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

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Chairman: CEN TC 189 WG6 Barriers; ASTM D35.04 GCLs, IGS Barriers 2012 - 2020,
Board: BoA Geosynthetic Institute (since 2002), The IGS Foundation, Technical Advisory Committee Geosynthetics
Member: ISO 221 WG2 and WG 6, IGS Council Member (2012 – 2020)
Lecturer : University of Applied Sciences Bielefeld, University of Applied Sciences Ostwestfalen-Lippe
Awards: Bob Koerner Honor Lecturer 2018 at GeoMEast, Kairo – ASTM Award of Merit 2019 – IGS appreciation Award 2020

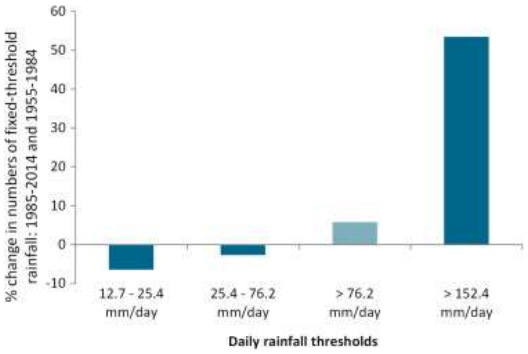
Support educational initiatives (https://theigsfoundation.com/request-for-funding/)

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

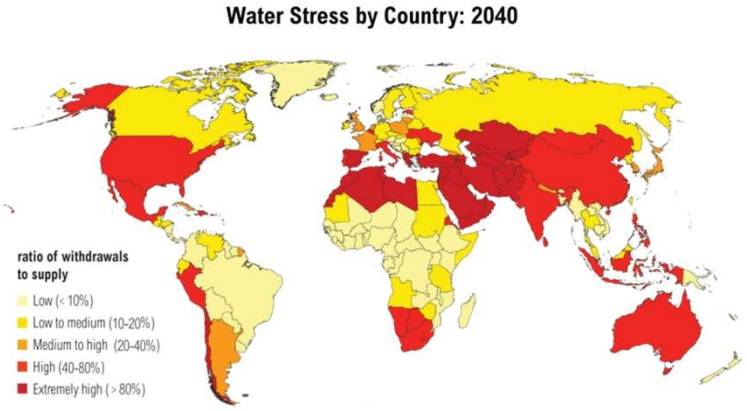
Similar yearly rainfall but mor intense.



https://www.sciencedirect.com/science/article/pii/S2212096315000054

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

Water is very valuable – today and tommorow



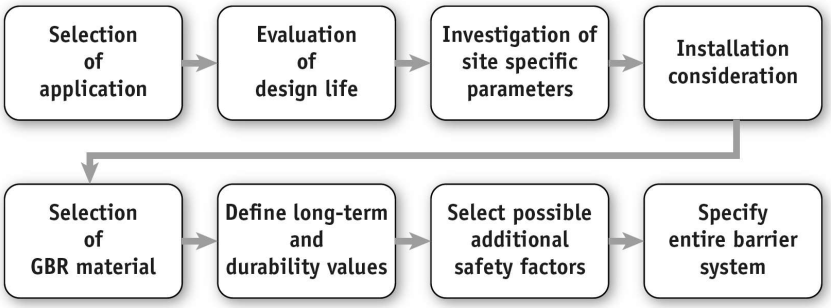
https://www.climatechangenews.com/2015/08/27/middle-east-faces-extreme-water-shortages-by-2040/

ISO/TR 18228-9 Design using geosynthetics - Barriers

The reason Introduction to geosynthetic newcomers.

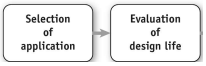
The Result: Show new technologies rather than using conservatism and past approaches.

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



ISO/TR 18228-9 Design using geosynthetics - Barriers

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

Investigation of site specific parameters → Installation consideration

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

Characteristic parameter		CA	CC	CW	LBL	LC	SC	TIA	TU	WRS-e	WRS-f
Chemical resistance		2	1	3	1	2	1	1	2	3	3
Physical properties											
Hydraulic resistance	permeability	1	1	1	1	1	1	1	1	1	1
Mechanical property	tensile, puncture, tear strength	1	1	2	1	1	2	1	1	1	1
	uni- and multi-axial elongation	2	2	3	3	2	2	2	3	2	2
Abrasion resistance		4	4	4	4	4	4	4	4	2	2
Durability		50 yrs	25 yrs	50 yrs	100 yrs	50 yrs	25 yrs	25 yrs	100 yrs	25 yrs	25 yrs
Installation		1	1	1	1	1	1	1	1	1	1

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

ISO/TR 18228-9 Design using geosynthetics - Barriers

Table 2 – Guide for the compound selection of a GBR to determine the suitability in a selected application

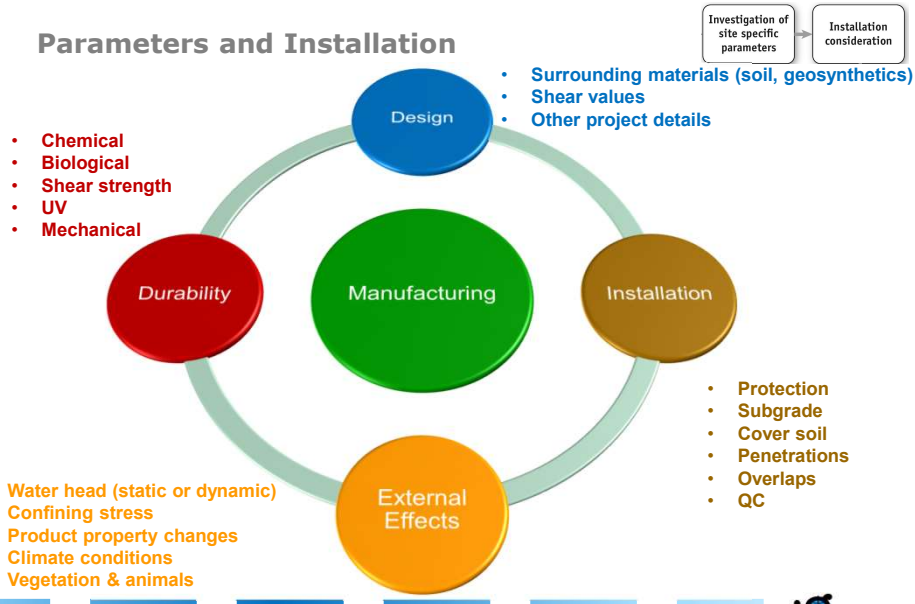
Barrier Type		CA	CC	CW	LBL	LC	SC	TIA	TU	WRS-e	WRS-f
GBR-P	HDPE	1	1	2	1	1	1	1	2	1	1
	LDPE	1	2	2	2	2	1	1	1	1	1
	PVC	3	4	3	4	3	4	3	2	2	1
	EPDM	3	4	3	4	3	4	3	3	1	1
	PP	3	3	3	4	2	3	2	3	2	2
GBR-C	Single-component	2	3	2	2	1	3	1	3	2	2
	Multi-component	2 (A)	2 (A)	2 (A)	2 (A)	1 (A)	2 (A)	1 (A)	2 (A)	2 (A)	2 (A)
GBR-B		3	3	2	4	3	3	2	2	2	2

1 – world-wide acceptance 2 – general acceptance 3 – rarely used
4 – not recommended
(A) compare with the relevant combined component

Selection of application → Evaluation of design life

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 structur, e.g. balancing ponds, dams, dykes and canals (usually empty)
WRS-f - Water retaining structure, e.g. reservoirs, canals (usually constantly filled)

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 Quynh Thang commune, Quynh Luu district, located in central Nghe An province, suddenly broke, submerging nearly 10ha of rice and subsidiary crops.

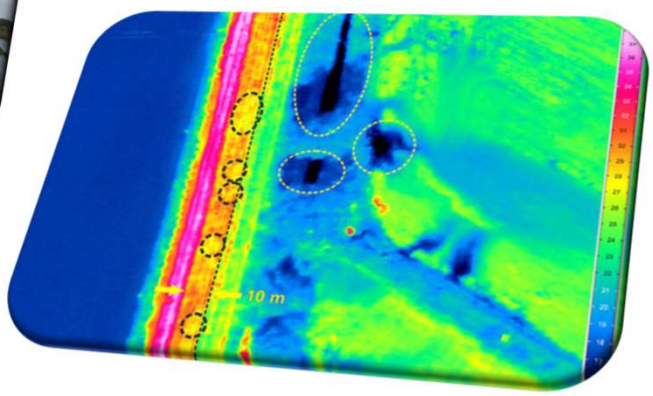
Flood Event in Germany

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



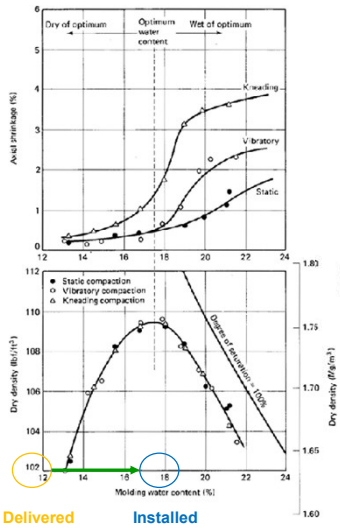
Black dotted circles indicate 3 – 5°C lower temperatures. Yellow dotted circles indicate low temperatures and possible saturated areas with a potential for failure. (Rothenseer Canal, Germany)

http://www.ingenieur.de/Branchen/Wasserwirtschaft/Deich-Experten-Wir-sagen-wo-genauer-geprueft-muss

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

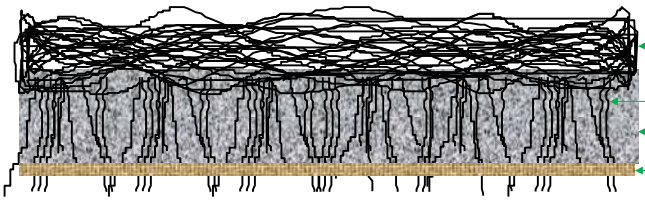
Minimum water amount pro capita: 20 l/person/day
(this is the supply of over 2000 people/year!)

Clay geosynthetic barrier (GBR-C)

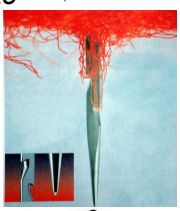
EN ISO 10318-1 *Clay Geosynthetic Barrier (GBR-C)*

*[**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.



Clay geosynthetic barrier – Generic specification

Property	ASTM Test Method	Reinforced GCL GT-Related			Testing Frequency
Clay (as received)					
swell index (ml/2g)	D5890	24			50 tonnes
fluid loss (ml)(1)	D5891	18			50 tonnes
Geotextiles (as received)					
cap fabric (nonwoven) - mass/unit area (g/m^2)(2)	D5261	200			20,000 m^2
cap fabric -(woven) - mass/unit area (g/m^2)	D5261	100			20,000 m^2
carrier fabric (nonwoven composite) - mass/(g/m^2)(2)	D5261	200			20,000 m^2
GCL (as manufactured)					
mass of GCL (g/m^2)(5)	D5993	4000			4,000 m^2
mass of bentonite (g/m^2)(5)	D5993	3700			4,000 m^2
moisture content(1) (%)	D5993	35			4,000 m^2
tensile str., MD (kN/m)	D6768	4.0			20,000 m^2
peel strength (N/m)	D6496	360			4,000 m^2
permeability(1) (m/sec), "or"	D5887	5×10^{-11}			25,000 m^2
flux(1) ($m^3/sec\text{-}m^2$),	D5887	1×10^{-8}			25,000 m^2
GCL permeability(1),(6),(7) (m/sec) (max. at 35 kPa)	D6766	1×10^{-8}			yearly
GCL permeability(1),(6),(7) (m/sec) (max. at 500 kPa)	D6766 mod.	5×10^{-10}			yearly
Component Durability					
geotextile and reinforcing yarns (8) (% strength retained)	See § 5.6.2	65			yearly

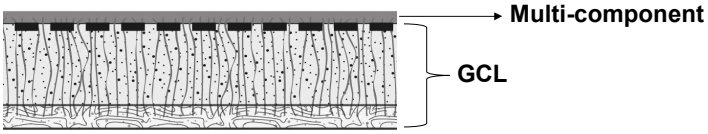
GRI-GCL3 Spec - S.I. (Metric) Units

n/a = not applicable with respect to this property :
(1) These values are maximum (all others are minimum)
(2) For both cap and carrier fabrics for nonwoven reinforced GCLs; one, or the other, must contain a scrim component of mass ≥ 100 g/m^2 for dimensional stability. This only applies to GM/GCL composites which are exposed to the atmosphere for several months or longer so as to mitigate panel separation.
(3) Calculated value obtained from difference of coated fabric to as-received fabric
(4) First value is for smooth geomembrane; second for textured geomembrane; third for geofilm
(5) Mass of the GCL and bentonite is measured after oven drying per the stated test method
(6) Value represents GCL permeability after permeation with a 0.1 M calcium chloride solution (11.1 g CaCl2 in 1-liter water); for termination criterion see § 5.6.1
(7) Test should be run on the pure bentonite only. Not on polymer modified bentonites.
(8) Value represents the minimum percent strength retained from the as-manufactured value after oven aging at 60°C for 50 days
(9) Durability criteria should follow the appropriate specification for the geomembrane type used; i.e., GRI GM-13 for HDPE, GRI GM-17 for LLDPE or GRI GM-18 for fPP

Multicomponent GCL

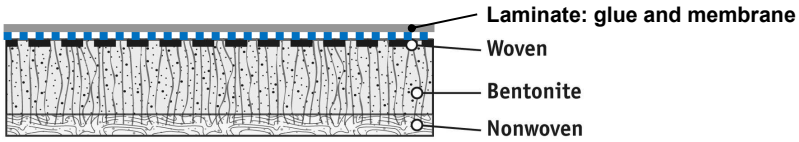
Definition of a geosynthetic clay liner (GCL) with an additional barrier.

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



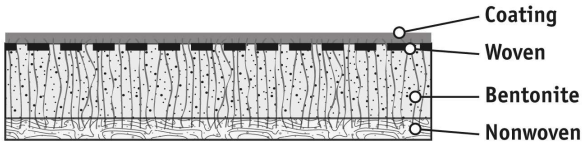
Multicomponent GCL

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



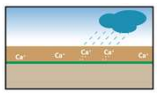
Likely only short-term bonding as adhesive hardly sticks long-term to e.g. PE laminate

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

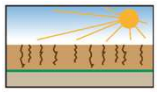


Permanent bonding due to fibre reinforcment of GCL bonded into the coating material

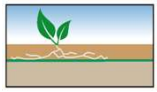
Facts pointing out benefits of a multicomponent GCL



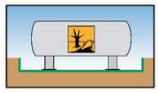
01 GCLs can be at the risk of cation exchange with surrounding soil. Cations such as Mg and Ca can replace sodium in the bentonite. This can increase the bentonite permeability (Kolstad et al., 2004). Using a coated GCL with the coating facing towards the cation rich soil can protect the GCL and its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



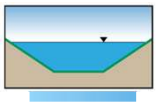
02 Bentonite can lose moisture due to desiccation. This can create micro cracks in the bentonite layer. Performance during this time can be reduced, e.g. gas permeable, in case of contact with critical fluids. This might increase in the GCL permeability. An extrusion coating layer prevents moisture loss 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.



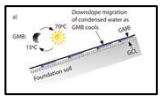
04 Hydration and degree of saturation are key parameters in the performance of a GCL as a successful barrier. GCLs need to be protected against contaminants and saline water to be able to get hydrated and achieve the required degree of saturation. In cases such as groundwater with high salinity, brine 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.

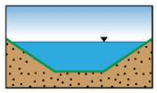
20

Facts pointing out benefits of a multicomponent GCL



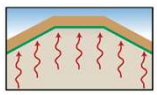
06

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.



07

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.



08

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 harmfull effects.

GCL – Transportiation benefits

Example:

4500m² sealing with GCL

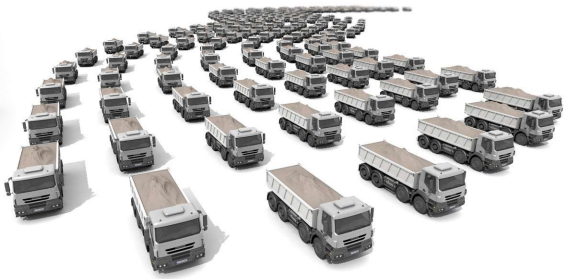
Equals:

1 truck

4500m² sealing with compacted clay (500mm thick)

Equals:

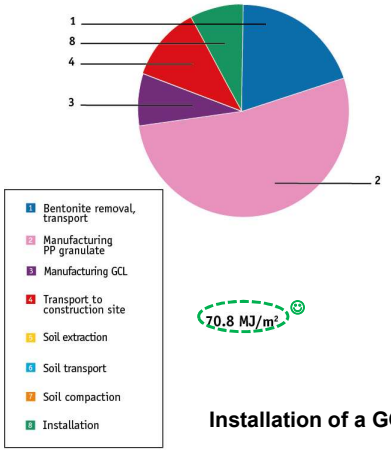
187 trucks



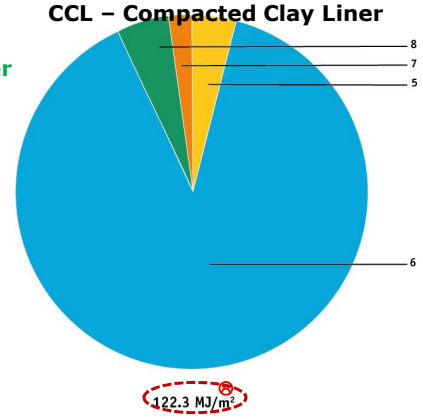
Characteristics of compacted clay liners vs geosynthetic

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

GCL – Geosynthetic Clay Liner



CCL – Compacted Clay Liner

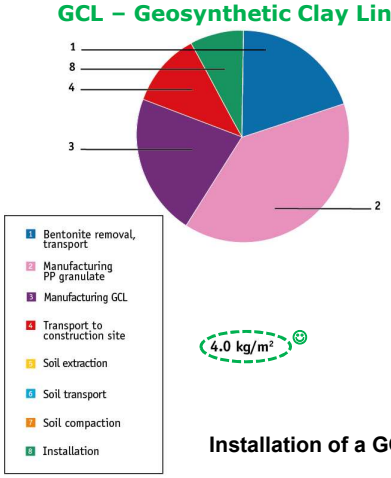


Installation of a GCL results in 42 % less energy demand than a CCL!

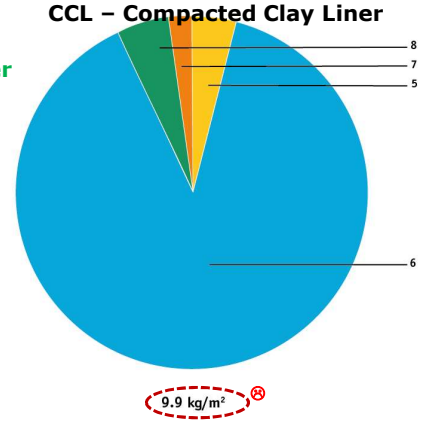
Characteristics of compacted clay liners vs geosynthetic

Comparison of CO_2 emissions [kg/m²] – 36,000 m²

GCL – Geosynthetic Clay Liner



CCL – Compacted Clay Liner



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

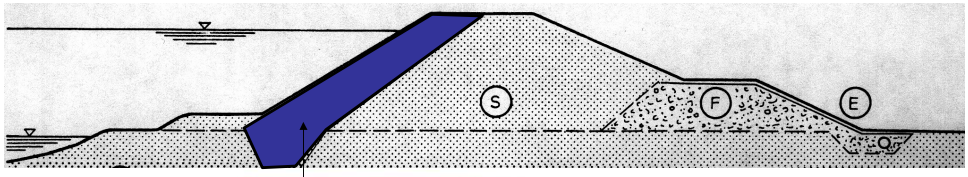
Less noise emission

Less impact to roads

GCL in various Dam Constructions

GCL in various Dam Constructions

Experience from German dam and dyke engineering



GCL in various Dam Constructions

Permeation of Dykes

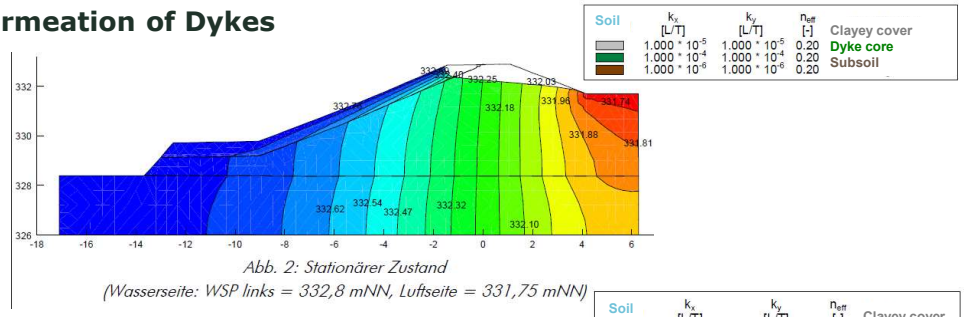


Abb. 2: Stationärer Zustand
(Wasserseite: WSP links = 332,8 mNN, Luftseite = 331,75 mNN)

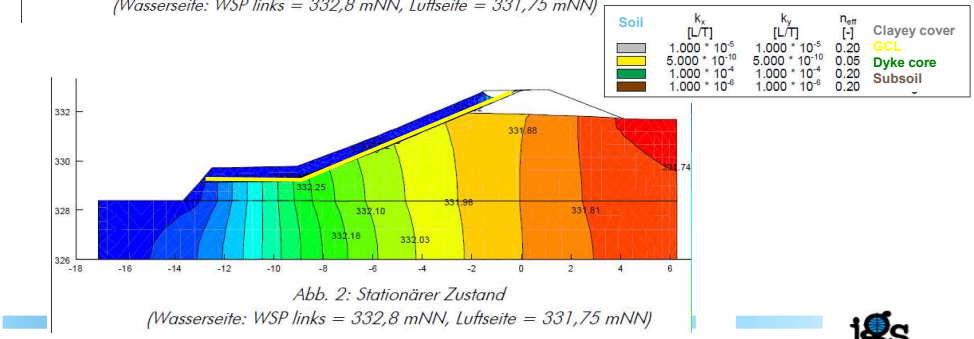


Abb. 2: Stationärer Zustand
(Wasserseite: WSP links = 332,8 mNN, Luftseite = 331,75 mNN)

GCL in various Dam Constructions

GCL in various Dam Constructions

Project – Pond & Encapsulation

GCL in various Dam Constructions

Storage Pond, Thailand - 250.000 m²

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 occured world-wide
- 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!**

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Thank You.

Building on sustainable ground.

Kent P. von Maubeuge
kvmaubeuge@naue.com