Geosynthetic Drainage Layers in Landfill Caps

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Geotechnik mit Geokunststoffen
geotechnics with geosynthetics

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1. Introduction

2. Influencing Factors for Drainage Systems

3. Design of Drainage Systems

4. Economic and Ecologic advantages of Drainage Geocomposites

5. Installation

6. Conclusions
Introduction

Approval Process for Geosynthetic Drainage Systems in Germany

Federal States
Approval

BAM/DepV
Geosynthetic Requirements

Drainage Geocomposites in Landfill Capping Sealing Systems

Recommendations of WG 6.1 GDA of the German Geotechnical Society (DGGT e.V.)
Introduction

Approval Process for Geosynthetic Drainage Systems in Germany

BAM-Guideline
Proof of suitability for synthetic drainage Geocomposites in landfill capping sealing systems

2003 / 2010

2004 / 2008

(\textit{in accordance to GM approval})

2010
Introduction

EXPERT REPORT


Durability > 100 years
Equivalence to 30 cm gravel with $k = 1 \cdot 10^{-3} \text{ m/s}$
Introduction

Approval Process for Geosynthetic Drainage Systems in Germany

Table of Contents:
- Synopsis
- 1. Introduction
- 2. The geocomposite drain
  - Secudrain R201Z WD601Z R201Z
- 3. The long-term-in plane water flow capacity
- 4. The long-term shear strength
- 5. Properties of the geotextile filter
- 6. Friction and geomembrane protection
- 7. Quality assurance
- 8. Installation requirements
- 9. Discussion and remarks
Introduction

Vegetation Layer $\geq 1.0 \text{ m}$

Filter Geotextile
Drainage Gravel
Protection geotextile
Drainage Geocomposite (BAM-approved)

30 cm

Lev. Layer / GCL

Waste

Lev. Layer / GCL

Waste

Vegetation

HDPE Geomembrane (BAM-approved)
Influencing Factors for Drainage Layers

Drainage discharge

Saturation

Filtration Efficiency

Water Retention

Design, Location and Vegetation of Top Soil Layer

Surface Runoff

Stability

Clogging

Shear Behaviour

Roots

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Influencing Factors for Drainage Layers

Drainage discharge

Saturation

Filtration Efficiency

Design, Location and Vegetation of Top Soil Layer

Surface Runoff

Stability

Clogging

Shear Behaviour

Roots

Water Retention
Influencing Factors for Drainage Layers

(decisive are slope toe areas!)

1. Vegetation Layer
2. Vegetation Layer (lower layer) which under consolidated, undrained conditions is stable on top of the geosynthetic drainage layer
3. Soil with relatively high permeability against Nr. 2 (e.g. Sand)
4. Geosynthetic drainage layer
5. Geomembrane
6. Clay
7. Gravel

Borrmann, SKZ 2007
Design of Drainage Systems

1. Filtration Efficiency
2. Drainage discharge of seepage water inside the core (flow rate)
3. Protection Efficiency, e.g. against geomembrane

Relevant for suitability (> 100 years): Retain Soil from Vegetation layer and water shall be drained freely into drainage layer!
1. Mechanical Filter Efficiency

**Opening size** $O_{90,w,\text{selected}}$

(90% Soil retention capacity of the geotextile)

(0.8 to 1.0) • $O_{90,w,\text{required}}$

**Thickness** $d$

$\geq$ (25 to 50) • $O_{90,w,\text{required}}$
1. Filtration Efficiency
2. Drainage discharge of seepage water inside the core (flow rate)
3. Protection Efficiency, e.g. against geomembrane

2. Hydraulic Filter Efficiency

Permeability:
\[ k_v = 50 \cdot k_{soil} \]
# Design of Drainage Systems

<table>
<thead>
<tr>
<th>Grain-size region</th>
<th>Scope in grain-size distribution diagram</th>
<th>Criteria for a soil with high single-grain mobility</th>
<th>Dimensioning of mechanical filter effectiveness</th>
<th>Dimensioning of hydraulic filter effectiveness</th>
</tr>
</thead>
</table>
| A                 |                                        | 1. Grain fraction < 0.06 mm  
|                   |                                        | c_u = d_{50} / d_{10} < 15  
| d_{50} ≤ 0.06 mm  |                                        | 2. 0.02 mm < d < 0.1 mm > 50 %  
|                   |                                        | 3. I_p < 0.15 = 15%  
|                   |                                        | or alternatively  
|                   |                                        | clay fraction/silt fraction < 0.5  
|                   |                                        | a) Hydrostatic load  
|                   |                                        | O_{0(w)} < 10 \cdot  d_{50}  
|                   |                                        | in addition, for soils with  
|                   |                                        | high single-grain mobility  
|                   |                                        | O_{0(w)} < d_{50}  
|                   |                                        | permissible for soils with  
|                   |                                        | long-term stable cohesion  
|                   |                                        | O_{0(w)} < 2 \cdot d_{50}  
|                   |                                        | b) Hydrodynamic load  
|                   |                                        | O_{0(w)} < d_{50} and  
|                   |                                        | O_{0(w)} < 0.3 mm |
| B                 |                                        | 1. Grain fraction < 0.06 mm  
|                   |                                        | c_u = d_{50} / d_{10} < 15  
| d_{15} ≥ 0.06 mm  |                                        | 2. 0.02 mm < d < 0.1 mm > 50 %  
|                   |                                        | a) Hydrostatic load  
|                   |                                        | O_{0(w)} < 5 \cdot d_{10} \sqrt{c_u} and  
|                   |                                        | O_{0(w)} < 2 \cdot d_{50}  
|                   |                                        | in addition, for soils with  
|                   |                                        | high single-grain mobility  
|                   |                                        | O_{0(w)} < d_{50}  
|                   |                                        | b) Hydrodynamic load  
|                   |                                        | O_{0(w)} < 1.5 \cdot d_{10} \sqrt{c_u} and  
|                   |                                        | O_{0(w)} < d_{50} |
| C                 |                                        | 1. Grain fraction < 0.06 mm  
|                   |                                        | c_u = d_{50} / d_{10} < 15  
| d_{15} ≤ 0.06 mm  |                                        | 2. 0.02 mm < d < 0.1 mm > 50 %  
| and d_{40} > 0.06 mm |                                        | 3. I_p < 0.15 = 15%  
|                   |                                        | or alternatively  
|                   |                                        | clay fraction/silt fraction < 0.5  
|                   |                                        | Dimensioning as for soils in  
|                   |                                        | grain-size region B, but with  
|                   |                                        | additional tests to determine  
|                   |                                        | the suffusion stability  
|                   |                                        | of the soil  
|                   |                                        | For critical suffusion stability  
|                   |                                        | see DVWK (1989)  
|                   |                                        | η \cdot k_v ≥ k |

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Design of Drainage Systems

1. Filtration Efficiency
2. Drainage discharge of seepage water inside the core (flow rate)
3. Protection Efficiency, e.g. against geomembrane

Gravel Drainage Layer

- Low Pore Volume
- High flow resistance!
Water retention in drainage gravel layer according to LESAFFRE – Influence of slope length at $k_f = 1 \times 10^{-3}$ m/s (Source: GDA E2-20 (1997))

**Design of Drainage Systems**

Water retention in drainage gravel
Design of Drainage Systems

Water retention in drainage gravel layer

Max. retention height [m]

Slope Length [m]

Flat Area: 5% inclination

30 mm/d
25 mm/d
20 mm/d
10 mm/d

L ≤ 65 m

Water retention in drainage gravel according to LESAFFRE – Influence of slope length at $k_f = 1 \times 10^{-3}$ m/s (Source: GDA E2-20 (1997))
Design of Drainage Systems

1. Filtration Efficiency
2. Drainage discharge of seepage water inside the core (flow rate)
3. Protection Efficiency, e.g. against geomembrane

Open layer, nearly no flow resistance
Design of Drainage Systems

1. Filtration Efficiency
2. Drainage discharge of seepage water inside the core (flow rate)
3. Protection Efficiency, e.g. against geomembrane

"Infinite wide rectangular tube"

„Alternate thickness of pores“
**Boundary Conditions:**

- Long-term thickness (>100a) at inclination of 5% and
- 1 m vegetation layer (BAM) = 9.1 mm
- Bedding hard/soft (BAM)
- Drainage length L = 170 m
- Drainage discharge: 35 mm/d (+40% compared to 25 mm/d)

"Infinite wide and 8 mm thick rectangular tube"
Design of Drainage Systems

5% Inclination

Max. retention height [mm]

<table>
<thead>
<tr>
<th>Time [h]</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>q_E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q_A / L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- t = 24 h
  - q_E = 35 mm/d = 1.46 mm/h
  - q_A / L = 1.21 mm/h

- t = 5 h
  - q_E = 0
  - q_A / L = 1.21 mm/h

max. h_Fill = d_Pore = 8 mm

Vegetation Layer

Geoc. Drain

V = 0
q_E = 35 mm/d = 1.46 mm/h
q_A / L = 1.21 mm/h
Long-term Creep Tests

For flat areas as e.g. Plateau (1:20) only creep resulting from compressive stress is relevant.

For slope sections (1:3), creep as a result of combined compressive/shear stress is examined.

(Extrapolation of $10^4$ h to long-term thickness ($10^6$ h/114 years)

<table>
<thead>
<tr>
<th>Stress</th>
<th>20 kPa</th>
<th>50 kPa</th>
<th>20 kPa, 3:1</th>
<th>50 kPa, 3:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final thickness (114 years)</td>
<td>9.1 mm</td>
<td>8.3 mm</td>
<td>8.8 mm</td>
<td>6.9 mm</td>
</tr>
<tr>
<td>Based on initial thickness</td>
<td>83 %</td>
<td>79 %</td>
<td>80 %</td>
<td>66 %</td>
</tr>
<tr>
<td>Respective compressive stress</td>
<td>73 kPa</td>
<td>91 kPa</td>
<td>80 kPa</td>
<td>129 kPa</td>
</tr>
</tbody>
</table>
Selected Procedure for assessing the long-term water flow capacity

1. Determine Creep Curve for defined compressive stress or compressive/shear stress (Long-term test)

2. Determine relevant compressive stress level at long-term thickness (Short-term test)

3. Determine long-term water flow capacity for different bedding conditions at relevant compressive stress

Long-term thickness (hard/hard)

Compressive Stress at long-term thickness (hard/hard)
### Water-flow capacity (l / m · s)

<table>
<thead>
<tr>
<th></th>
<th>$i = 0,05$</th>
<th>$i = 0,1$</th>
<th>$i = 0,3$</th>
<th>$i = 1,0$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>hard/hard</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 kPa</td>
<td>0,18</td>
<td>0,29</td>
<td>Not relevant</td>
<td>Not relevant</td>
</tr>
<tr>
<td>50 kPa</td>
<td>0,11</td>
<td>0,19</td>
<td>Not relevant</td>
<td>Not relevant</td>
</tr>
<tr>
<td>20 kPa, 6,7 kPa</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>0,51</td>
<td>1,12</td>
</tr>
<tr>
<td>50 kPa, 16,7 kPa</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>0,18</td>
<td>0,42</td>
</tr>
<tr>
<td><strong>soft/hard</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 kPa</td>
<td>0,12</td>
<td>0,19</td>
<td>Not relevant</td>
<td>Not relevant</td>
</tr>
<tr>
<td>50 kPa</td>
<td>0,09</td>
<td>0,14</td>
<td>Not relevant</td>
<td>Not relevant</td>
</tr>
<tr>
<td>20 kPa, 6,7 kPa</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>0,35</td>
<td>0,78</td>
</tr>
<tr>
<td>50 kPa, 16,7 kPa</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>0,17</td>
<td>0,39</td>
</tr>
<tr>
<td><strong>soft/soft</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 kPa</td>
<td>0,06</td>
<td>0,1</td>
<td>Not relevant</td>
<td>Not relevant</td>
</tr>
<tr>
<td>50 kPa</td>
<td>0,04</td>
<td>0,07</td>
<td>Not relevant</td>
<td>Not relevant</td>
</tr>
<tr>
<td>20 kPa, 6,7 kPa</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>0,19</td>
<td>0,42</td>
</tr>
<tr>
<td>50 kPa, 16,7 kPa</td>
<td>-</td>
<td>-</td>
<td>0,05</td>
<td>0,12</td>
</tr>
</tbody>
</table>
Design of Drainage Systems

Long-term water drainage capacity

\[ L = \frac{q_{LZ}}{(1,2 \cdot 1,2)/q_s} \]

Drainage Length → Variation Creep Test Results → Inaccuracy in Overlaps, Joints & Connections → Drainage discharge (e.g. 25 mm/d)

BAM (2004)

Extract from BAM (2004), Secudrän

Table 3.4: Drainage lengths still permissible (without consideration for collectors)

<table>
<thead>
<tr>
<th>Bedding</th>
<th>Plateau, ( i = 0.05 ), compressive stress</th>
<th>Slope, ( i = 0.3 ), compressive stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 kPa</td>
<td>50 kPa</td>
</tr>
<tr>
<td>hard/soft</td>
<td>288 m</td>
<td>216 m</td>
</tr>
<tr>
<td>soft/soft</td>
<td>34 m</td>
<td>14 m</td>
</tr>
</tbody>
</table>

without water retention!
How much does the drainage efficiency reduce under consideration of influences from installation conditions?

Design Equation:

\[ q_{entw} = q_{exp} \cdot \left( \frac{1}{FS_{IN} \cdot FS_{CR} \cdot FS_{CC} \cdot FS_{BC}} \right) \cdot \frac{1}{FS_{SY}} \]

- \( q_{entw} \): acceptable seepage water inflow
- \( q_{exp} \): water flow capacity as determined in short-term test

<table>
<thead>
<tr>
<th>GDA: E 2-20 Drainage Systems in Landfill Caps</th>
</tr>
</thead>
<tbody>
<tr>
<td>( FS_{IN} )</td>
</tr>
<tr>
<td>( FS_{CR} )</td>
</tr>
<tr>
<td>( FS_{CC} )</td>
</tr>
<tr>
<td>( FS_{BC} )</td>
</tr>
<tr>
<td>( FS_{SY} )</td>
</tr>
</tbody>
</table>

☑️ (already considered in BAM-approval)
Design of Drainage Systems

Design Nomograph (GDA-recommendations) on maximum drainage length, without using collectors, for Secudrán® R201Z WD601Z R201Z

Remarks:
- only for bedding hard/soft
- determined via creep curves for bedding hard/hard; percentage reduction from initial values for hard/soft
- see section 9.2, BAM-expert report, file number IV.32/1317/84
- using factor of safety according to Naue Fasertechnik; BBG: FS_{pl} = 1.25; FS_{cr} = 1.0; FS_{z} = 1.0; total: FS = 1.7
- using seepage water discharge and factors of safety according to GDA-E2-20 (1997): 10 mm/d FS_{pl} = 2.0; bel 25 mm/d FS_{z} = 1.1
Design of Drainage Systems

1. Filtration Efficiency
2. Drainage discharge of seepage water inside the core (flow rate)
3. Protection Efficiency, e.g. against geomembrane

Compression test DIN EN 13719 (BAM Method)

\[ L = \gamma \cdot h \cdot 1.5 \cdot \eta_t \cdot \eta^\circ C \]

- \( L \): Test load
- \( \gamma \): Unit weight of waste
- \( h \): Height of waste
- \( \eta_t \): Safety factor time (1000 h = 1; 100 h = 1.5)
- \( \eta^\circ C \): Safety factor temperature (40°C = 1; 21°C = 1.5)
Design of Drainage Systems

1. Filtration Efficiency
2. Drainage discharge of seepage water inside the core (flow rate)
3. Protection Efficiency, e.g. against geomembrane

Arch Strain:
\[ \varepsilon = \frac{(l_d - l_u)}{l_u} \leq 0.25\% \]
Economic & Ecologic Advantages of Drainage Geocomposites

50 cm Gravel / Sand:
100 Trucks (24t) 2,500 m²
Economic & Ecologic Advantages of Drainage Geocomposites

Geocomposite Drain:
1 Truck 2,500 m²
Installation

Landfill „Am Turm“ in Wernigerode, Germany
Installation

Landfill Friedländer Berg, Germany
Installation

Landfill Saugrund in Freital, Germany
Conclusions

Under consideration, that as drainage layer a drainage geocomposite with high robustness for a design life > 100 years (BAM-Approval) is designed, installed, covered and inspected appropriately, an extraordinary high servicability of the drainage layer can be expected.

Field tests and excavations provide valuable information.

Additional mineral drainage layers are not required!

Decisive for the Stability of the system is the Design of the Vegetation Layer and the toe of the slope.
Thank you for your attention!
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