Geosynthetic Clay liners – Sustainable and resilient barriers for hydraulic engineering applications

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Testing Innovation Fellowship Program* for students (https://www.igs-na.org/testing-innovation-fellowship-program-call-for-applications)

Content of the Presentation

- Introduction – water stress and rainfall
- ISO/TR 18228-9 Design using geosynthetics — Part 9: Barriers
- Failure in past designs
- Geosynthetic clay liner – sustainable and resilient solution
- Multi-component geosynthetic clay liner – improved sustainable and resilient solution
- Summary and questions
Similar yearly rainfall but more intense.

Water is very valuable – today and tomorrow.

https://www.mei.edu/publications/addressing-worldwide-flood-concerns-empowering-local-communities

ISO/TR 18228-9 Design using geosynthetics - Barriers

The reason: Introduction to geosynthetic newcomers.

The Result: Show new technologies rather than using conservatism and past approaches.

The Solution: Educating and removing the fears or concerns about geosynthetic solutions

Application and Design Life

- Containment application, non-landfill (CA)
- Chemical containment, non landfill (CC)
- Construction Waterproofing (CW)
- Landfill base lining (LBL)
- Landfills caps (LC)
- Secondary containment (SC)
- Transport infrastructure applications (TIA)
- Tunnels (Tu)

- Water retaining structure (WRS-e), e.g. balancing ponds, dams, dykes and canals (usually empty)
- Water retaining structure (WRS-f), e.g. reservoirs, canals
### ISO/TR 18228-9 Design using geosynthetics - Barriers

#### Table 1 - Subjective ratings for importance of various criteria of common GBR applications

<table>
<thead>
<tr>
<th>Characteristic parameter</th>
<th>CA</th>
<th>CC</th>
<th>CW</th>
<th>LBL</th>
<th>LC</th>
<th>SC</th>
<th>TIA</th>
<th>TU</th>
<th>WRS-e</th>
<th>WRS-f</th>
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</table>

1 - important    2 - project-dependent requirement 3 - rarely required 4 - not relevant

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#### Table 2 - Guide for the composed selection of a GBR to determine the suitability in a selected application

<table>
<thead>
<tr>
<th>Barrier Type</th>
<th>CA</th>
<th>CC</th>
<th>CW</th>
<th>LBL</th>
<th>LC</th>
<th>SC</th>
<th>TIA</th>
<th>TU</th>
<th>WRS-e</th>
<th>WRS-f</th>
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</tbody>
</table>
| 1 - world-wide acceptance 2 - general acceptance 3 - rarely used 4 - not recommended
(A) compare with the relevant combined component

CA - Containment application, non-landfill
CC - Chemical containment, non landfill
CW - Construction Waterproofing
LBL - Landfill base lining
LC - Landfills caps
SC - Secondary containment
TIA - Transport infrastructure applications
TU - Tunnels
WRS-e - Water retaining structure, e.g. balancing ponds, dams, dykes and canals (usually empty)
WRS-f - Water retaining structure, e.g. reservoirs, canals (usually constantly filled)
Parameters and Installation

- Chemical
- Biological
- Shear strength
- UV
- Mechanical

- Water head (static or dynamic)
- Confining stress
- Product property changes
- Climate conditions
- Vegetation & animals

ISO/TR 18228-9 Design using geosynthetics - Barriers

Flood Event in Vietnam and the Consequences

September 12, 2012 Written by vovnews – (VOV) – The Tay Nguyen diversion dam in Quyhn Thang commune, Quyhn Luu district, located in central Nghe An province, suddenly broke, submerging nearly 10ha of rice and subsidiary crops.
Flood Event in Germany
More than 100 dykes bursted and caused floods around River Mulde Aug. 2002

Clearly a problem

http://www.geo.uu.nl/fg/palaeogeography/results/flooding
Infra-red thermal camera measurement

Black dotted circles indicate 3 – 5°C lower temperatures. Yellow dotted circles indicate low temperatures and possible saturated areas with a potential for failure. (Rothenseer Canal, Germany)


Compacted clay liner crack during installation

While compacted clay might look fine during installation / at moderate temperatures water desiccates and it starts cracking
Compacted clay liner needs water

- Size: 400,000m² - Clay liner thickness: 0.5m
- Required amount of water ca. 15 million litres
- Minimum water amount pro capita: 20 l/person/day (this is the supply of over 2000 people/year!)

Clay geosynthetic barrier (GBR-C)

EN ISO 10318-1 Clay Geosynthetic Barrier (GBR-C)

[Geosynthetic Clay Liner (GCL) or bentonite mat]

- factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is essentially fulfilled by clay

The connecting fibre is pushed from the nonwoven geotextile, through the bentonite into the carrier geotextile, in most cases a woven or woven/nonwoven composite.
Multicomponent GCL

Definition of a geosynthetic clay liner (GCL) with an additional barrier.

Multi-component GCL, n - GCL with an attached film, coating, or membrane decreasing the hydraulic conductivity or protecting the clay core or both.

![Multi-component GCL](image-url)
Multicomponent GCL

**laminated GCL**, n—GCL product with at least one film or membrane layer superimposed and bonded to the GCL by an adhesive (e.g. glue) usually under heat and pressure.

![Laminated GCL Diagram]

**coated GCL**, n - GCL product with at least one layer of a synthetic substance applied to the GCL as a fluid and allowed to solidify.

![Coated GCL Diagram]

Facts pointing out benefits of a multicomponent GCL

01. GCLs can be at the risk of cation exchange with surrounding soil. Cations such as Mg and Ca can replace sodium in the bentonite. This can increase the bentonite permeability (Kolstad et al., 2004). Using a coated GCL with the coating facing towards the cation rich soil can protect the GCL and its bentonite against cation exchange and ensure the long-term performance in such environments.

02. Bentonite can lose moisture due to desiccation. This can create micro cracks in the bentonite layer. Performance during this time can be reduced, e.g. gas permeable, in case of contact with critical fluids. This might increase in the GCL permeability. An extrusion coating layer prevents moisture loss due to desiccation and therefore ensures a long-term functioning two component barrier, especially in low confining stress applications.

03. For several applications root penetration can be a risk for the performance. Roots search for moisture and bentonite stores water. Facing the coating side against the root growth side can help prevent roots from growing into the bentonite and removing water from the bentonite. The effect is the same as with desiccation. Micro cracks can occur reducing the overall GCL performance. An extrusion coating layer reduces root growth into the bentonite layer.

04. Hydration and degree of saturation are key parameters in the performance of a GCL as a successful barrier. GCLs need to be protected against desiccation and saline water to be able to get hydrated and achieve the required degree of saturation. In cases such as groundwater with high salinity, brine ponds, tailings dams, etc. a coated GCL with the coating facing the contamination can protect the GCL and allow pre-hydration with non-contaminated water.

05. When water storage or a lowest possible permeation is required a multicomponent GCL with a bentonite and a polymer barrier is a best choice. Two barriers act together and perform in a best way, combining the benefits of both barrier systems. Additionally the polymeric barrier gives add-on values, such as protecting the bentonite core and preventing possible desiccation of the bentonite core.
In exposed composite liners where the GCL is installed below a geomembrane on a slope, the GCL is at the risk of downslope bentonite erosion. Full scale long term field monitoring at Queens University shows that GCLs (especially with granular bentonite) can achieve extreme erosion and lose their performance in these conditions (Rowe et al., 2016). Same research showed no evidence of downslope erosion where a Coated GCL was installed under the geomembrane.

Typically regulations or recommendations suggest 0.5m thick clay liners as a sealing element (with a permeability of e.g. \( k \leq 5 \times 10^{-9} \) m/s). According to Darcy’s law the permeation rate at a 0.3m water head would be 6.91 m³/ha/day. A Bentofix® GCL with \( k \leq 5 \times 10^{-11} \) m/s would have - under same conditions - a permeation rate of only 1.34 m³/ha/day.

Internal erosion is the formation of voids within a soil caused by the removal of material by seepage. It occurs when the hydraulic forces exerted by water seeping through the pores and cracks of the soil are sufficient to detach bentonite particles and transport them out of the GCL. Piping is then induced by regressive erosion of particles out of the GCL. The higher the water head, the higher the risk. A PE coating on the GCL will largely reduce the water pressure and any piping risks.

To install a more demanding barrier system with respect to the performance and safety, a double lined sealing system may be used to reduce any risks associated with the containment of large amounts of potentially harmful liquids, desiccation and also ensure immediate gas impermeability. A PE coated Bentofix GCL combines the synergy of a bentonite clay and a polymeric barrier, mainly protecting the bentonite clay barrier to allow its full performance and reducing any harmful effects.

GCL – Transportation benefits

Example:

4500m² sealing with GCL

4500m² sealing with compacted clay (500mm thick)

Equals:

1 truck

187 trucks
Characteristics of compacted clay liners vs geosynthetic

Comparison of energy demand [MJ/m²] – 36,000 m²

Installation of a GCL results in 42 % less energy demand than a CCL!

Characteristics of compacted clay liners vs geosynthetic

Comparison of CO₂ emissions [kg/m²] – 36,000 m²

Installation of a GCL results in 59 % less CO₂ emissions than a CCL!
Installation of compacted clay vs geosynthetic clay liner

Compacted Clay Liner

Bentonite mat (Geosynthetic Clay Liner)

Less transportation vehicles
Less noise emission
Less impact to roads

GCL in various Dam Constructions
GCL in various Dam Constructions

Experience from German dam and dyke engineering

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GCL in various Dam Constructions

Permeation of Dykes

**Table:**

<table>
<thead>
<tr>
<th>Soil</th>
<th>( k_s )</th>
<th>( k_h )</th>
<th>( n_p )</th>
<th>Clayey cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.00 ( \times ) ( 10^{-9} )</td>
<td>1.00 ( \times ) ( 10^{-9} )</td>
<td>0.03</td>
<td>Dyke core</td>
</tr>
<tr>
<td></td>
<td>1.00 ( \times ) ( 10^{-7} )</td>
<td>1.00 ( \times ) ( 10^{-7} )</td>
<td>0.20</td>
<td>Subsoil</td>
</tr>
</tbody>
</table>

*Abb. 2: Stationärer Zustand*

(Wasserseite: WSP links = 332,8 mNHN, Luftseite = 331,75 mNHN)
GCL in various Dam Constructions

Project – Pond & Encapsulation

- 200 cm gravel cover
- 20 cm sand
- GCL coating up
- GCL coating down
- 20 cm sand
- Phenol contamination
GCL in various Dam Constructions

Storage Pond, Thailand - 250.000 m²

Half of the slope

Highlight project – historic canal in Delitzsch

Cover soil placement
Highlight project – historic canal in Delitzsch

Brief summary

• Water is a valuable!

• With compacted clay liners failures occurred worldwide

• Geosynthetic solutions, e.g. Geosynthetic clay liners (GCLs) or better, multicomponent Geosynthetic Clay liners offer a technical and economical solution

• Dams and canals should not be built based on costs only but be based on performance!
Thank You.

Building on sustainable ground.

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