VERSOS´12

Vertederos y Sostenibilidad

Palacio Euskalduna, Bilbao

21 y 22 de noviembre de 2012

Landfill Covers with Steep Slopes using Geosynthetics

BAUBERATUNG GEOKUNSTSTOFFE

Katja Werth, Dipl. Ing.

BBG Bauberatung Geokunststoffe GmbH & Co. KG

Germany

NAUE

Burkard Lenze, Dipl. Geoök.

NAUE GmbH & Co. KG

Germany

Landfill Covers with Steep Slopes: Requirments on Long-Term Internal Shear Strength of Geosynthetic Clay Liners

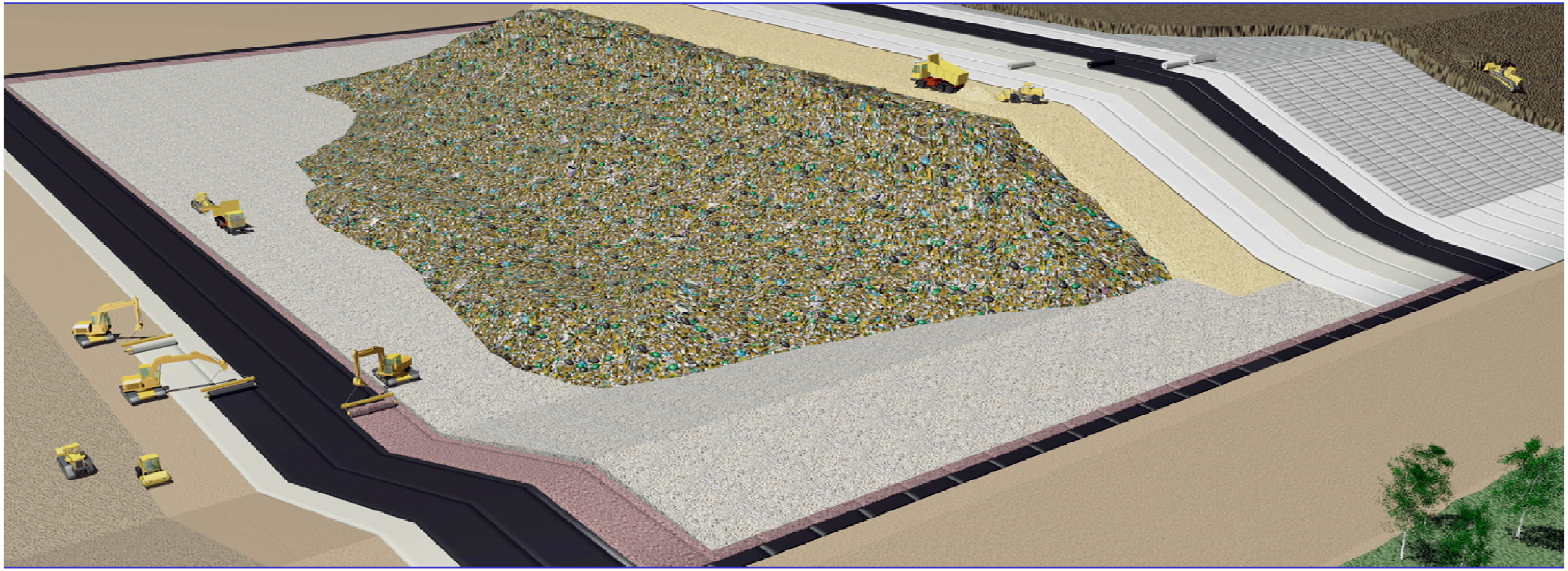
…based on laboratory testing and project experiences

- Introduction:
  - Application of GCL in Landfill Covers
  - GCL- Characteristics
- Internal Long-Term Shear Strength
  - Test Methode
  - Test Results
- Interface Shear Strength
  - Shear Box Testing
  - Stability Calculation based on Shear Box Tests

1. Introduction

Landfill Engineering with Geosynthtics

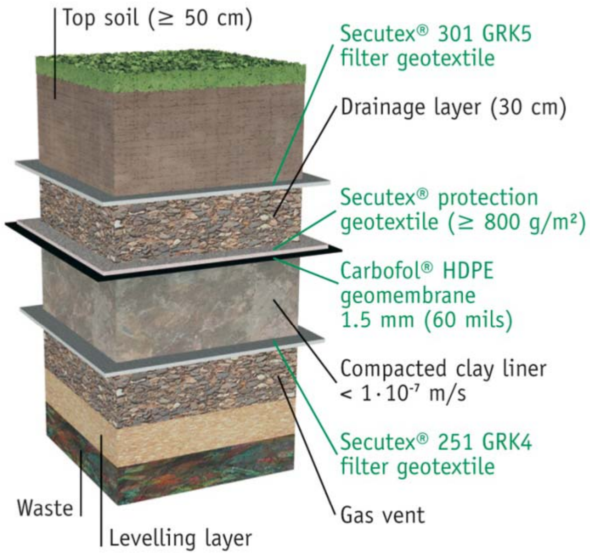
Landfill Capping



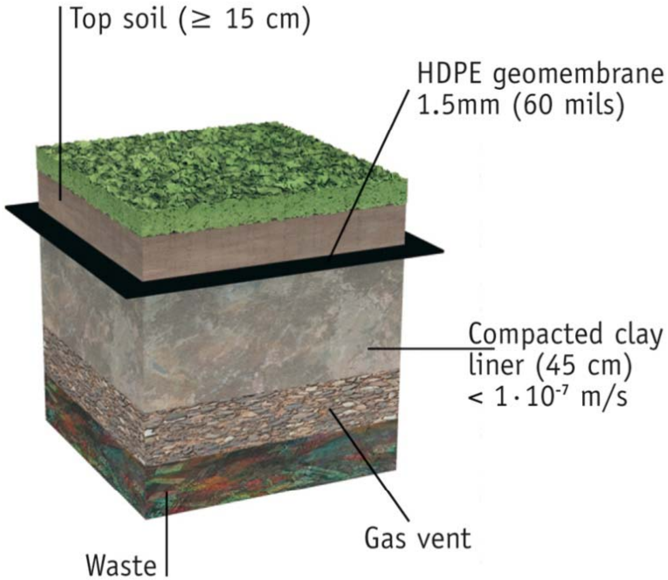
Landfill Base Lining

Landfill Capping Systems

NAUE Geosysnthetic solution following the European landfill regulations

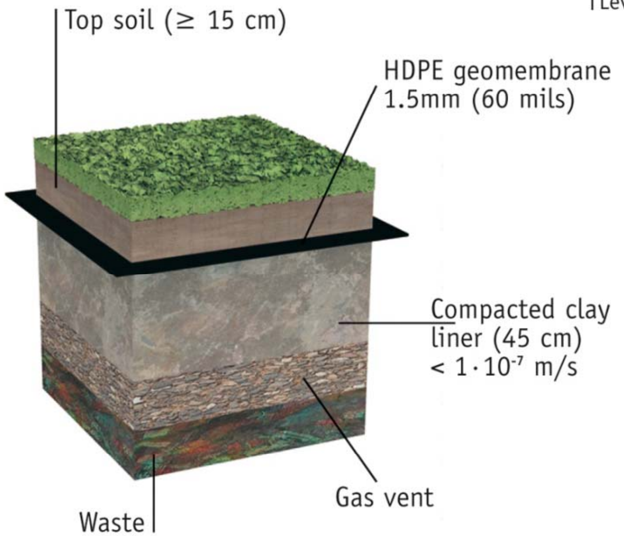


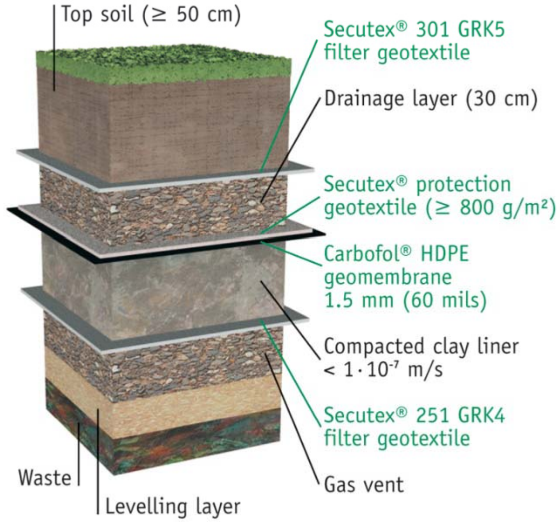
US-EPA directive for landfill caps (non-hazardous)



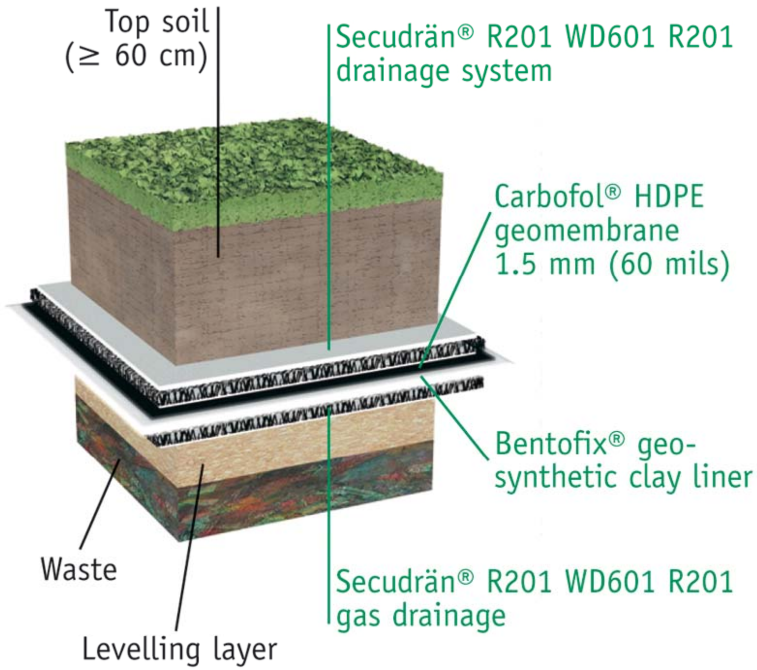
Composition of mineral layers and geosynthetic components

US-EPA directive for landfill caps (non-hazardous)

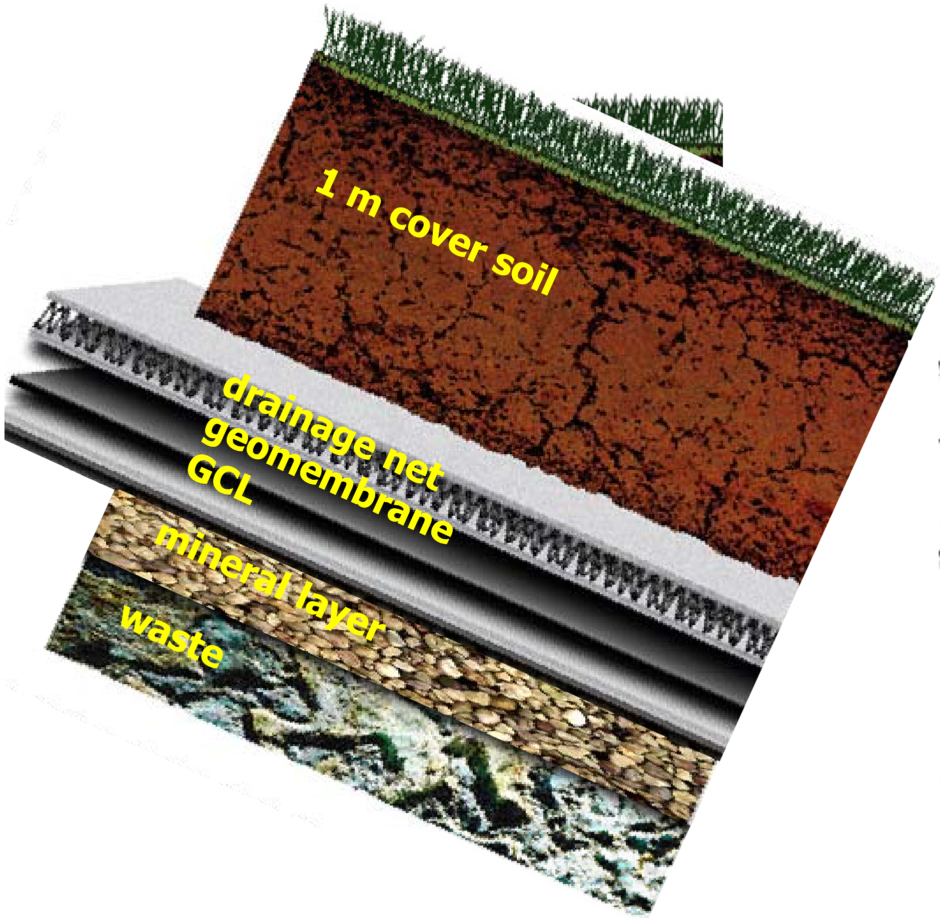


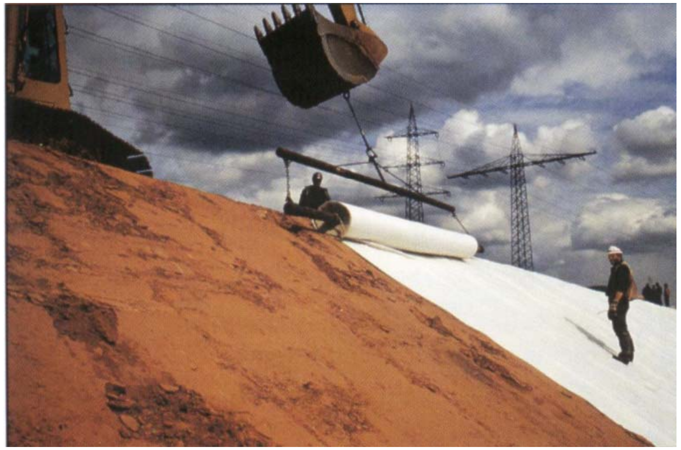


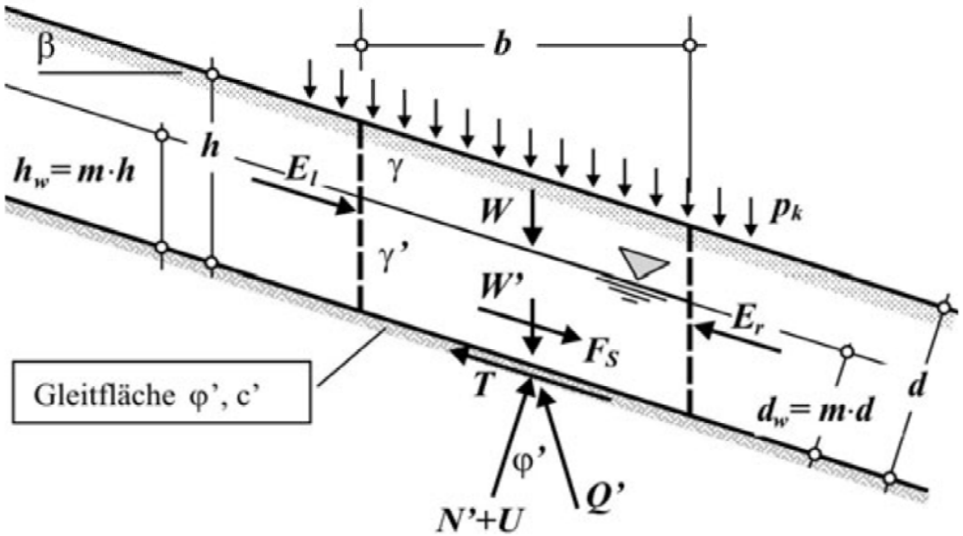
NAUE Geosysnthetic solution following the European landfill regulations



Slope of landfill cappings

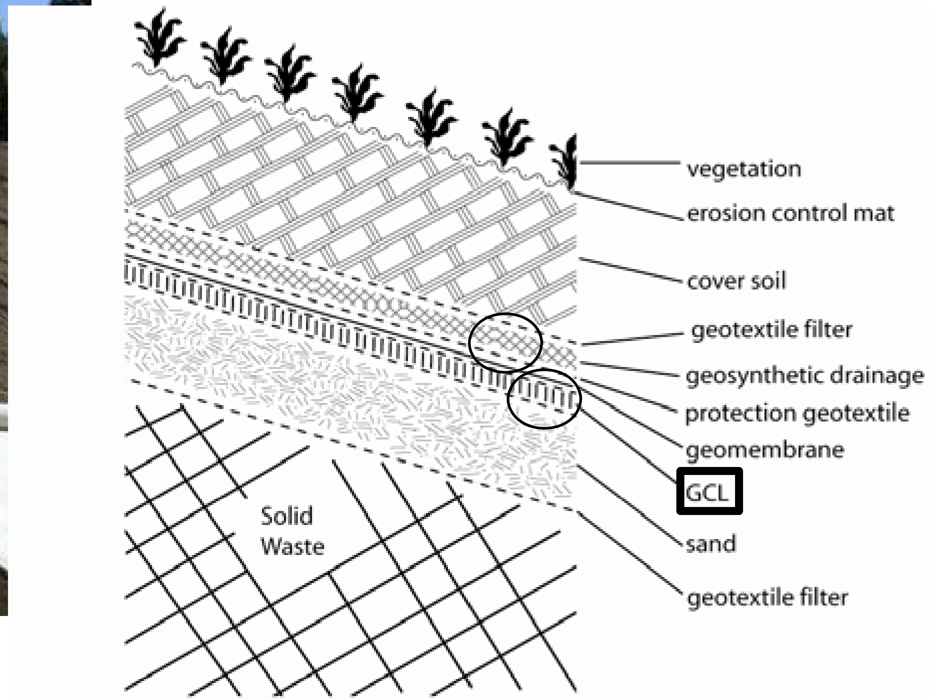






2. Internal Long- Term Shear Strength

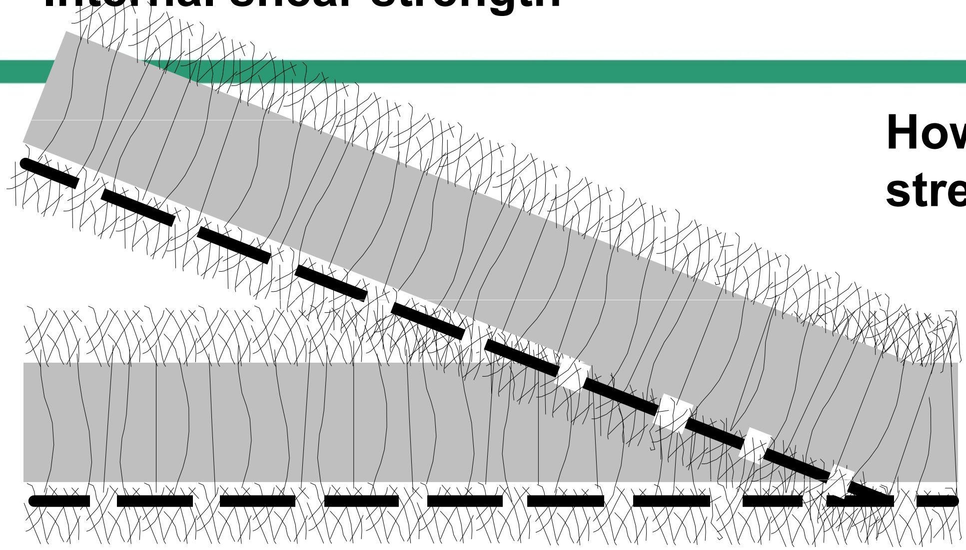
Internal shear strength Geosynthetic Clay Liner (GCL) and Geosynthetic Drainage Mat



Internal shear strength

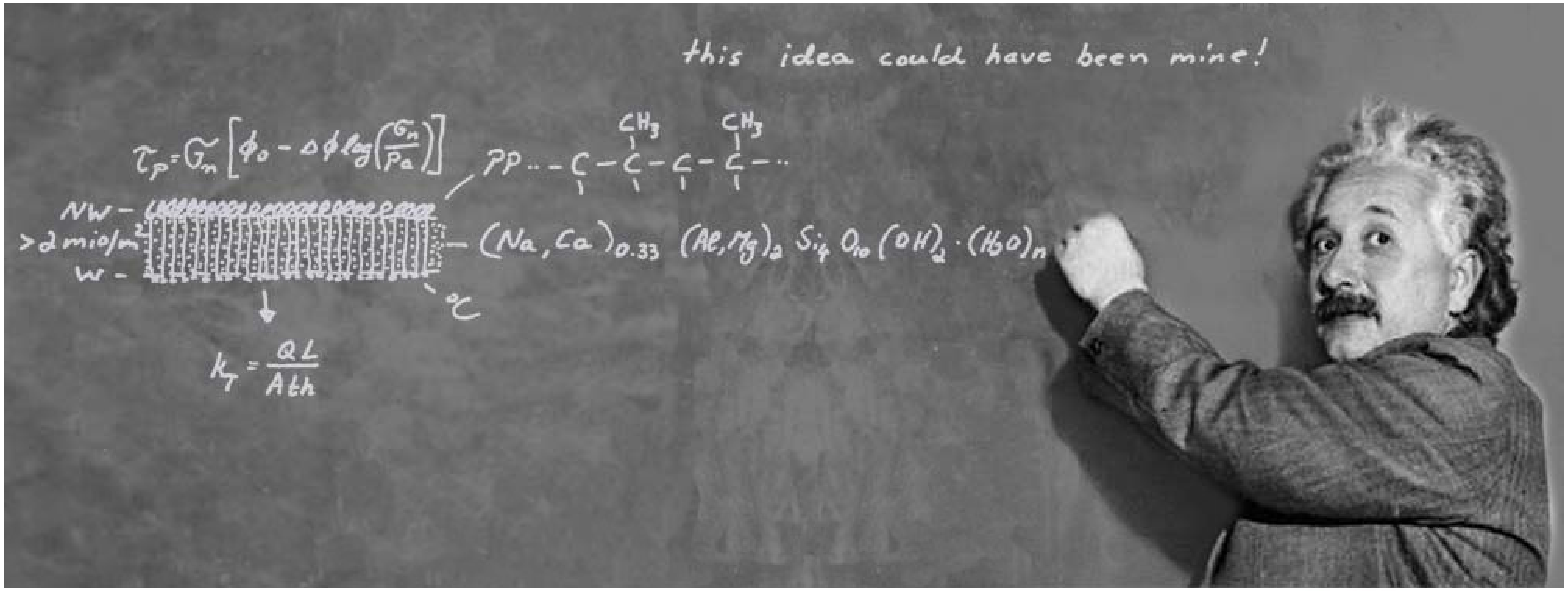
Failure because of low internal shear strength

Internal shear strength



How to reach high internal shear strength in GCLs?

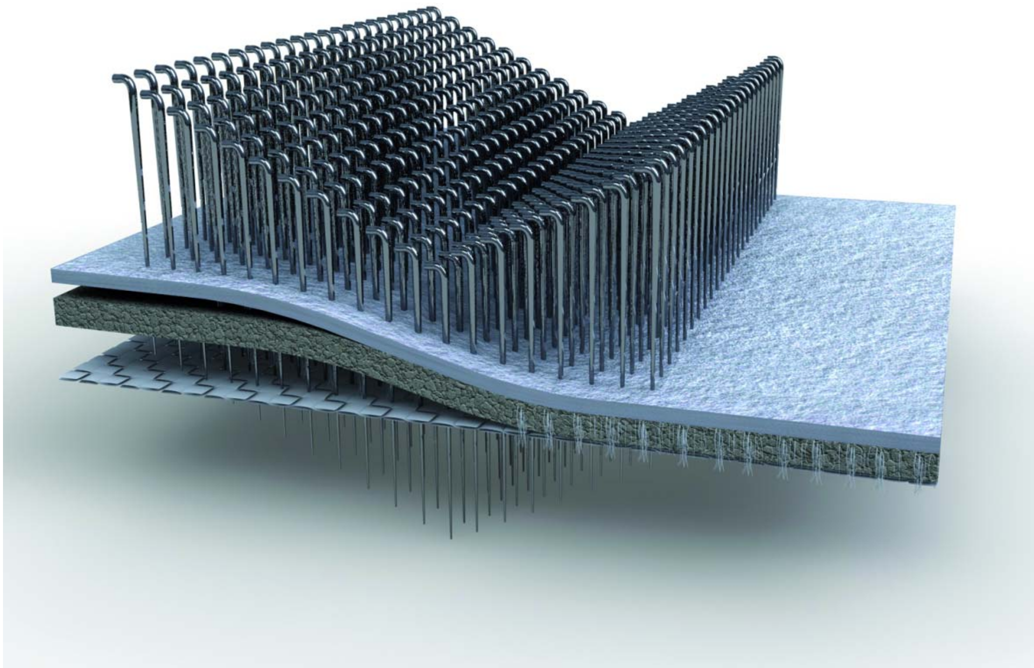
- cover nonwoven
- fibre-reinforced bentonite layer
- carrier geotextile



Needle-punched Geosynthetic Clay Liner (GCL)

Needle-punching of all components creating a unifirm internal shear strength

GCL components:
two durable geotextiles and one unifom core of high quality sodium bentonite powder



Measurement of the internal shear strength

Shear box tests to measure the hydrated shear strength for stabilty analysis

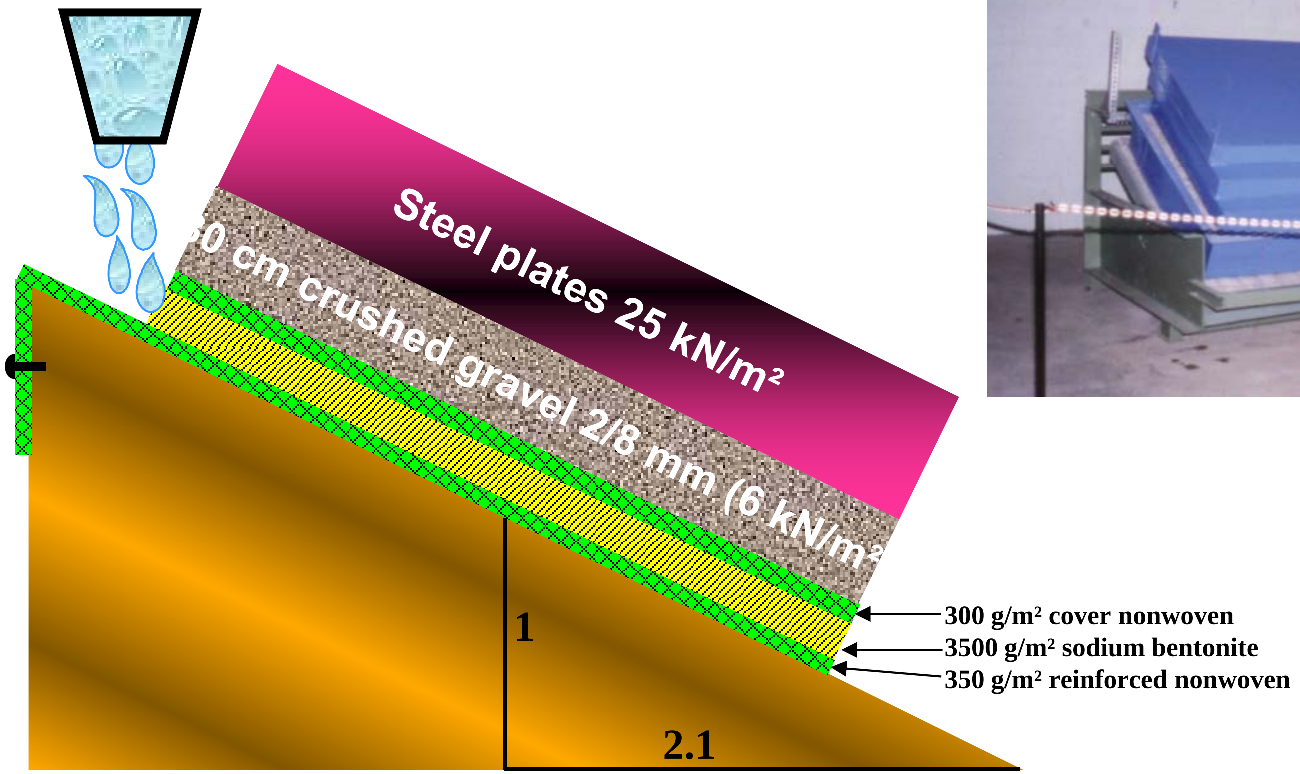
Peel test to measure the peel strength for quality control

Long-term shear strength testing with large scale tilt tables

Different GCL types have been tested in the 90´s in order to test the long term shear performance

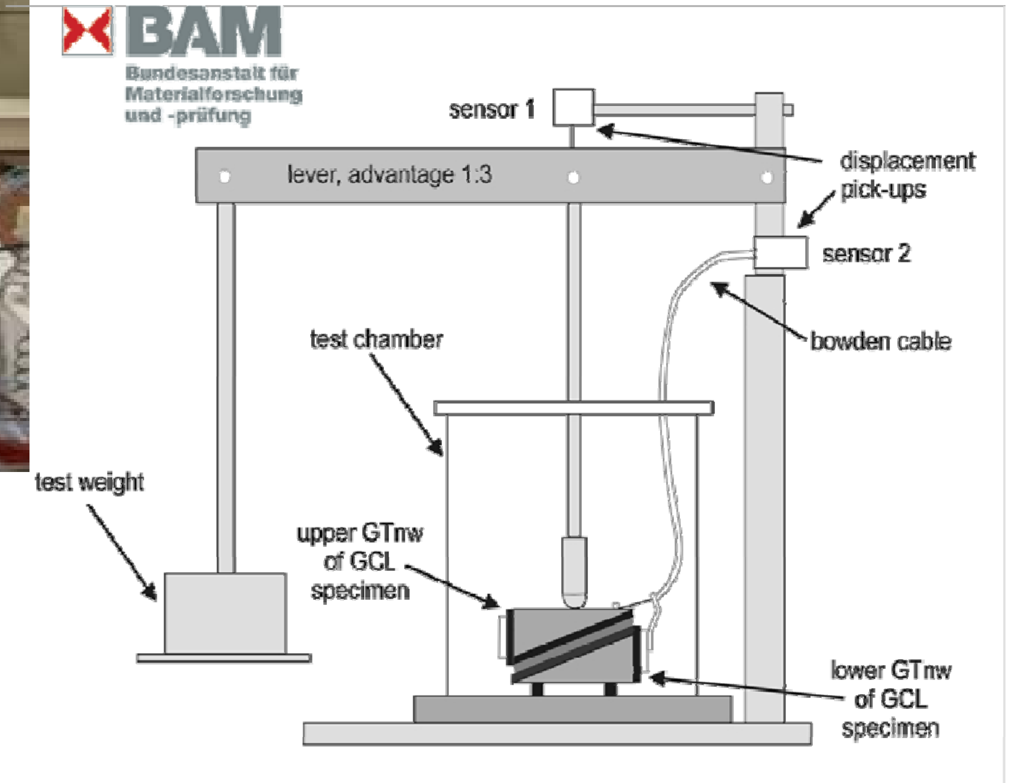
25° (2.1 : 1) and loaded with 31 kPa

→ No displacement!



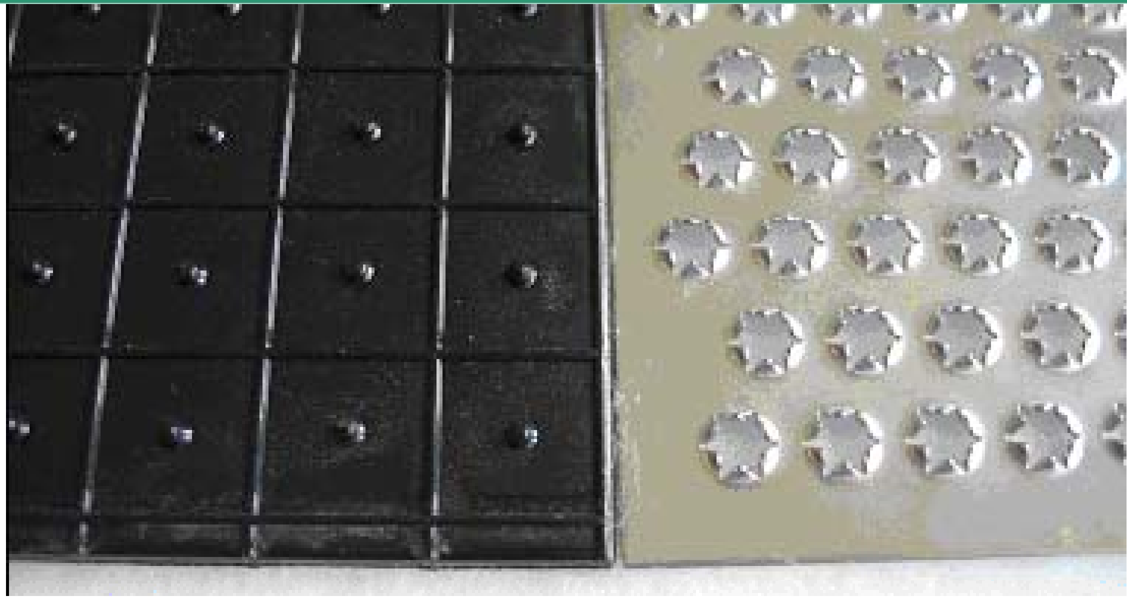
Test device for ´long-term shear test`

In 2000 BAM (Federal Institute for Materials Research and Testing) developed a methodology to measure long-term shear behavior of GCLs



BAM and NAUE started in September 2000 a research project to measure the creep performance of GCs in order to esimate service lifetimes of GCL

Internal shear strength



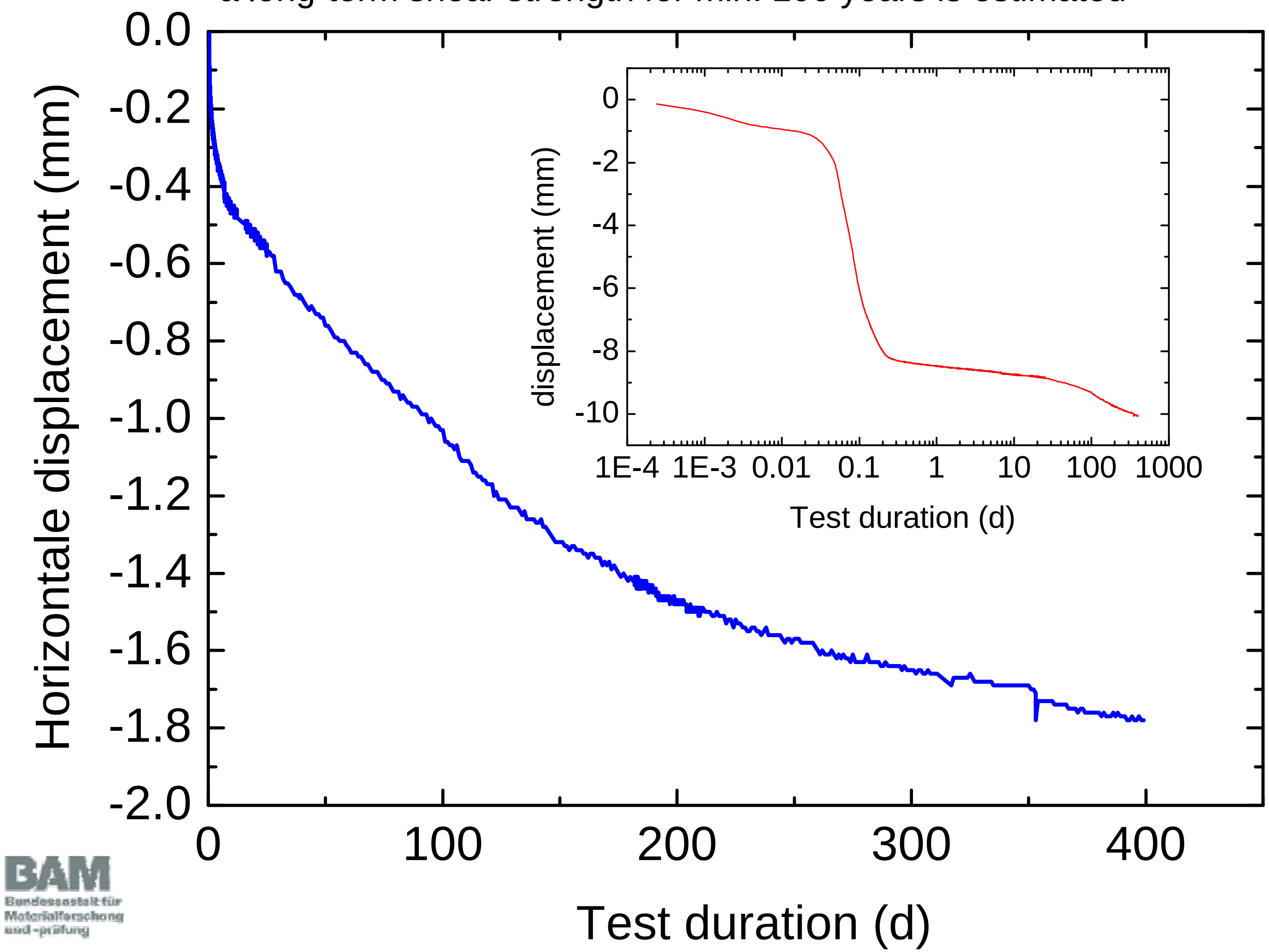
Textured geomembrane   Metal food grater

➡ Uniform adhesion of the wedges to upper and lower surfaces of GCLs

Internal shear strength

German Requirement 365 days/ 80°C/ 2,5 :1/ 50 kPa

BAM determination: if a product withstand these conditions
a long-term shear strength for min. 100 years is estimated



BAM Bundesanstalt für Materialforschung und -prüfung

Internal shear strength

Tested GCL types

Sample	Top layer		Bottom layer		Peel strength N/(10 cm)	Thermal Lock
GCL 1A	300 g/m²	HDPE - nw	350 g/m²	HDPE - w/nw	230	yes
GCL 1B	300 g/m²	HDPE - nw	350 g/m²	HDPE - w/nw	214	no
GCL 2Aa	300 g/m²	PP1 - nw	350 g/m²	PP1 - nw / PP3 - w	119	yes
GCL 2Ab	300 g/m²	PP2 - nw	350 g/m²	PP2 - nw / PP4 - w	163	yes
GCL 2Ac	300 g/m² 500 g/m*	PP1 - nw PP1 - nw	350 g/m²	PP1 - nw / PP3 - w	111	yes
GCL 2Ad	220 g/m²	PP2 - nw	110 g/m²	PP5 – w	110	yes
GCL 2B	300 g/m²	PP1 - nw	300 g/m²	PP1 - nw / PP3 - w	60	no

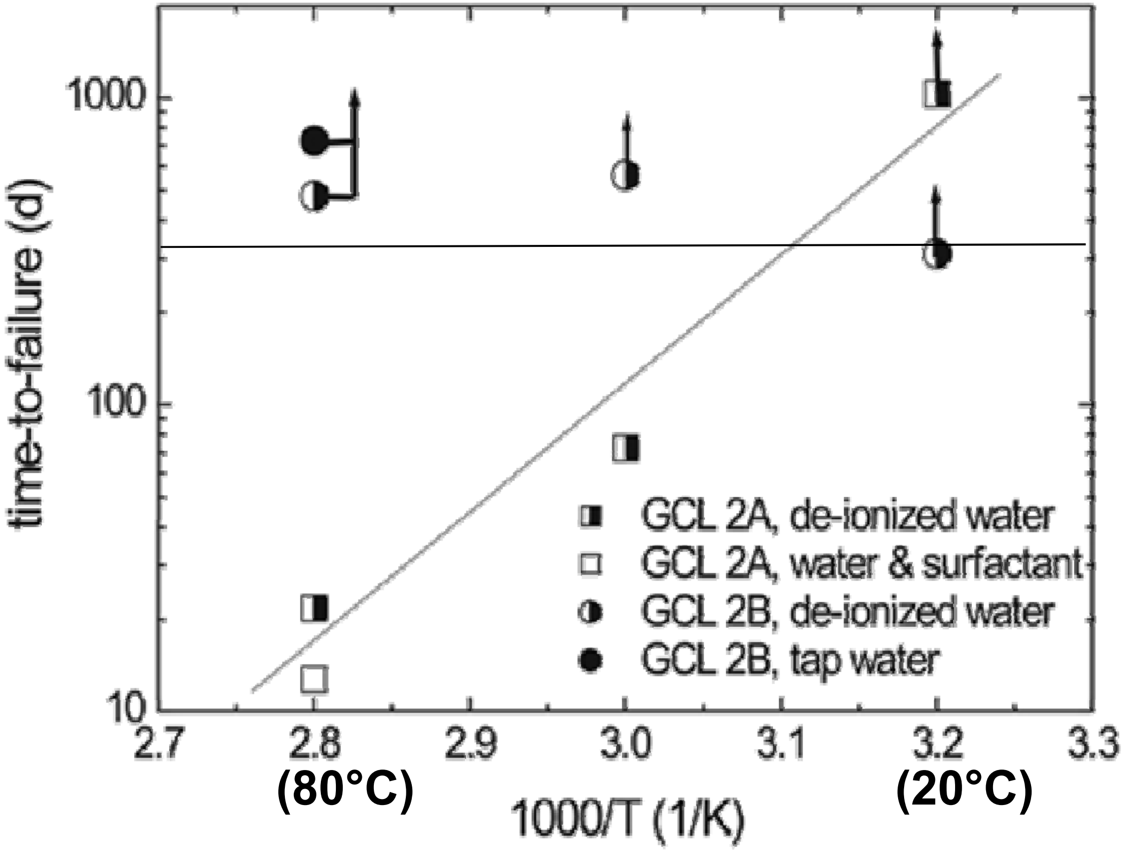
GCLs with woven/ nonvoven carrier layer

GCLs with woven carrier layer and Thermal Lock

Internal shear strength

Results of the ´long-term shear tests`

Time to failure using different testing liquids



GCLs fulfil the requirement of 365 days

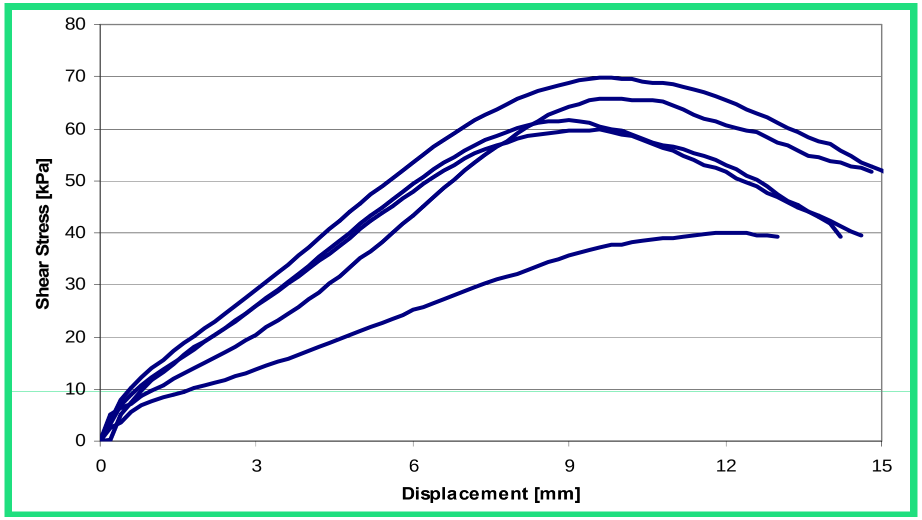
Arrhenius diagramm of shear test results of GCL 2Aa and 2B

Internal shear strength

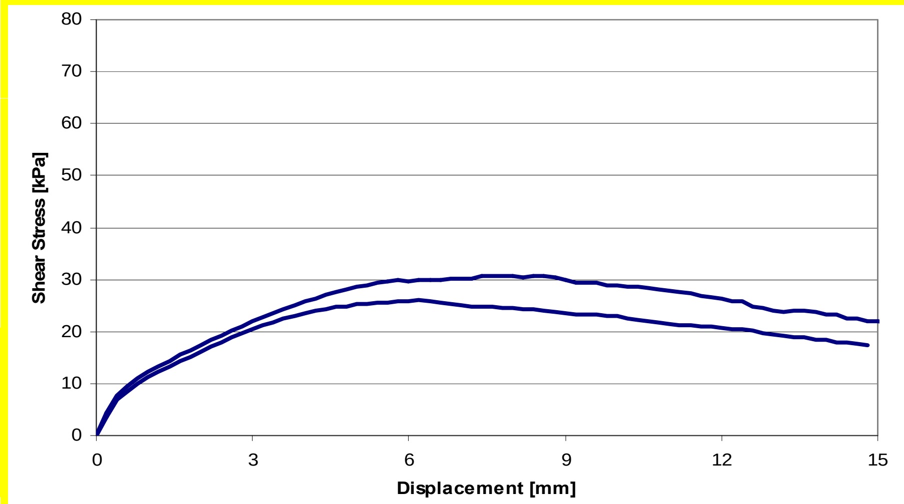
Retaining shear strength after ´~250* years lifetime`

* Estimated lifetime referring to the long-term shear test results

Shear box tests with a normal load of 20 kPa after the testing period in ´long-term shear tests`



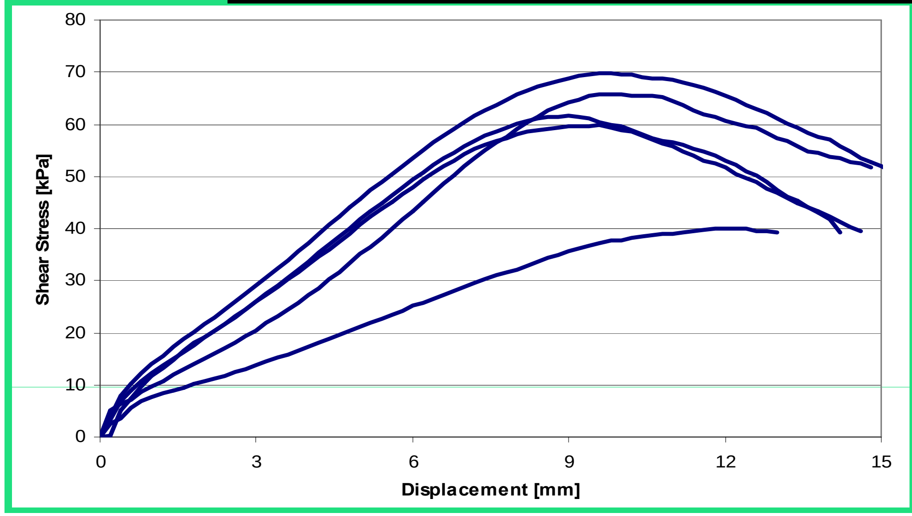
GCLs with woven/ nonvoven carrier layer

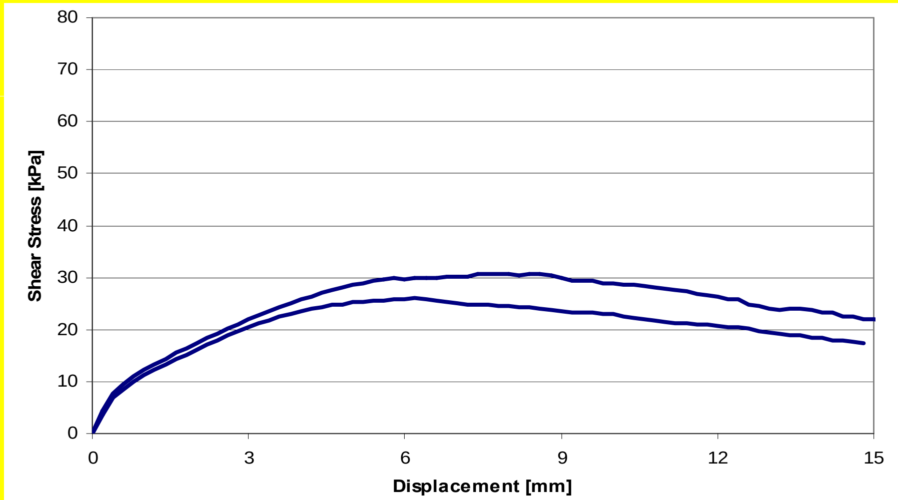


GCLs with woven carrier layer

Internal shear strength

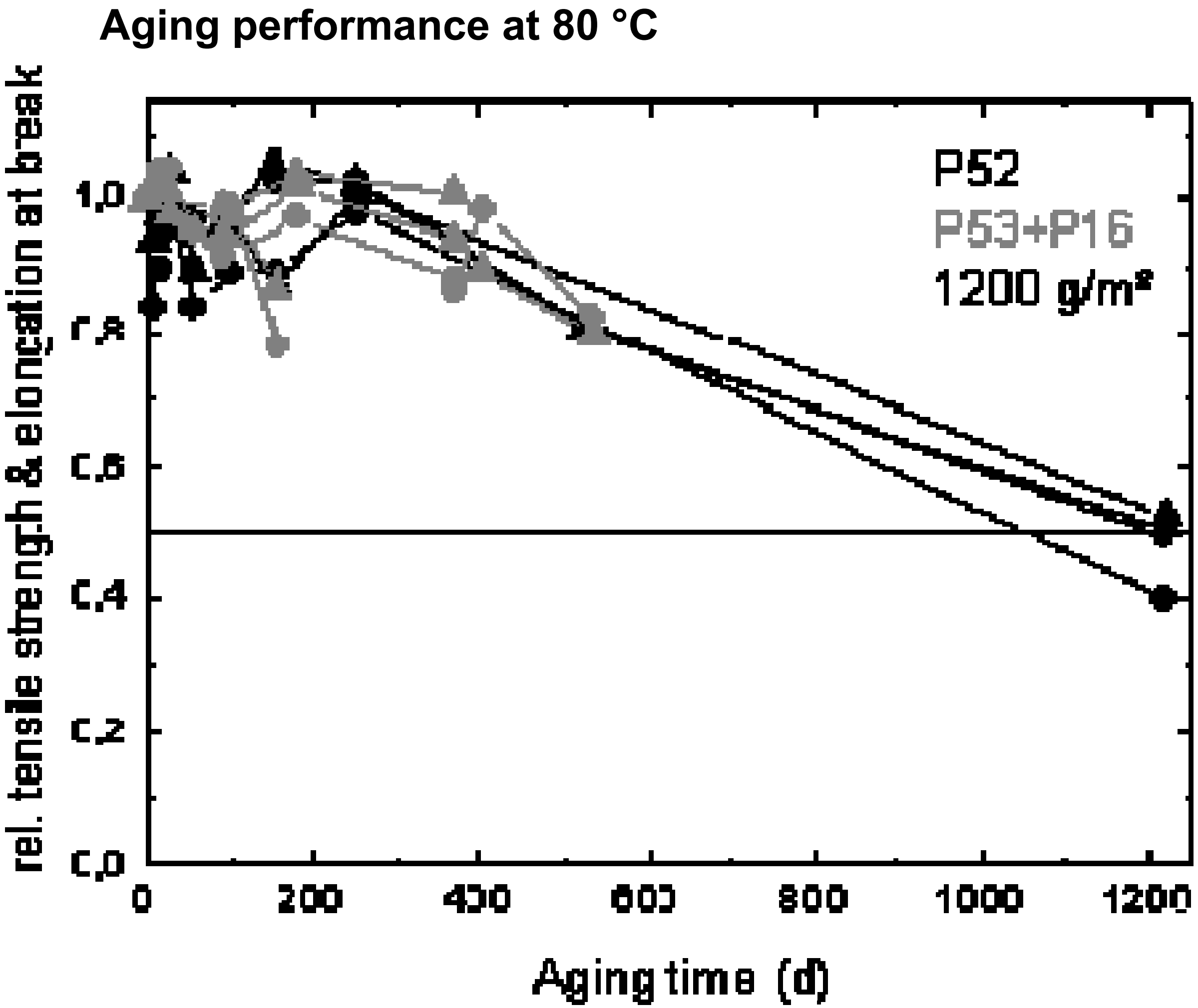
Sample	average maximum shear strength (load 20 kPa) [kPa]	average maximum internal friction angles [°]
Product 2Aa	59.4	71
Product 2B	31.7	58
Product 2Ad	28.4	54





Leibniz Universität Hannover
IGBE
Institut für Grundbau, Bodenmechanik und Energiewasserbau

Resistance of stabilized PP-fibers of geotextiles against oxidative degradation



Stabilized polyolifins has a high concentration of antioxidants which protect PP material from oxidizing

- Conclusion:
  - Special test device allows measurement of creep performance of GCLs
  - GCLs are tested under different temperatures, liquids and mechanical stresses
  - Exellent long-term performance of Thermal Lock treated GCLs and GCLs with nonwowen/woven composite carrier layer were measured
  - Eststimated service life of more than 250 years
  - High quality PP-fibers waranty long term tensile and peel strength
  - Tested GCLs meet GRI-GCL-3 specification

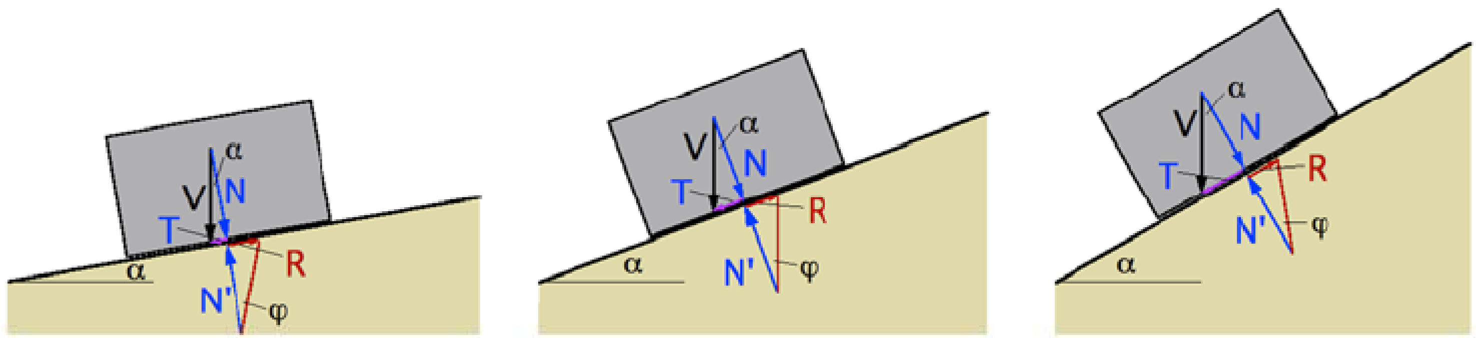
3. Interface Shear Strength

Failure mechanisms

Reasons of failure

Steep and long slopes
+ wrong type of geomembrane (smooth side)
+ high loads from cover (1 m soil)
+ reinforcing element with poor tensile strength
+ poor anchorage design
= poor friction
= sliding failure

Design basis on interface for cap lining systems against sliding on slopes

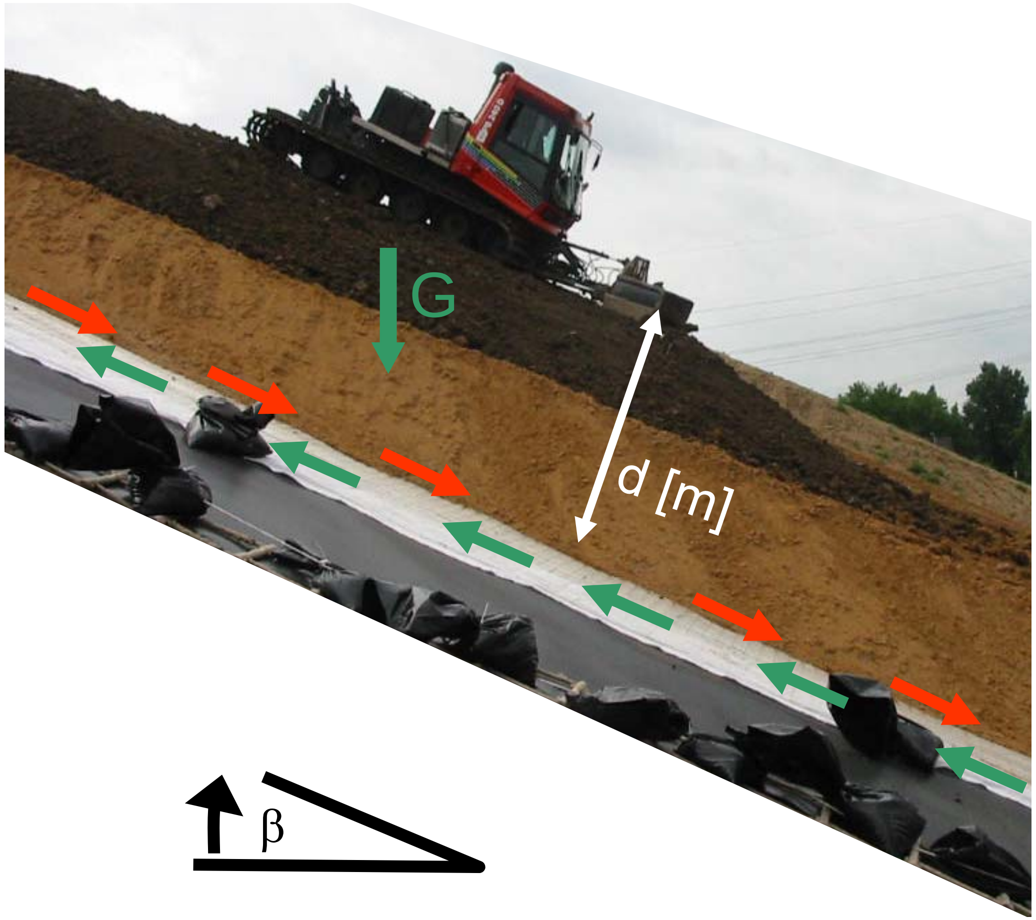


Sufficient stability against sliding

stability – ultimate state

No stability – sliding in slope direction

Geosynthetic Lining System in slopes - stability



Scope

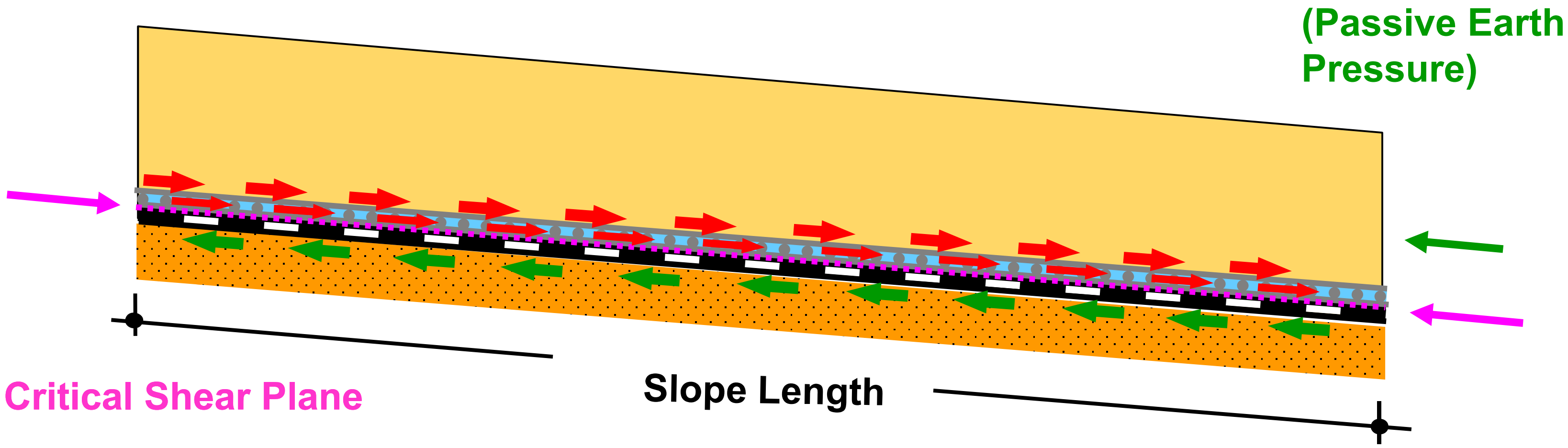
- All layers are installed parallel to slope surface
- Avoiding any stresses in the lining element
- Cover layer causes stress in slope direction
- Avoiding sliding on interfaces => failure
- All forces have to be transferred by friction mobilization

Stability of sealing system against sliding

General design principles following EUROCODE 7 (Partial Safty Design Concept)

$$\frac{\sum \text{Driving Forces}}{\sum \text{Resisting Forces}} = \text{Degree of utilization} \leq 1 \; \checkmark$$

The driving forces have to be multiplied with partial safety factors and the holding forces have to be divided by partial safety factors.



Determination of the required reinforcing element to reach a sufficient stability of the sealing system against sliding!

If utilisation $\mu > 1$

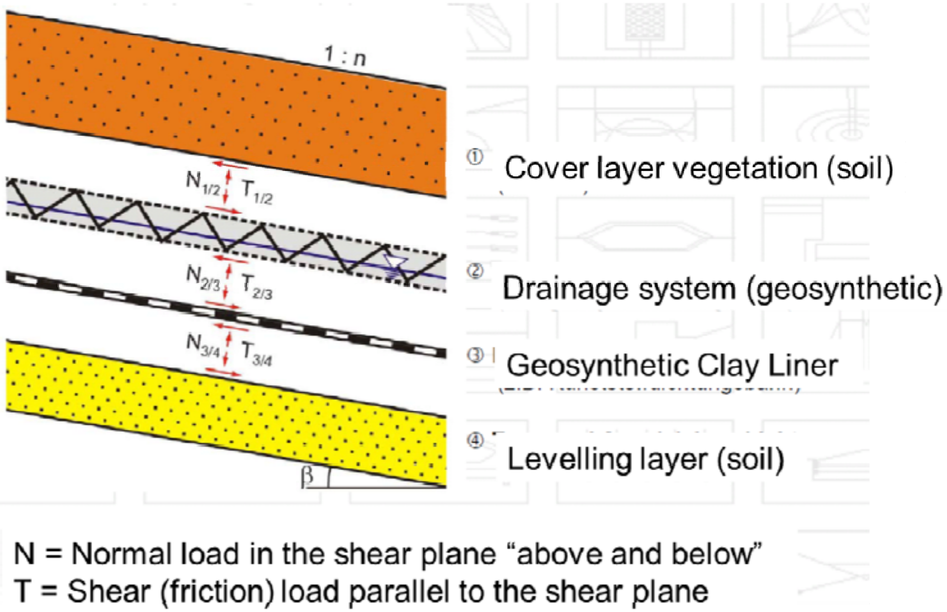
1. The veneer reinforcement „helps“ to come back to $E_d \leq R_d$ and is part of R_d.
2. If veneer reinforcement is required => Slope length is relevant (multiplied by the length).

Deficit long-term tensile strength

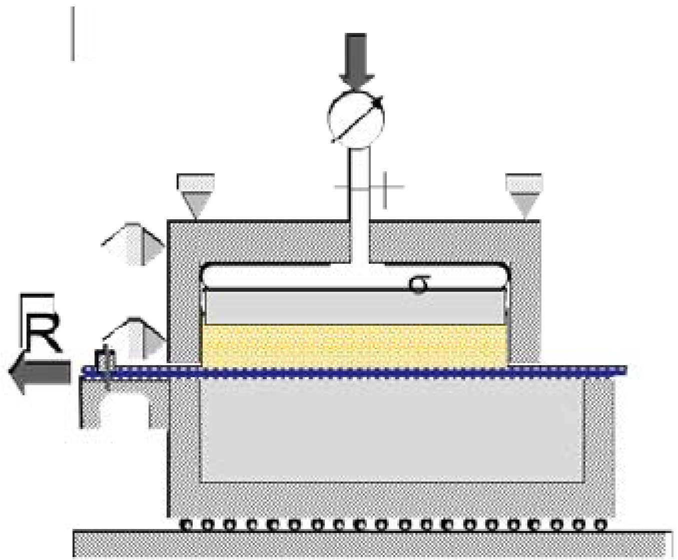
$$T_{G,d} = 1.0 \times ((t_{B,d} + s_{w,d} + t_{S,d}) \times l) - ((t_{f,d} + t_{s,h,d}) \times l)$$

(driving forces – resisting forces)

Interface shear strength

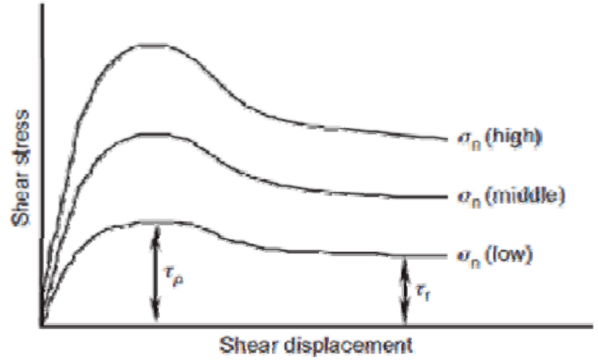


Different interface friction between geosynthetics and between geosynthetics ans soils

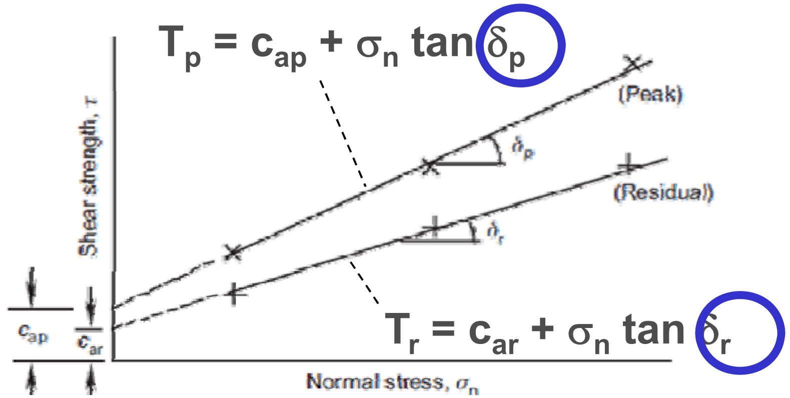


Interface shear box tests according to GDA E2-8 (2005)

Interface Shear Testing / direct shear box test



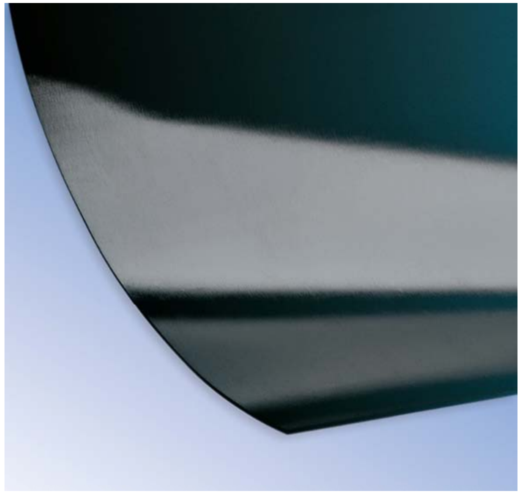
Direct shear test data



Mohr-Coulomb stress space

Input values - interface friction angles

- Using GM smooth/smooth



Carbofol s/s

δ = 10°

Valid for all types of smooth GM

Top side

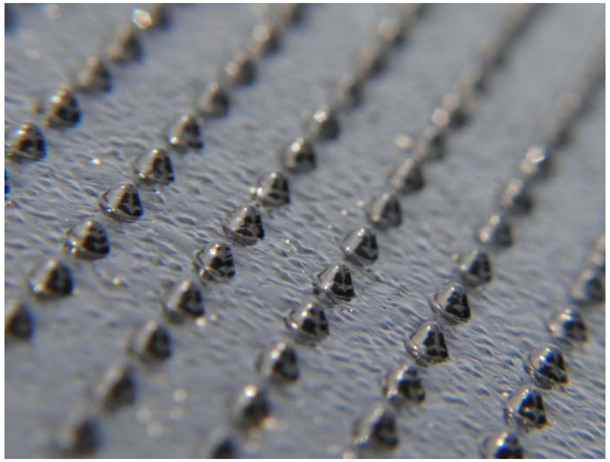
Bottom side

Secutex protection geotextile (nonowoven)

GCL Bentofix (cover geotextile = nonwoven)

Input values - interface friction angle

- Using GM Megafriction/Megafriction



Carbofol MF/MF

δ ≥ 30°

Top side

Bottom side

Secutex protection geotextile (nonwoven)

GCL Bentofix (cover geotextile = nonwoven)

Interface shear strength

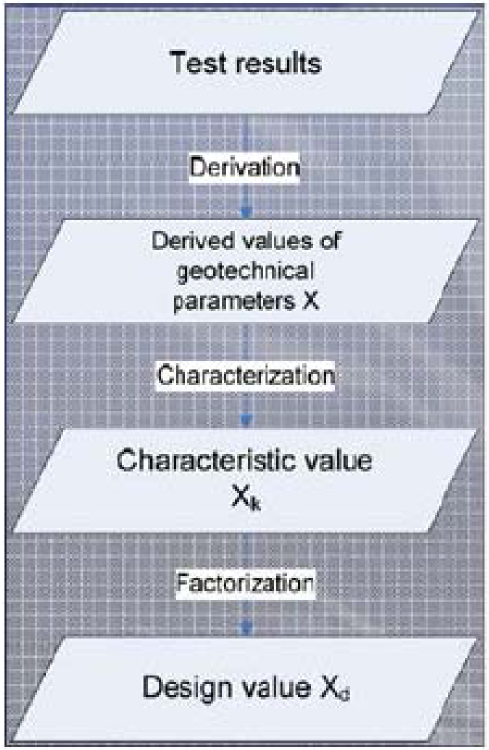
Examples of interface shear values

between different geosynthetics and soil. The indicated approximate values result from over 15 years of project experience. The specific design values must be determined on a project by project basis and follow as close as possible on-site conditions.

- Thermally fused nonwoven achieves the higher value (blue)
- Is rarely designed (yellow)

	Bentofix®	Secudrän®	Secutex® nonwoven	Carbofol® smooth	Carbofol® MegaFriction	Sand 0/2 mm	Gravel 8/16 mm	Mixed grained top soil
Bentofix®	33°	19-25° (blue)	(yellow)	11°	30°	29°	32°	26°
Secudrän®	19-25° (blue)	(yellow)	(yellow)	11°	30°	29°	32°	26°
Secutex® nonwoven	(yellow)	(yellow)	18°	11°	30°	29°	32°	26°
Carbofol® smooth	11°	11°	11°	(yellow)	(yellow)	18°	(yellow)	(yellow)
Carbofol® MegaFriction	30°	30°	30°	(yellow)	(yellow)	25°	(yellow)	(yellow)
Sand 0/2 mm	29°	29°	29°	18°	25°	32°	-	-
Gravel 8/16 mm	32°	32°	32°	(yellow)	(yellow)	-	36°	-
Mixed grained top soil	26°	26°	26°	(yellow)	(yellow)	-	-	28°

- **Imput parameters for stability calculation based on shear box tests**



Direct interface friction tests

↓ *Determination of shear stresses in dependence of normal stresses*

Lab results: peak value δ_0

↓ *Applying reduction factor on material variance / test conditions*

Characteristic value: $\tan \delta_k = \delta_0 / 1.1$

↓ *Applying partial factors on safety according to Eurocode 7*

Design values
Results

Interface shear strength

Garanty slope stability with:
-improoving interface friction angle
-or using a geogrid for verneer reinforcement

NAUE

Tensile strength

The veneer reinforcement „helps“ to come back to $E_d \leq R_d$ and is part of R_d.
If veneer reinforcement is required => Slope length is relevant (multiplied by the length).

Calculation of the long term design strength of a reinforcing element

given from calculation:

- action forces:

$t_{B,d}$ = 8,944 kN/m²

$s_{w,d}$ = 0,116 kN/m²

$t_{S,d}$ = 0,000 kN/m²

- resisting forces:

$t_{f,d}$ = 6,582 kN/m²

$t_{S,h,d}$ = 0,000 kN/m²

- calculation length:

l = 40 m

Calculation of the deficit long-term tensile strength:

$$\mu = ((t_{B,d} + s_{w,d} + t_{S,d}) * l) / (t_{f,d} + t_{S,h,d}) * l + T_{G,d})$$

$$T_{G,d} = 1,0* ((t_{B,d} + s_{w,d} + t_{S,d}) * l) - ((t_{f,d} + t_{S,h,d})* l)$$

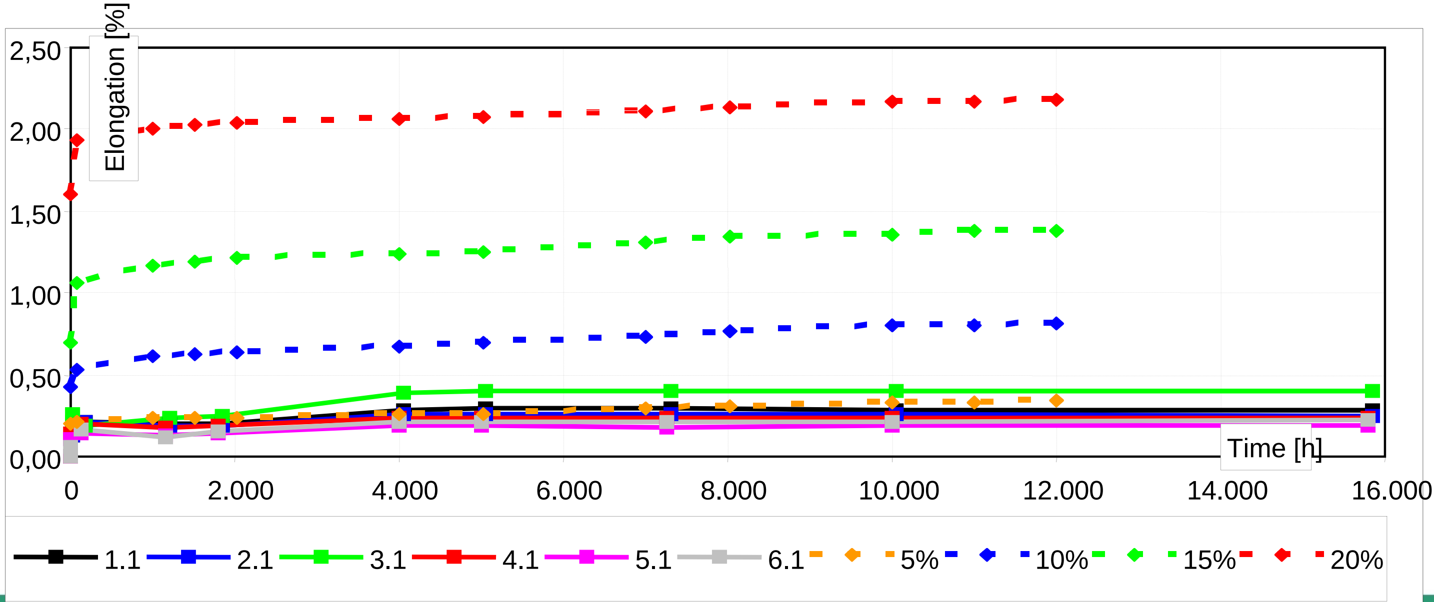
$T_{G,d}$ = 99,1 kN/m

Interface shear strength

Creep monitoring of the verneer reinforcement

Field Tests/ Landfill Duisburg-Sudamin

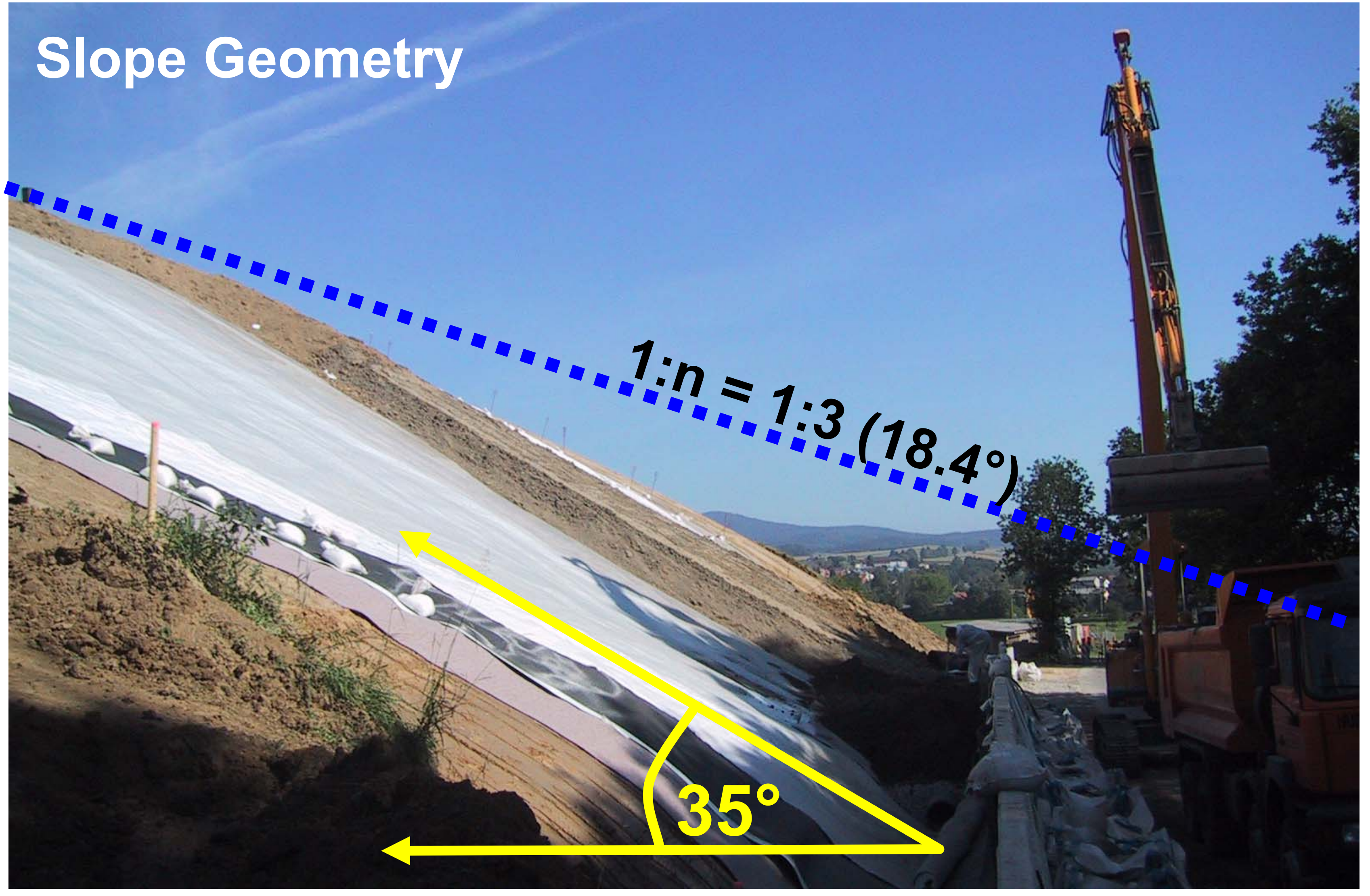
Installation of the strain gauches



Results of ín air tests`

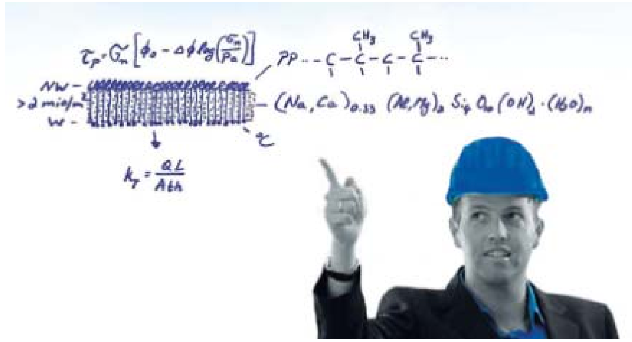
Measured strain values

(approx. 0,3 %)



Landfill "Furth im Wald", Bavaria

- Conclusion:
  - All internal and interface shear strength must be considered in stability analysis
  - Shear box tests are required
  - Different test devices and test performance may lead to different results
  - Sensitive use of test results is necessary



Thank you for your attention.
Any questions?

BAUBERATUNG GEOKUNSTSTOFFE

Katja Werth, Dipl. Ing.

BBG Bauberatung Geokunststoffe GmbH & Co. KG

Germany

NAUE

Burkard Lenze, Dipl. Geoök.

NAUE GmbH & Co. KG

Germany