6279 (84 %)	985 (13.2 %)	99 (1.3 %)	112 (1.5 %)	0 (0 %)
Dry compacted part	6279 (84 %)	985 (13.2 %)	45 (0.6 %)	58 (0.8 %)	108 (1.4 %)

5. Performance of the top drainage geocomposite

According to the analysis of the water balance in chapter 4 it is evident that the amount of seepage water infiltrating the compacted clay (core material) is very low. This can be attributed mainly to the performance of the topsoil in combination with the drainage geocomposite installed between the topsoil and the core material. As the data in Table 1 show, only 2.8 % (S_B + S_I) of the precipitation seep into the top drainage mat. Due to the high water retention capacity of the topsoil a large amount of seepage water can be stored before the topsoil is fully saturated. The drainage geocomposite acts as a capillary break and does not draw water from the topsoil. Thus, the percolation from the topsoil into the underlying drainage geocomposite is only gravity driven, which means that it occurs, when the water content at field capacity of the topsoil is exceeded. This corresponds to almost saturated conditions as explained below. Additionally the saturated hydraulic conductivity of the topsoil and the inclination of the slope of the test fill are of importance. Based on flexible wall permeameter tests acc. to Birle et al. [5] the saturated hydraulic conductivity of the topsoil is in the range of $2 \cdot 10^{-8}$ m/s through $2 \cdot 10^{-7}$ m/s. That comparatively low hydraulic conductivity limits the maximum water infiltration rate under saturated conditions and increases a surface runoff. The latter is also favoured by the steep slope inclination.

The capillary break effect of the nonwoven geotextile is illustrated by figures 6 and 7. They show the soil-water retention curves (SWRC) and the unsaturated hydraulic conductivities of the topsoil and a nonwoven geotextile. The SWRC of the topsoil was experimentally determined by use of a suction-controlled oedometer cell (ATT) for suctions up to 500 kPa and a dew-point hygrometer for the high suction range. Additionally measurements with tensiometers were performed for the determination of the main wetting path in the low suction range (below 100 kPa). Sample preparation and test procedures are described by Birle et al. [5]. Details about the functionality of the suction-controlled oedometer cell (ATT) are given by Birle [1]. The data for the non-woven geotextile were taken from McCartney et al. [8]. In Figure 6 additionally to the measurements the best-fit SWRCs defined using the van Genuchten-Mualem model [9] are shown. The hydraulic conductivity functions in Figure 7 were defined using the van Genuchten-Mualem model under consideration of the saturated hydraulic conductivity values. For the topsoil a saturated hydraulic conductivity of $5 \cdot 10^{-8}$ m/s was considered.

Due to its high porosity the non-woven geotextile shows a very low air-entry suction value of approx. 0.6 kPa and a very flat slope of the SWRC. In contrast, the topsoil has a much higher air-entry value and a high water retention capacity. Under consideration of the data given in Figure 6 a field capacity of 63 % and an effective field capacity of 40 % can be assumed for the tested sample of the topsoil.

The capillary break effect of the nonwoven geotextile against the topsoil is clearly visible from figure 7. As soil suction at the interface between the topsoil and the nonwoven geotextile is continuous, for suction values larger than approx. 1 kPa the hydraulic conductivity of the nonwoven geotextile is much smaller than the hydraulic conductivity of the topsoil. Thus, a significant water uptake by the nonwoven geotextile takes place only for suction values lower than 1 kPa. Similar results about the capillary-breaking effect of nonwoven geotextiles were reported by McCartney et al. [8], Krisdani et al. [10], Bathurst et al. [11] and Zornberg et al. [12].

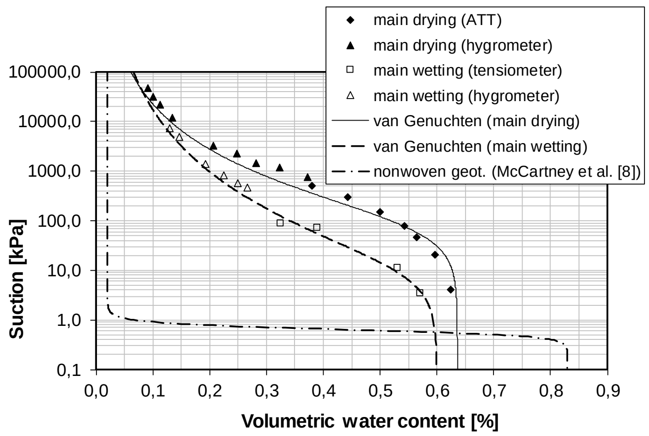

Figure 6. SWRC of topsoil according to Birle et al. [5] and nonwoven geotextile according to McCartney et al. [8]

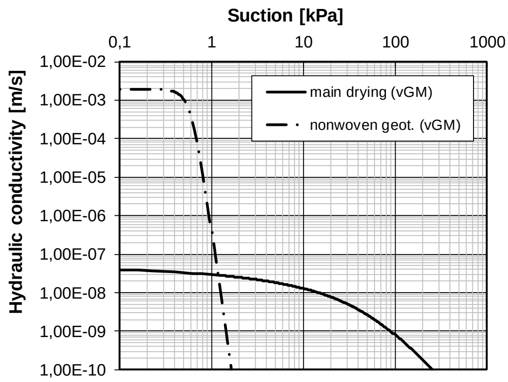

Figure 7. Hydraulic conductivity of topsoil and nonwoven geotextile with van Genuchten&Mualem model (vGM)

The comparison of seepage water into the dry and wet compacted clay shows that also the hydraulic properties of the core material have a certain impact on the leachate. Due to its low hydraulic conductivity and low soil suction the water uptake by the wet compacted clay is low, which favours the interflow in the drainage geocomposite. In contrast, the dry compacted clay takes up considerably more water, which is why a similar seepage rate as in the wet part can be expected at some point in the future.

6. Conclusions

The results of 10 years of measurement on a test fill which was covered by a 60 cm thick topsoil and an underlying drainage geocomposite show very low leachate quantities, although humid climatic conditions with average annual precipitation of approx. 745 mm were present. The low leachate rates can be mainly attributed to the capillary-breaking effect of the drainage geocomposite installed between the topsoil and the core material and the high water retention capacity of the topsoil. Similar to results presented by other authors [8][10][11][12] an inflow of water from the top layer into the drainage geocomposite occurs only under almost saturated conditions, which however, rarely arise in the seasonal course. Additionally, the steep slope inclination of the test fill (1:2) was assessed to favour surface runoff and reduce seepage flow.

For embankments and noise barriers in road-way design the presented simple cover system can be an efficient and effective solution for minimizing infiltration water into the core material. Specific attention should be paid to the hydraulic properties of the top layer as it strongly influences the seepage rate. Soils with a high water retention capacity (e.g. as a result of a high fines or organic content) are materials of choice in this context. Compared to the topsoil, the core material has only a minor influence on the amount of seepage water. But with respect to minimising seepage through the core material, the portion of percolate from the topsoil being diverted and discharged by the top drainage geocomposite is essential. For this reason, a core material with a low hydraulic permeability should be chosen.

References

[1] Birle E, Boso M, Heyer D 2010 Investigation of the water flow in an embankment built of organic soil: Experimental results and large scale field test *5th Int. Conf. on Unsaturated Soils*. vol. II pp 1299-304

[2] Birle E, Heyer D 2012 Water balance of an earth fill built of slightly contaminated organic clay *GeoCongress 2012* Oakland

[3] Birle E, Heyer D 2016 Water balance of an earth fill built of organic clay, *E-Unsat 2016 3rd Europ. Conf. on Unsaturated Soils* Paris

[4] Birle E 2012 Geohydraulische Eigenschaften verdichteter Tone unter besonderer Berücksichtigung des ungesättigten Zustandes, Dissertation, TU München, 2012

[5] Birle E, Heyer D, Rentemeister M, Boso M, Schweller G, Stalter S, Gahbauer M, Vogt N 2010: Grundbautechnische Untersuchungen und umweltgerechte Verwendung von organischen Böden in Geländeaufschüttungen, Lehrstuhl und Prüfamt für Grundbau, Bodenmechanik, Felsmechanik und Tunnelbau, Technische Universität München, unpublished report

[6] Allen R G, Pereira L S, Raes D, Smith M 1998 Computing crop water requirements - FAO irrigation and drainage paper 56, http://www.fao.org/docrep/X0490E/x0490e00.htm

[7] Disse M 1999 Physics and Chemistry of the Earth **24** pp. 325-30 Elsevier Science Ltd.

[8] McCartney J S, Kuhn J A, Zornberg J G 2005 Geosynthetic Drainage Layers in Contact with Unsaturated Soils *Proc. of the 16th Int. Conference of Soil Mechanics and Geotechnical Engineering (ISSMGE)* pp 2301-05

[9] van Genuchten M T 1980 A closed-form equation for predicting the hydraulic conductivity of unsaturated soils *Soil Science Society of America Journal* **44** pp 892-8.

[10] Krisdani H, Rahardjo H, Leong E-C 2006 Experimental study of 1-D capillary barrier model using geosynthetic material as the coarse-grained layer *Proceedings Unsaturated Soils* 2006, Carefree AZ, pp 1683–94.

[11] Bathurst R J, Ho A F, Siemens G 2007 A column apparatus for investigation of 1-D unsaturated-saturated response of sand-geotextile systems *ASTM Geotechnical Testing Journal* **30** pp 433–41

[12] Zornberg J G, Bouazza A, McCartney J S 2010 Geosynthetic capillary barriers: current state of knowledge *Geosynthetics International* **17** pp 273–300