IGS University Online Lecture Series

Geosynthetic reinforced earth walls

Dr. Ing. Oliver Detert

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www. geosyntheticssociety.org

About the lecturer

- Dr. Oliver Detert is Chief Engineer for HUESKER and based at the headquarters, HUESKER Synthetic GmbH in Gescher, Germany. He joined the company in 2005. He did his Dipl.-Ing. at RWTH Aachen in 2005 and later on his doctoral degree at Ruhr-University Bochum in 2016.
- He is active in working groups, like the AK 5.2 of the DGGT in Germany, which is responsible for the EBGEO. Furthermore, he is member of the DIN NA 106-01-11 AA, CEN/TC 189 and ISO/TC 221, ISSMGE/TC 218 (Vice-Chair), IGS/TC-R and IGS TC-S.
- He is a member of the German Society for Geotechnics (DGGT), of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) and of the International Geosynthetics Society (IGS).
- He has published and presented more the 75 papers on international conferences or in journals.

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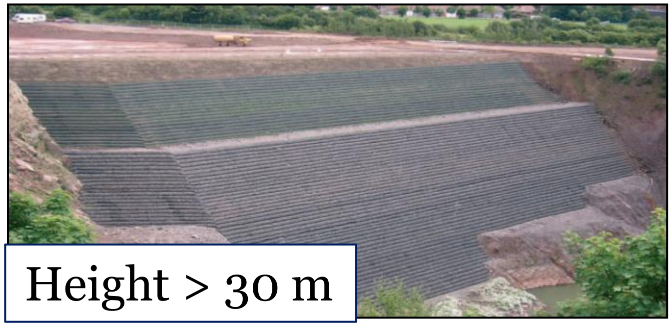
Outline

- Introduction
- Overview of systems
- Design aspects
- Research and laboratory tests
- Applications and case studies
- Conclusion

Introduction


Height > 30 m

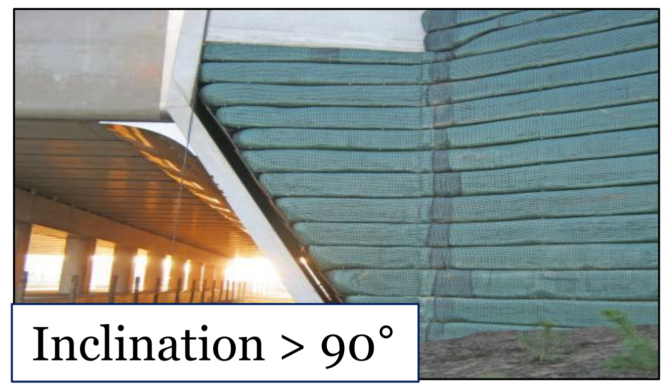
Retaining structures

Loads > 300 kPa

Bridge abutments


Deformation < 1% of height

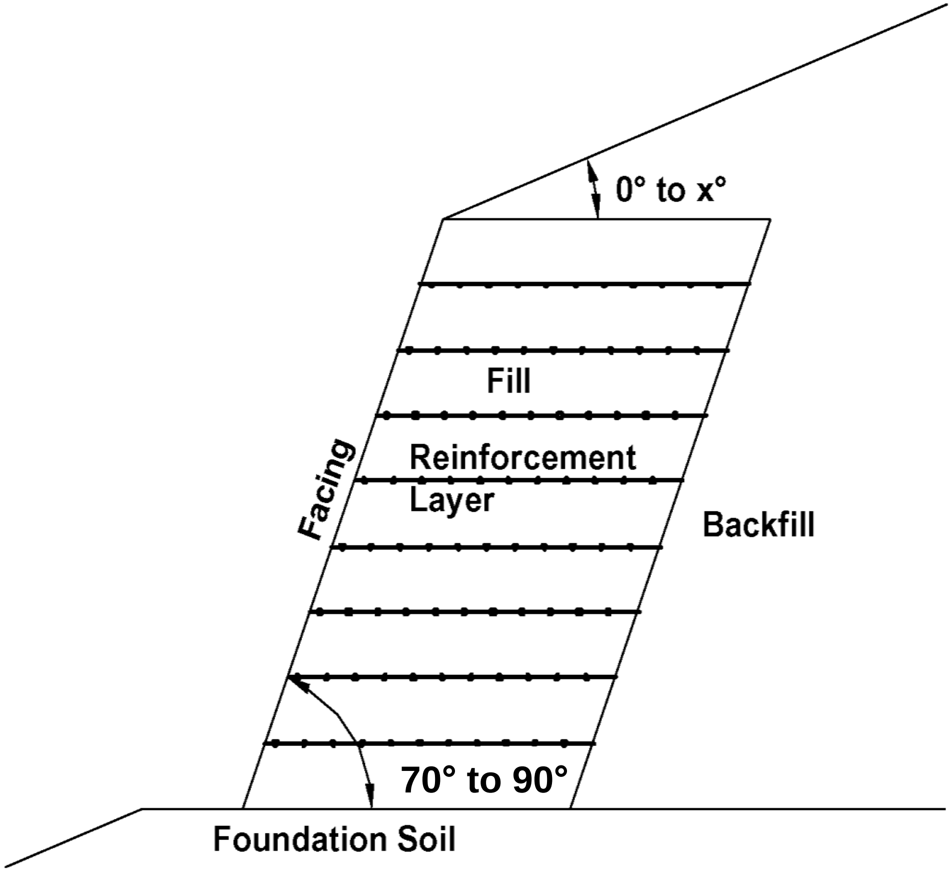
Earth Pressure Relief


Inclination > 90°

Over steep Walls

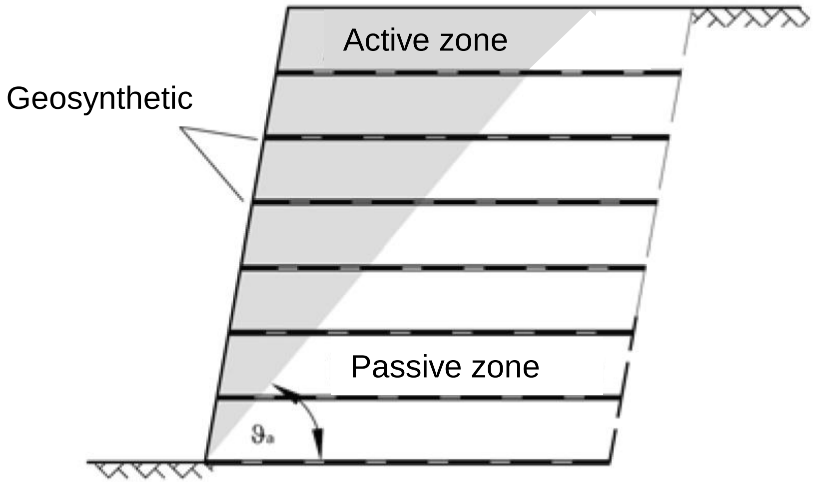
Introduction

What is a reinforced earth wall?



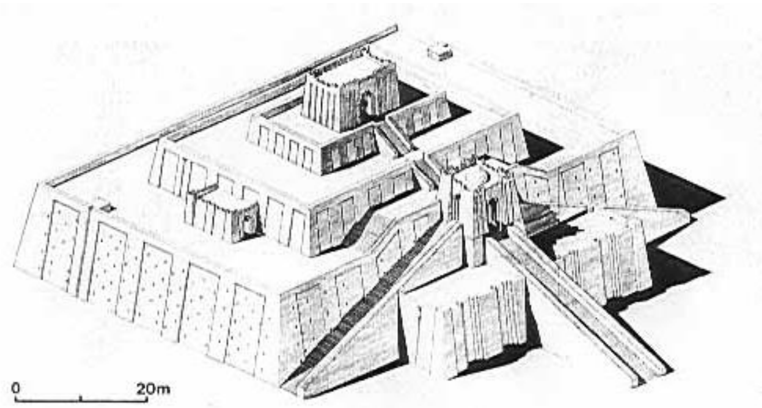
Introduction

What is a reinforced earth wall?



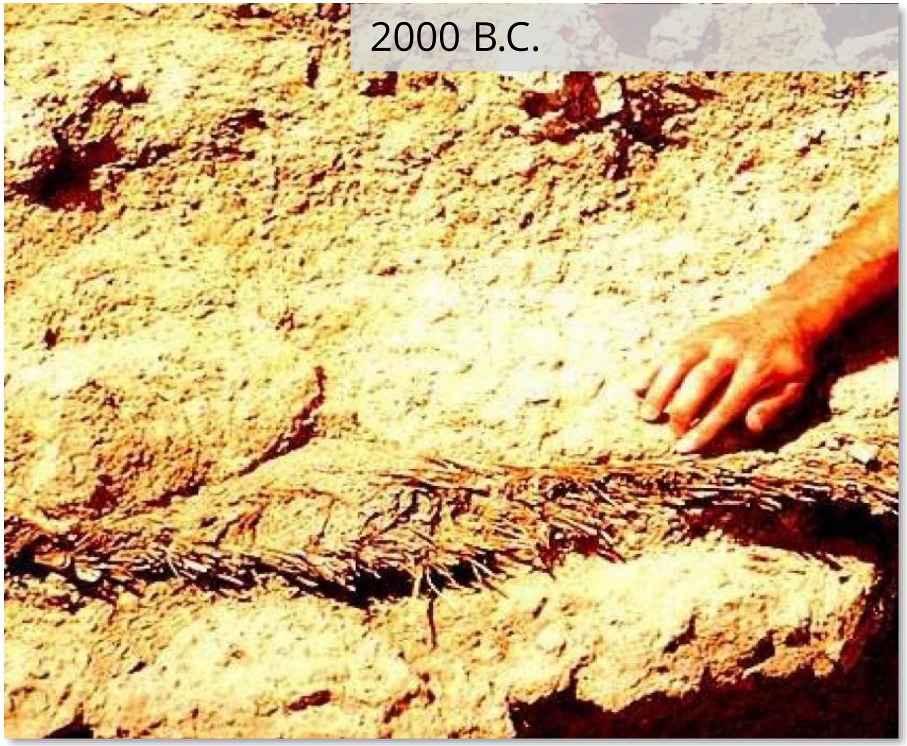
Introduction

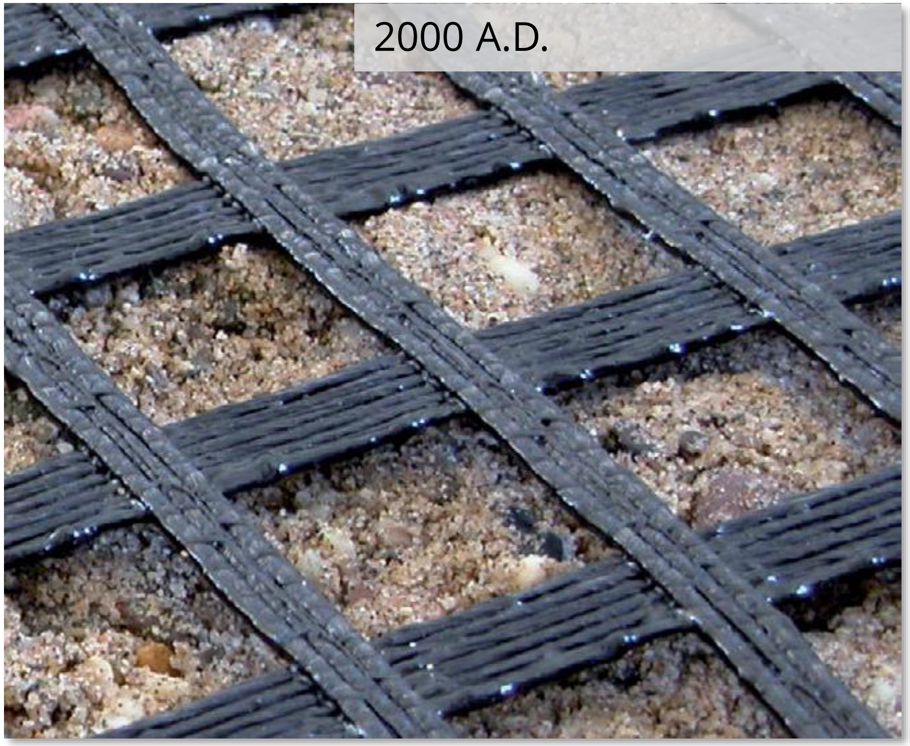
Ancient Babilon ~ 2000 B.C.



Introduction

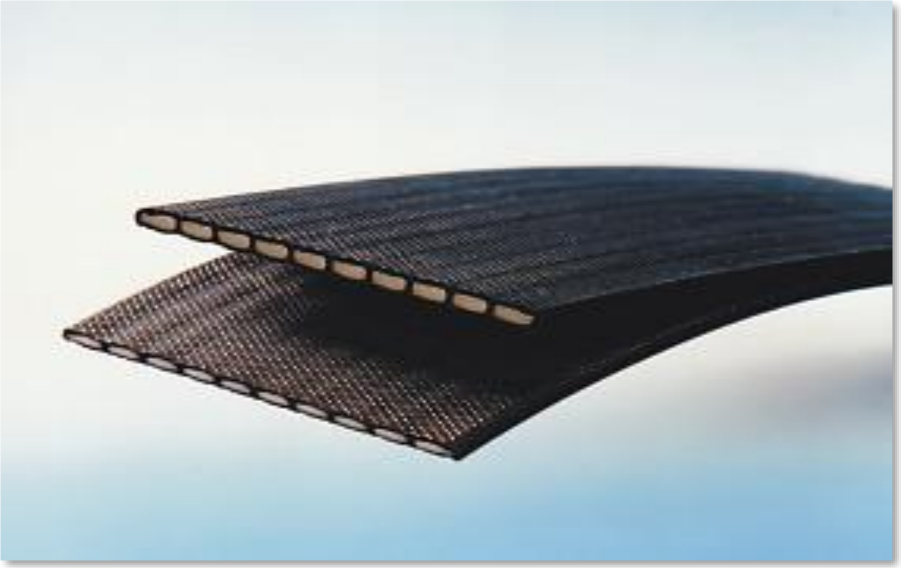
Reinforcing materials





Introduction

Reinforcing materials



Introduction

The (probably) first walls with geosynthetics in Europe

Introduction

Geosynthetic reinforced earth retaining structures

The solution has become increasingly accepted and established:

Design options
Shape, slope, facing, curvature, etc.
Integration into the landscape
Construction technologies
Ductility
Cost

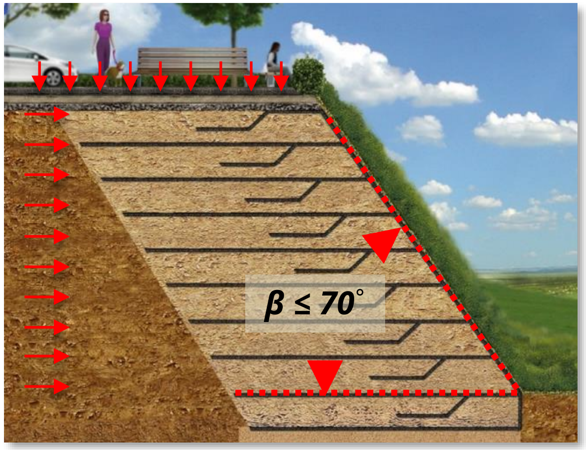
Introduction

Reinforced soil *slopes* versus reinforced soil *walls*

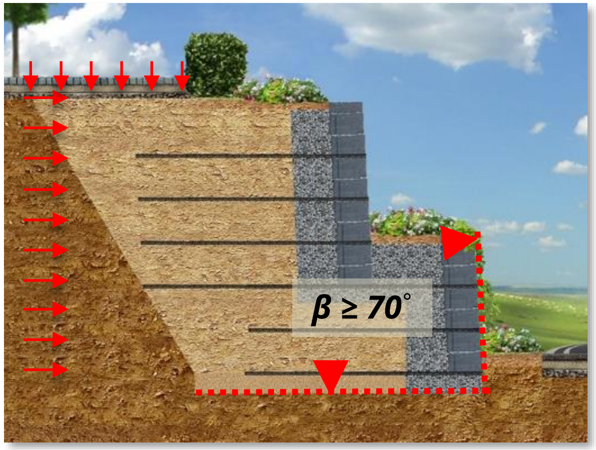
Differentiation by slope inclination: below 70° it is considered a "slope", above 70° a "wall"
The soil mechanical behaviour is identical, but extra geotechnical analysis are required for walls, such as

- Bearing failure
- Overturning
- Sliding

Reinforced soil slopes



Reinforces soil walls



Introduction

Applications

- Noise barriers

Introduction

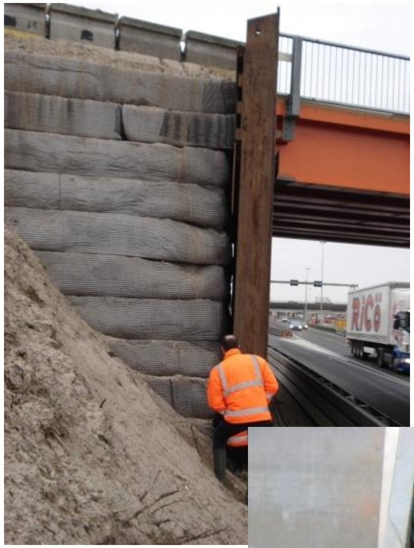
Applications

- Noise barriers
- Retaining structures / steep slopes / soil level differences

Introduction

Applications

- Noise barriers
- Retaining structures / steep slopes / soil level differences
- Earth pressure relieve



Introduction

Applications

- Noise barriers
- Retaining structures / steep slopes / soil level differences
- Earth pressure relieve
- Bridge abutments

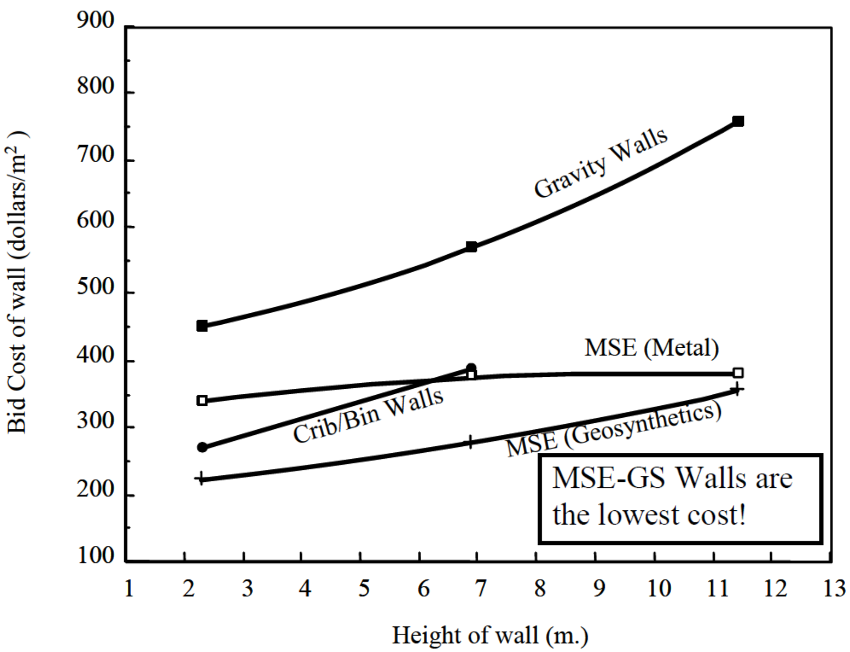
Introduction

Traditional techniques

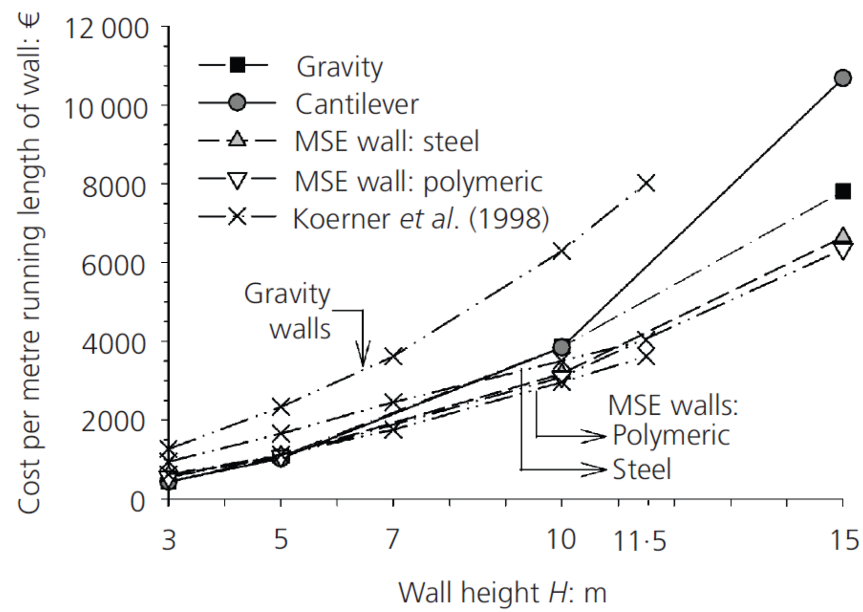
L-Walls	Gravity Walls	Tangent Pile Walls	Sheet Pile Walls
			

Introduction

Cost comparison



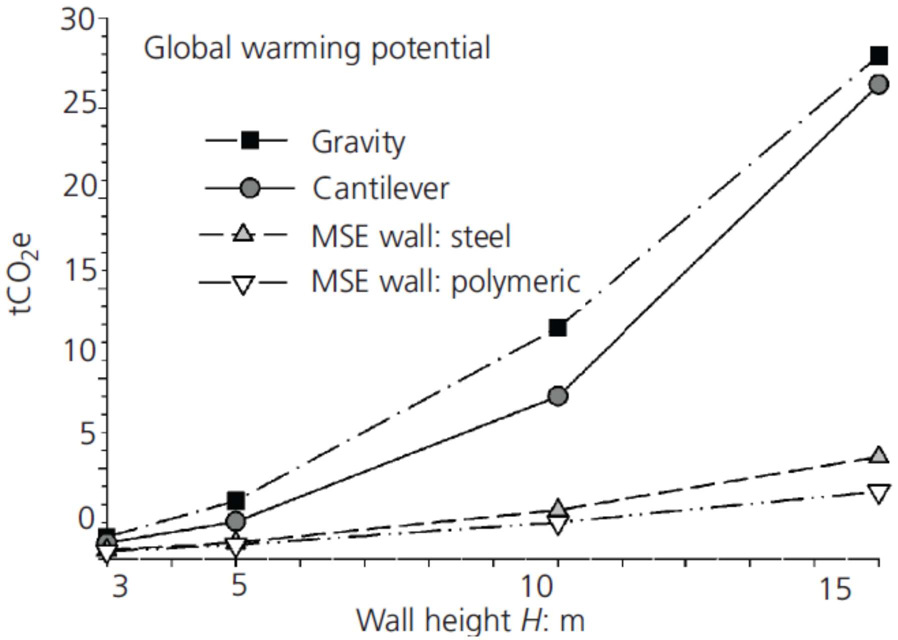
GRI Report #40

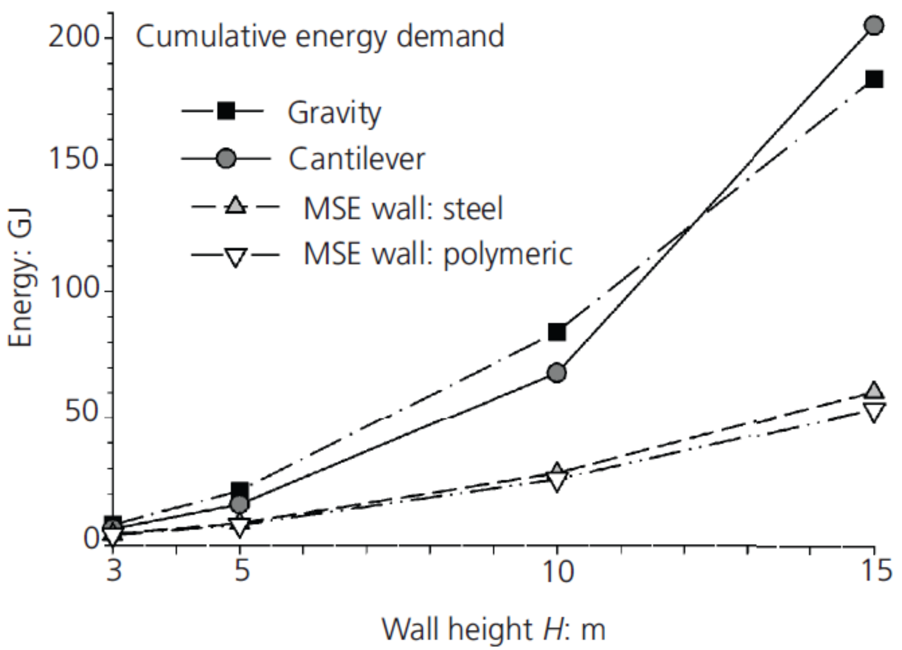


Damians et al.

Introduction

Environmental comparison





Damians et al.

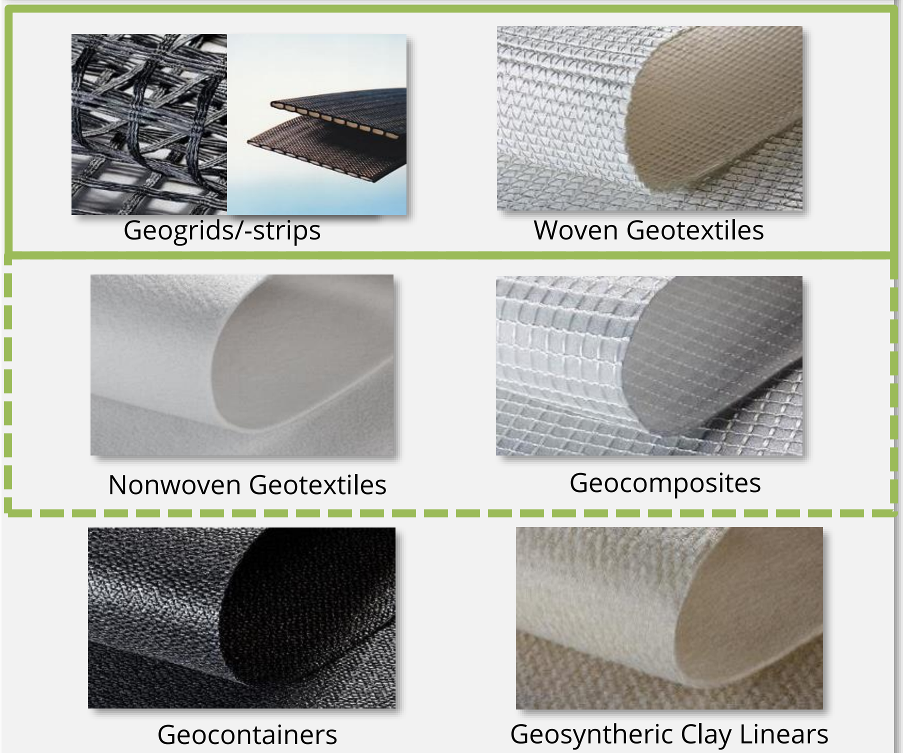
Introduction

Components of reinforced soil

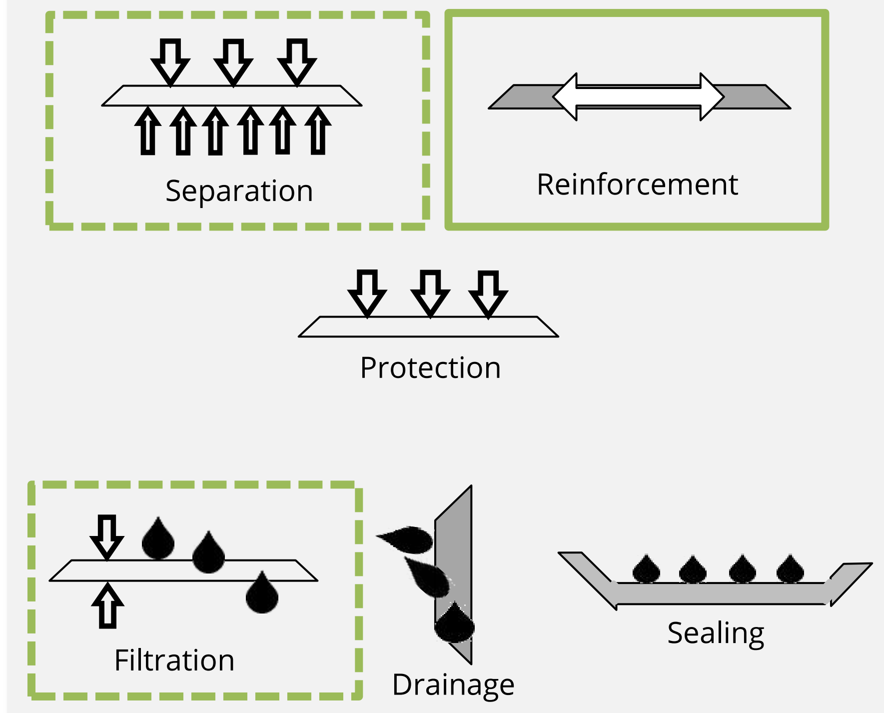
Components	Soils / Fill materials	Reinforcements	Drainage	Facing / Erosion Protection
				Passive
				Active

Introduction

Geosynthetics



Functions



Introduction

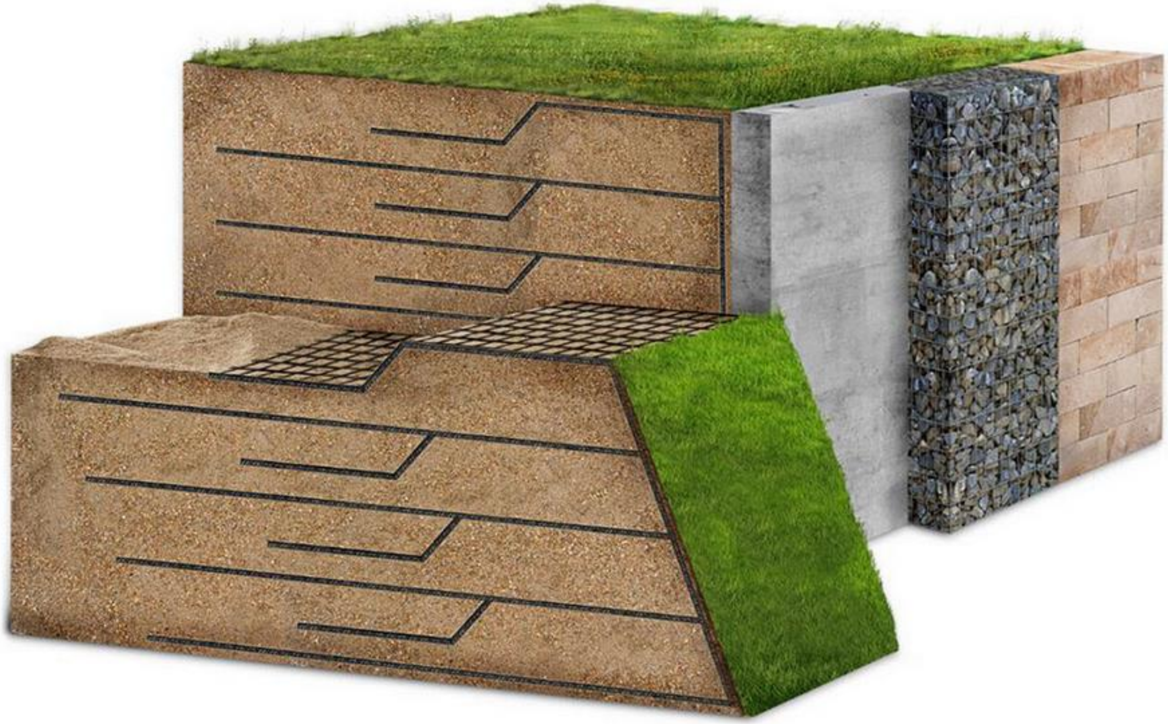
Reinforcement components

Tensile Strength + **Interaction** + **Tensile Stiffness**

- Tensile Strength: Compensation of the strength deficit in the earth structure by accommodating tensile stresses
- Interaction: Activation of the geogrid, which allows it to take forces from the soil and to transfer forces into the soil
- Tensile Stiffness: Mobilization of forces under compatible deformations

Sufficient strength + Good interaction + Sufficient stiffness = **Optimal & safe structure**

Overview of systems

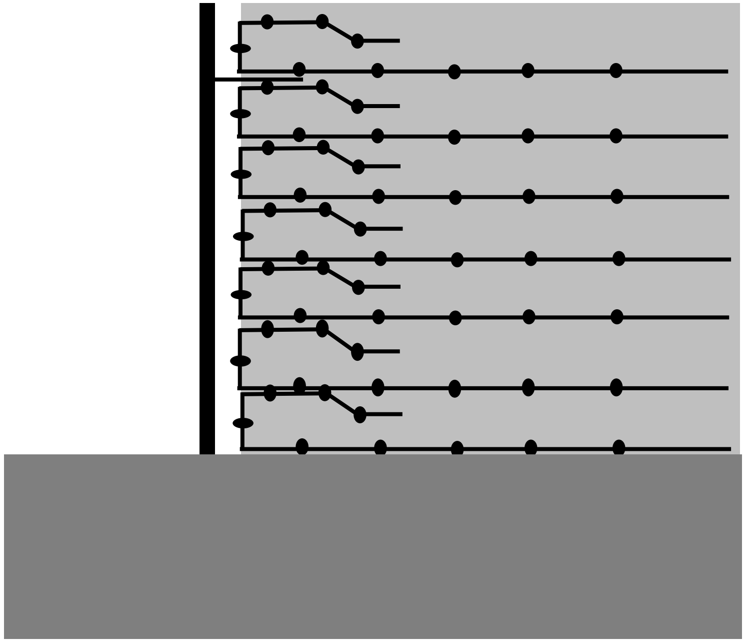


Facing

- Protection
  - Fire
  - UV- radiation
  - Vandalism
- Visible part of GRE
  - Appearance
  - Acceptance
  - Costs

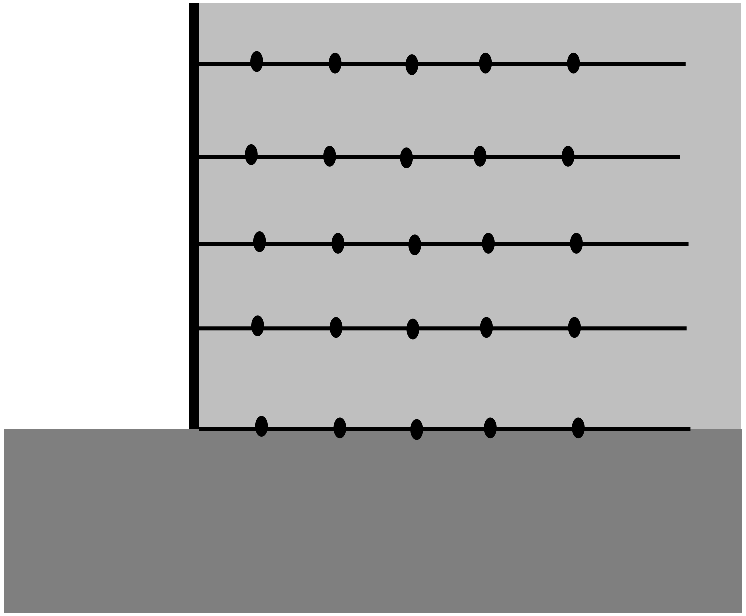
Facing

Passive



- No earth pressure is transferred to facing
- Facing can be attached after consolidation settlements of the wall itself

Active



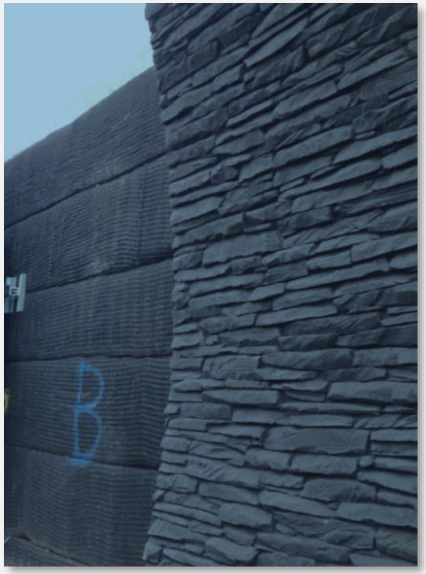
- Earth pressure is transferred to facing
- Facing (elements) are used as formwork during construction

Facing

Panel connections - Examples

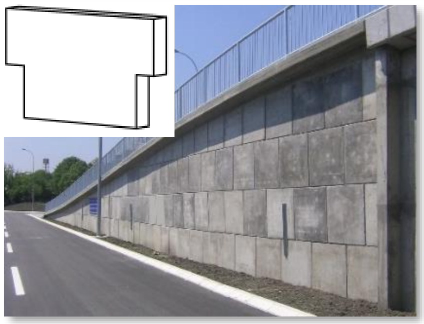
Active

Passive

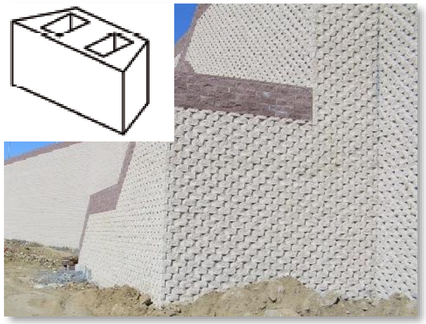


Facing

Panels

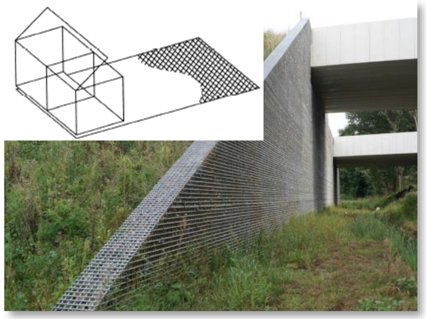


Blocks



Green walls

Gabions



Costs

1 м^2 geogrids

1 м^2 facing

Construction methods

Typical/selceted systems

Temporary formwork

Facing elements

Lost formwork

Active panels

Construction methods

Temporary formwork

Construction methods

Temporary formwork

1. Prepare planum
   Set-up formwork
2. Place geogrid
3. Place erosion protection
4. First layer
5. Front area
6. Wrap back
7. Complete second layer
8. Rearrange formwork and Point 1 – 7
9. Finished wall

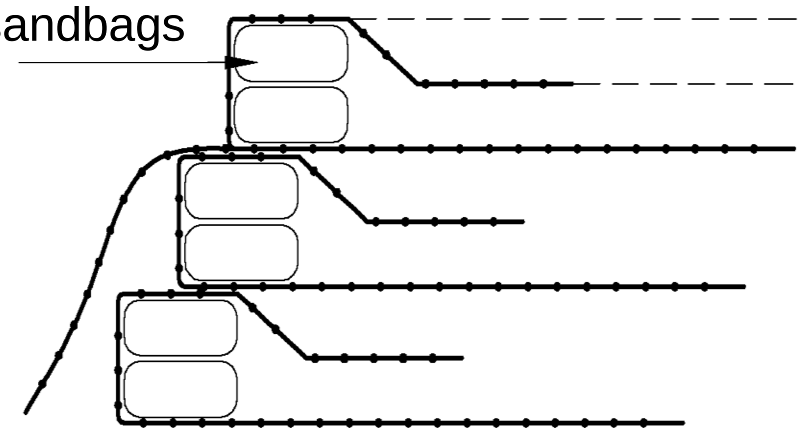
Construction methods

Facing Elements

1. Prepare planum Bedding
2. Placing geogrid and blocks
3. Leveling
4. Fill and compaction
5. Fill and compaction
6. Point 2-5
7. Finished wall

Construction methods

Lost formwork



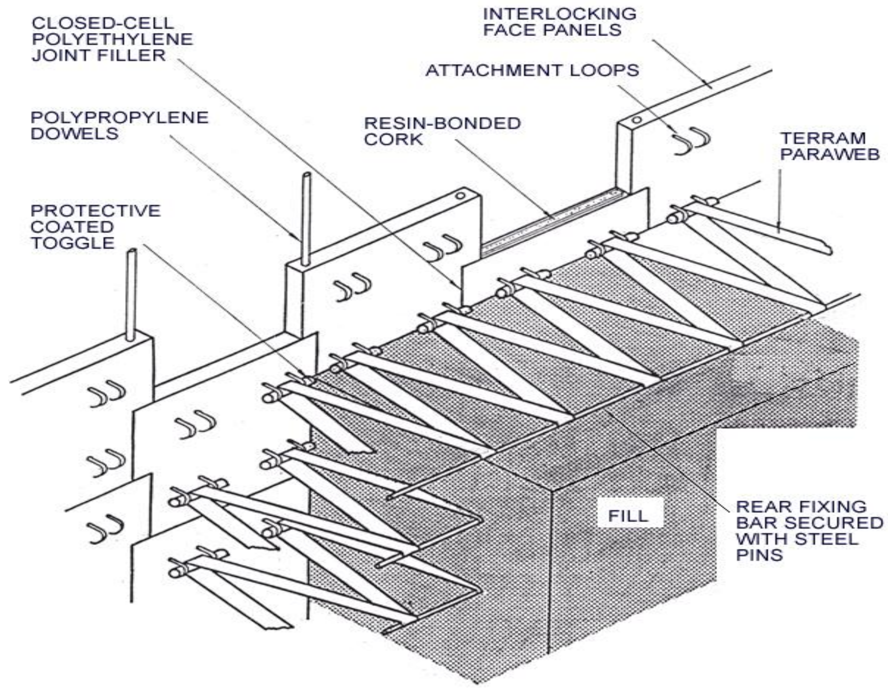
Construction methods

Lost formwork

1. Prepar planum
   Set-up formwork
2. Place erosion protection
3. Place geogrid
4. First layer
5. Front area
6. Wrap back
7. Wrap back erosion protection
8. Complete second layer
9. Point 1 – 8
10. Finished wall

Construction methods

Active concrete panels with geostrips



Construction methods

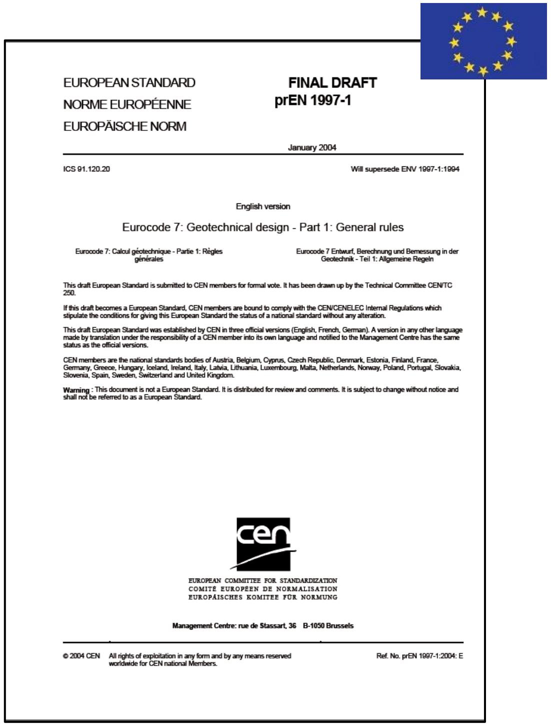
Active concrete panels with geostrips

1. Prepar planum Set-up formwork
2. Panel foundation
3. Panel placing
4. Geostrip connecting
5. Geotrip anchoring at the back
6. Compaction
7. Finished wall

Design

Guidelines – EN 1997 Geotechnical Design

- Partial Safety Factor Concept
  - resisting forces are decreased
  - driving forces are increased
  - degree of utilization $\mu < 1.0$
- Ultimate Limit State (ULS)
  - Structural and geotechnical failure
- Serviceability Limit State (SLS)
  - Intolerable deformations



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

FINAL DRAFT
prEN 1997-1

January 2004

ICS 91.120.20

Will supersede ENV 1997-1:1994

English version

Eurocode 7: Geotechnical design - Part 1: General rules

Eurocode 7: Calcul géotechnique - Partie 1: Règles générales

Eurocode 7 Entwurf, Berechnung und Bemessung in der Geotechnik - Teil 1: Allgemeine Regeln

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If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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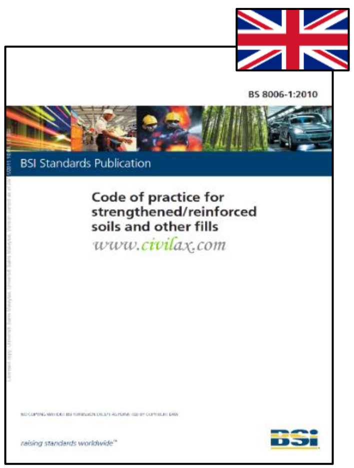
EUROPÄISCHES KOMITEE FÜR NORMUNG

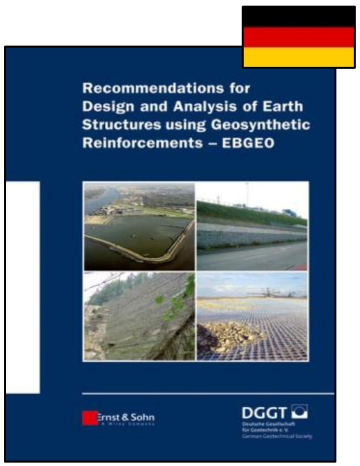
Management Centre: rue de Stassart, 36 B-1050 Brussels

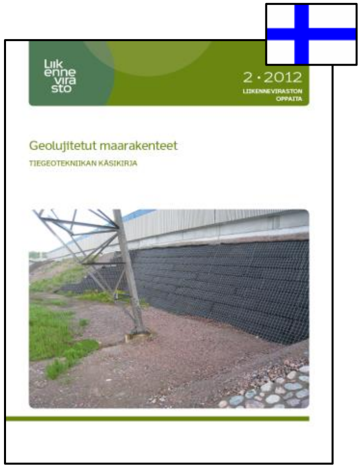
Ref. No. prEN 1997-1:2004: E

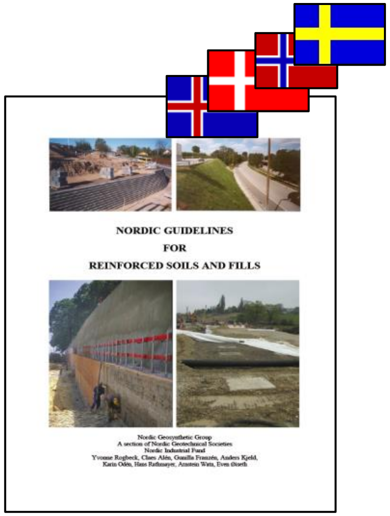
Design

Guidelines dealing with geosynthetics









Design

Failure modes (e.g. according to EBGEO)

- ULS
  - Pull out of reinforcement
  - Rupture of reinforcement
  - Slope stability
  - Facing failure
  - Bearing capacity
  - Overturning
  - Sliding
- SLS
  - Deformation and settlements

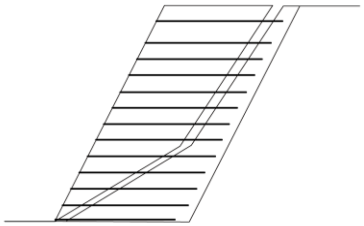


Fig. 1: Pull out

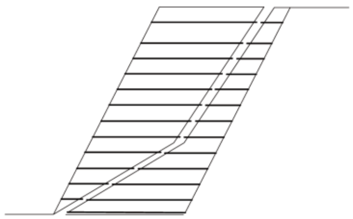


Fig. 2: Rupture of reinforcement

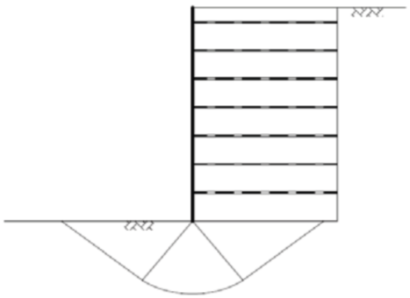


Fig. 3: Bearing Capacity

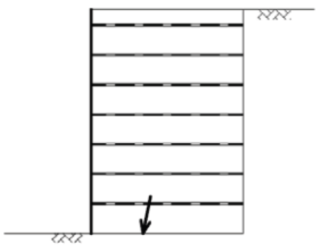


Fig. 4: Overturning

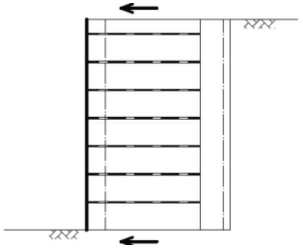


Fig. 5: Sliding

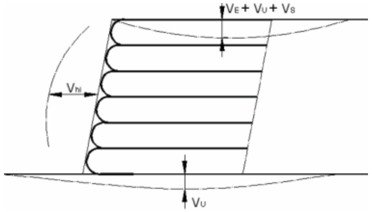


Fig. 6: Settlements

Design

Slope stability analysis

- Failure Lines
  - Internal
  - External / global
  - Compound
- Calculation methods
  - Janbu
  - Bishop
  - Vertical Slice
  - Etc….

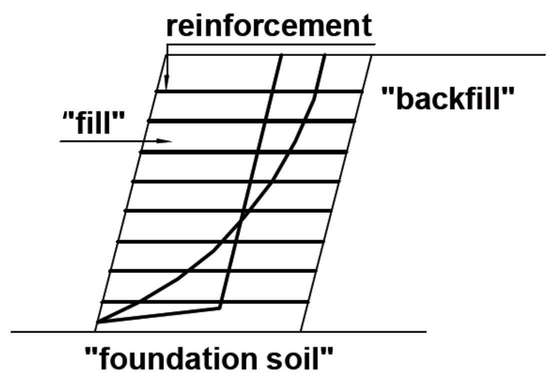


Fig. 1: Internal failure lines

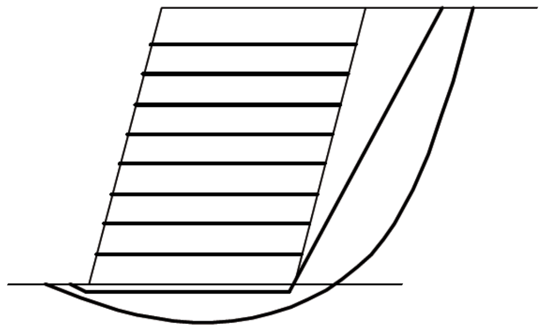


Fig. 2: External / global failure lines

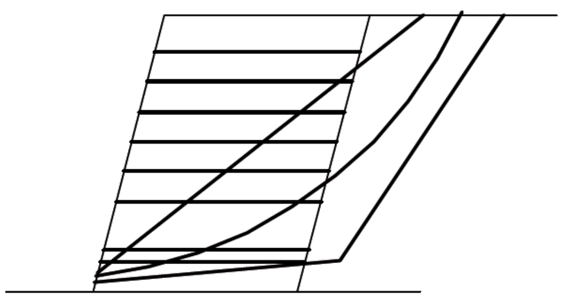
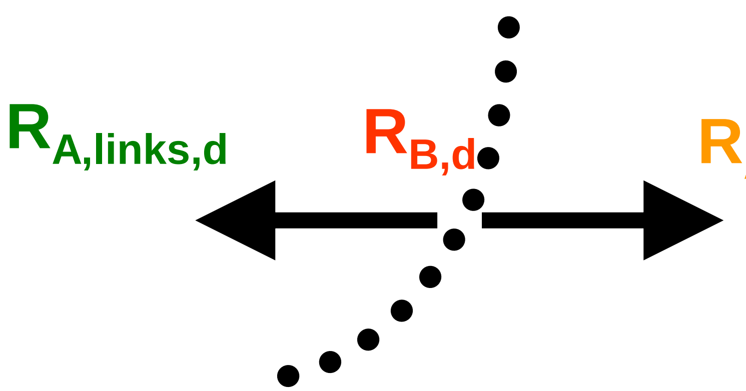


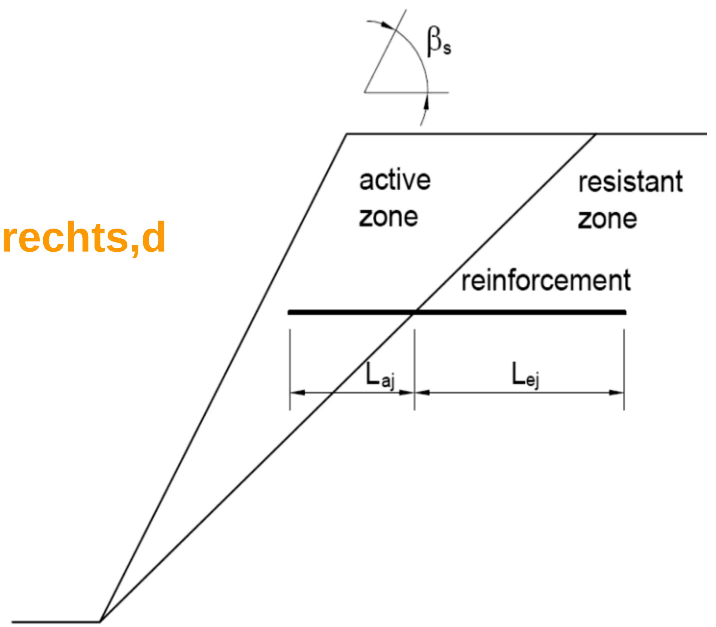
Fig. 3: Compound faillure lines

Design

Consideration of geosynthetic contribution in the design



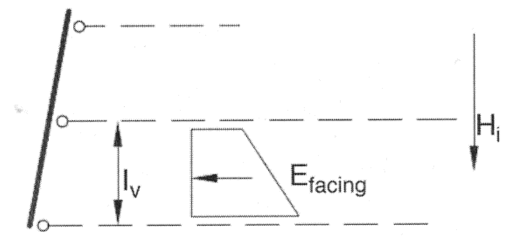
Smallest value is decisive.



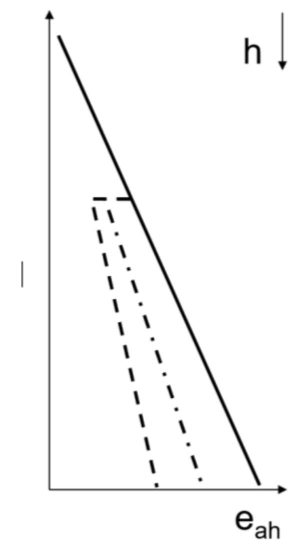
Design

Connection → Analysis of Facing Elements in acc. with EBGEO

- $R_{b,i}$ or $R_{Ai,d} \geq E_{facing}$
  - $E_{facing} = e_{facing} \cdot l_v$
  - $e_{facing} = \eta_g \cdot K_{agh,k} \cdot \gamma_k \cdot H \cdot \gamma_G + \eta_q \cdot K_{aqh,k} \cdot q \cdot \gamma_Q$



- $R_{Ai,d}$ – design value of the entire **pull-out resistance provided by friction or as connection force** (design value determining using γ_{B})
- $R_{b,i}$ – design value of the long-term tensile strength of the geosynthetics in the n^{th} reinforcement layer

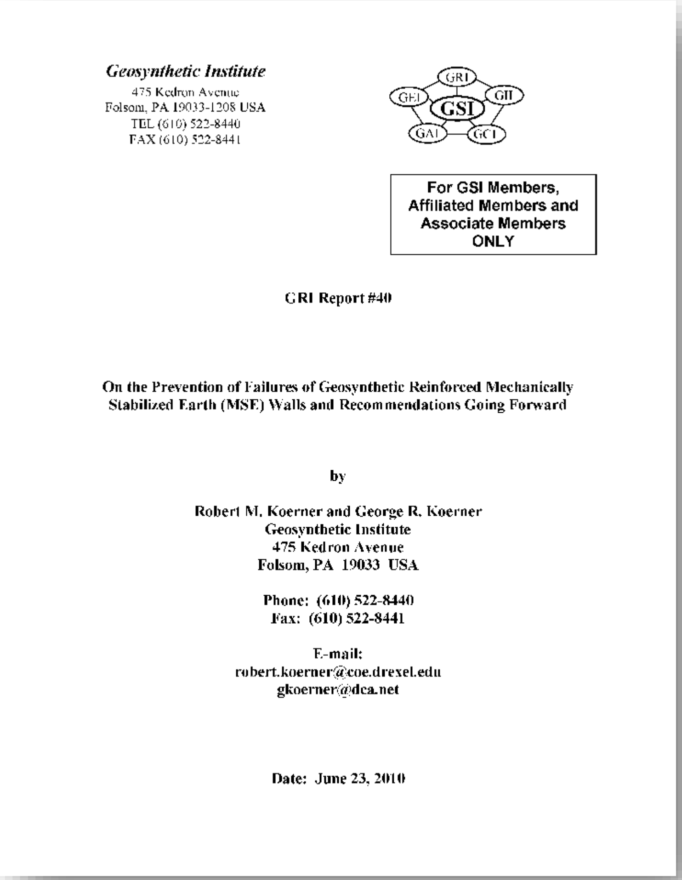


		Calibration factor			Earth pressure angle
		η_g		η_q	δ
		$0 < h \leq 0.4\ H$	$0.4\ H < h \leq H$		
——	Non-deformable facing elements	1.0	1.0	1.0	Analogous to DIN 4085
— · -	Partially deformable facing elements	1.0	0.7	1.0	1/3 φ' to 1.0 φ'
- - -	Deformable facing elements	1.0	0.5	1.0	0.0

Design

Drainage

- Study of the Geosynthetic Research Institutes GSI (USA)
- *On the Prevention of Failures of Geosynthetic Reinforced Mechanically Stabilized (MSE) Walls and Recommendations Going Forward*
- GRI Report #40



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For GSI Members, Affiliated Members and Associate Members ONLY

GRI Report #40

On the Prevention of Failures of Geosynthetic Reinforced Mechanically Stabilized Earth (MSE) Walls and Recommendations Going Forward

by

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Date: June 23, 2010

Design

Drainage

GRI report 40 → Analysis of 171 failures of GRS structures

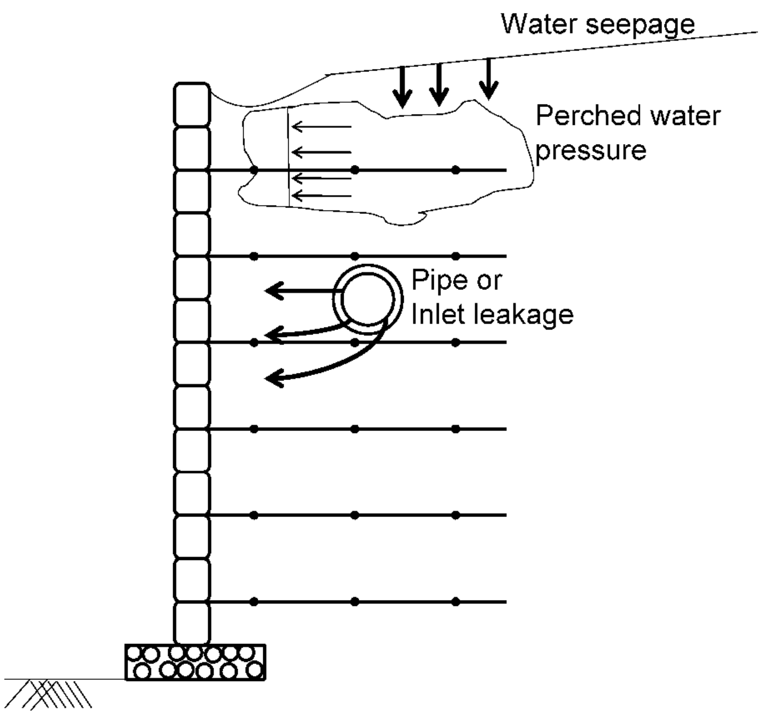
Damage pattern SLS/ULS	74% ULS / 26 % SLS
Compaction Achieved	72% poor to moderate
Quality of fill soil cohesive/rolly	61% cohesive soils used
Drainage	***60% inadequate drainage***
Improper planning	98%

Private/public builder 96% private

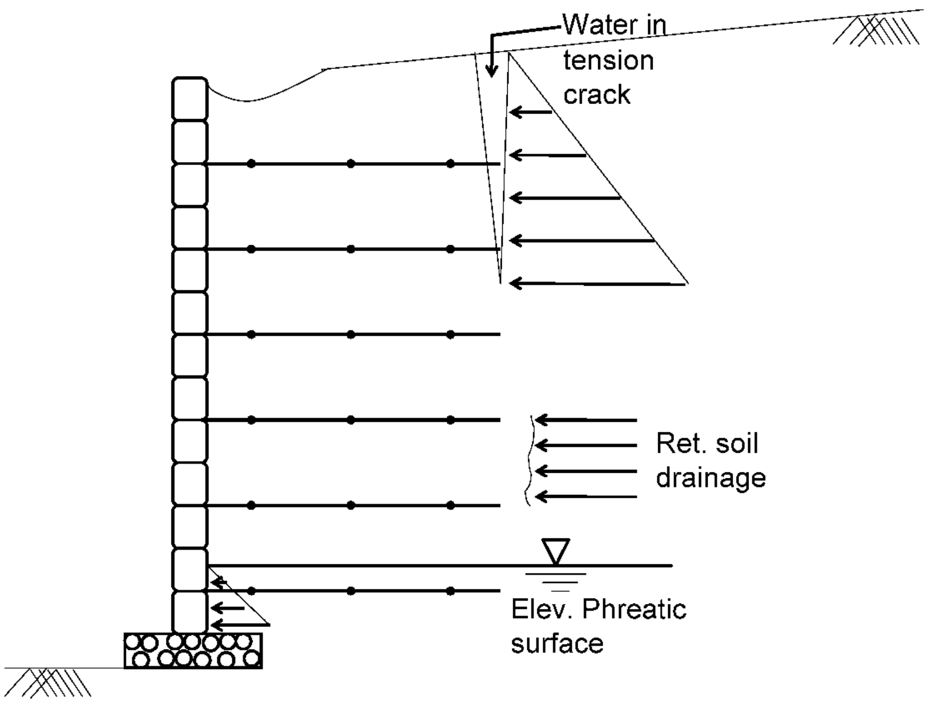
Cause of damage is NOT the geosynthetic as a building material

Design

Drainage



(c) Internal water; 38 cases (46%)



(e) External water; 18 cases (22%)

GRI Report #40

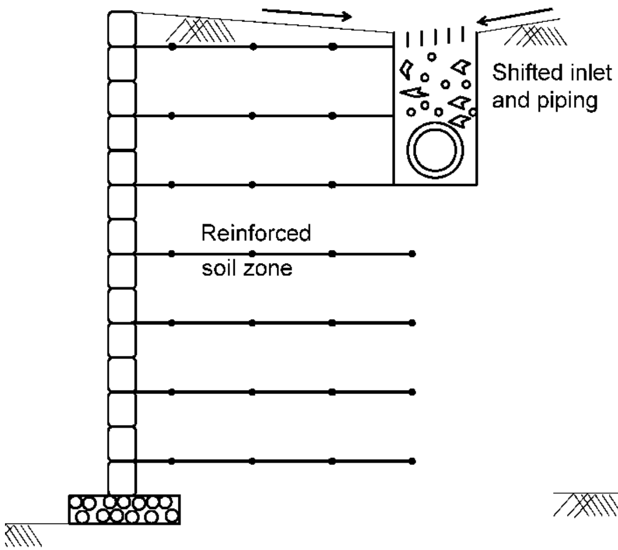
Design

Drainage

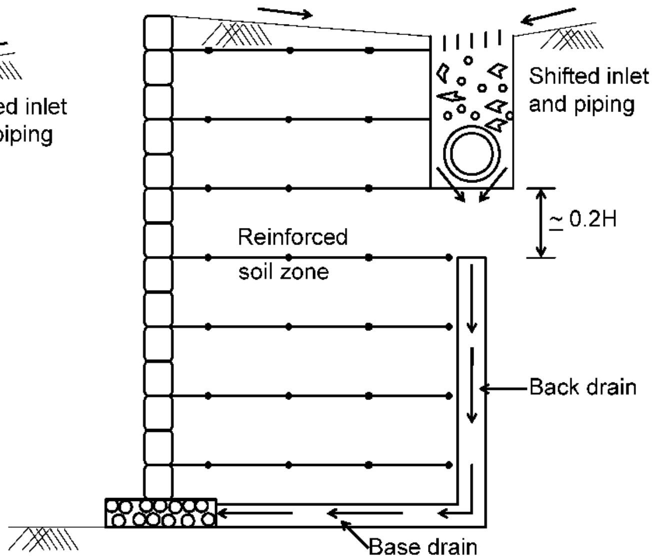
GRI Report #40

Design

Drainage



(b) Recommended external drainage for surface water behind reinforced soil zone



(c) Recommended external drainage for surface water coupled with back/base drain

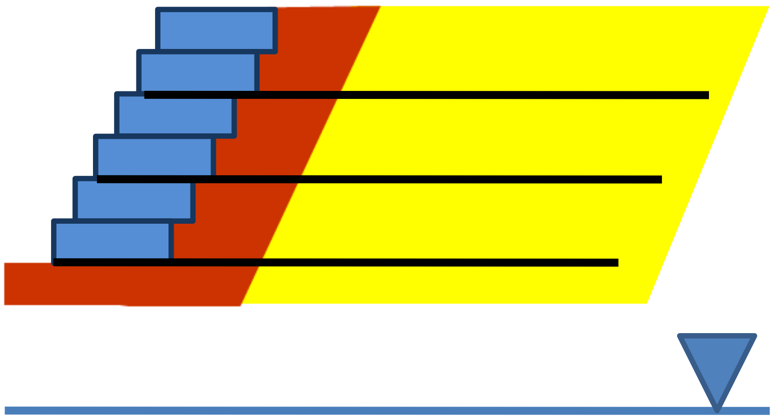
GRI Report #40

Design

Drainage

When and where?

Case 1



Wall face drain

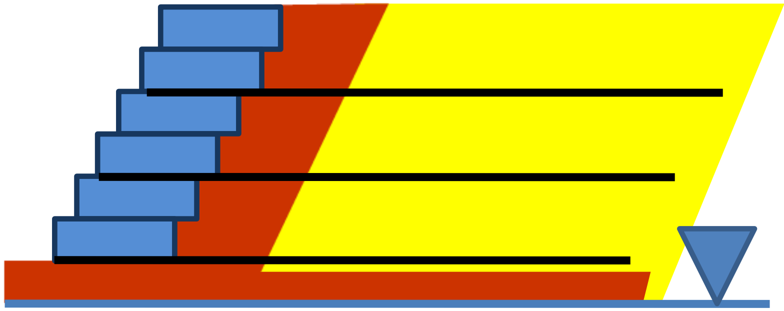
- Groundwater permanent below bottom of wall
- No horizontal groundwater flow into infill and retained soils

Design

Drainage

When and where?

Case 2



Wall face and bottom drain

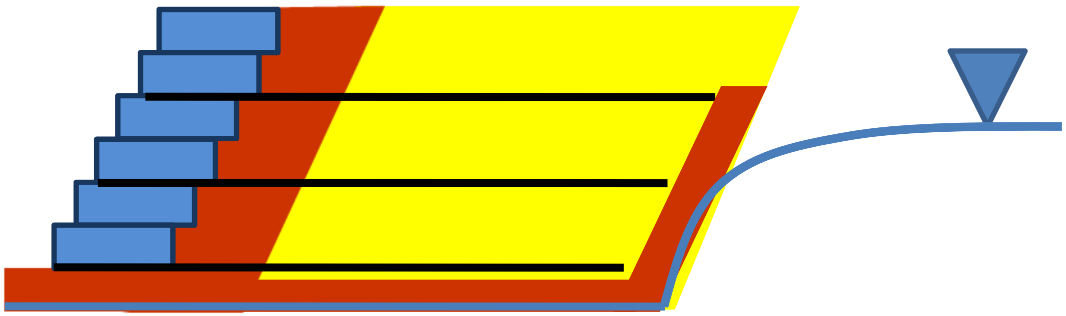
- Groundwater near bottom and possible rise (e.g. heavy rain)

Design

Drainage

When and where?

Case 3



Groundwater level

Complete drainage system

• Groundwater near bottom and possible rise (e.g. heavy rain)

•Horizontal groundwater will flow into infill and retained soils

Should be used if groundwater situation is not known or if there uncertainties

Design

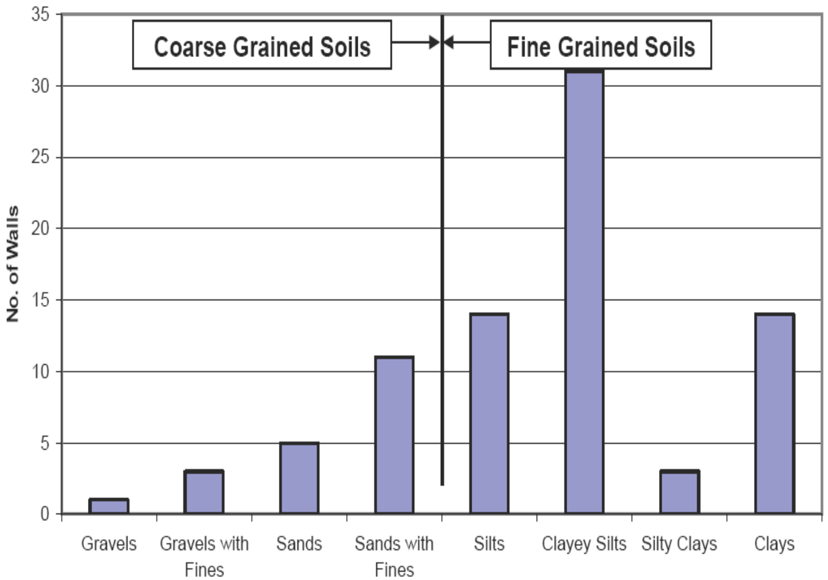
Use of marginal fill

- 98% wrong design
- 96% private project owner
- **61% cohesive material**
- 60% drainage
- 50% poor compaction

Conclusion?

- Do not built with marginal fill?

No necessarily, BUT be aware about the properties, special boundary conditions and limitations!



Failure distribution over soil type

GRI Report #40

Design

What do we consider as “marginal fill”?

- Recycling material (e.g. crushed concrete or similar)
  - Good shear parameters
  - Good stiffness parameters
  - Chemical composition (e.g. pH-value)?
- Contaminated granular material
  - Good shear parameters
  - Good stiffness parameters
  - Chemical composition (e.g. pH-value)?
- Cohesive material
  - Moderate to bad shear parameters
  - Stiffness from very stiff to very soft
  - Characteristics highly dependent on water content
- Mixture of above
- (soils with significant content of organic matter e.g. peat)

Design

Why should marginal fill be used at all?

- Availability of 'good' granular fill material
- (Local) availability of marginal fill material
  - Very cost efficient
  - No disposal of marginal fill necessary
  - No transport over large distance required
- Sustainable use of existing resources

Design

What is the difference and challenge?

- Cohesive marginal fill
  - Low friction angle
  - Cohesion, which should no be considered in the design
  - Stiffness highly depending on water level → deformation possible
  - Compaction (50% failure due to bad compaction!)
- For all
  - Chemical composition
    (→ durability of reinforcement)

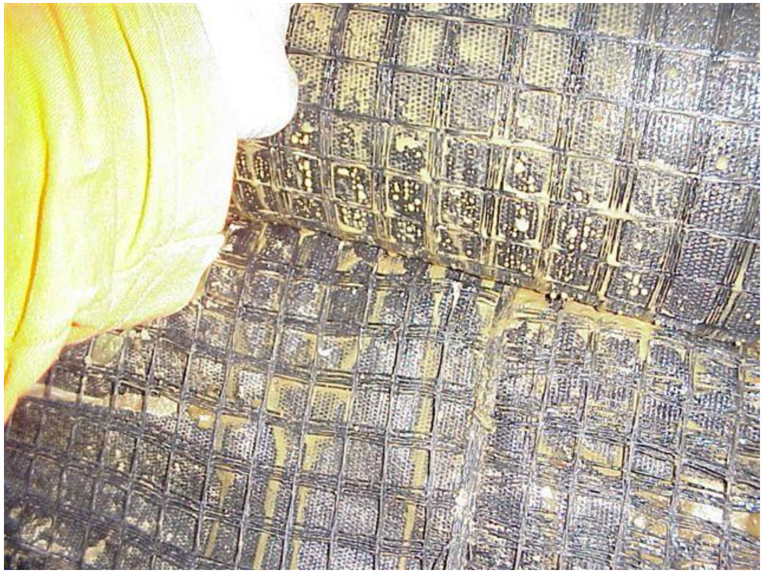
Design

What is important in the use of GRS?

- Shear strength
  - Shear strength deficit can be compensated by a geosynthetic reinforcement, if…
- Interaction behavior
  - …there is a sufficient interaction / load transfer capability between the fill and reinforcement
- Stiffness of the structure / deformation behavior
- Water content dependent material behavior

Design

What is important in the use of GRS?

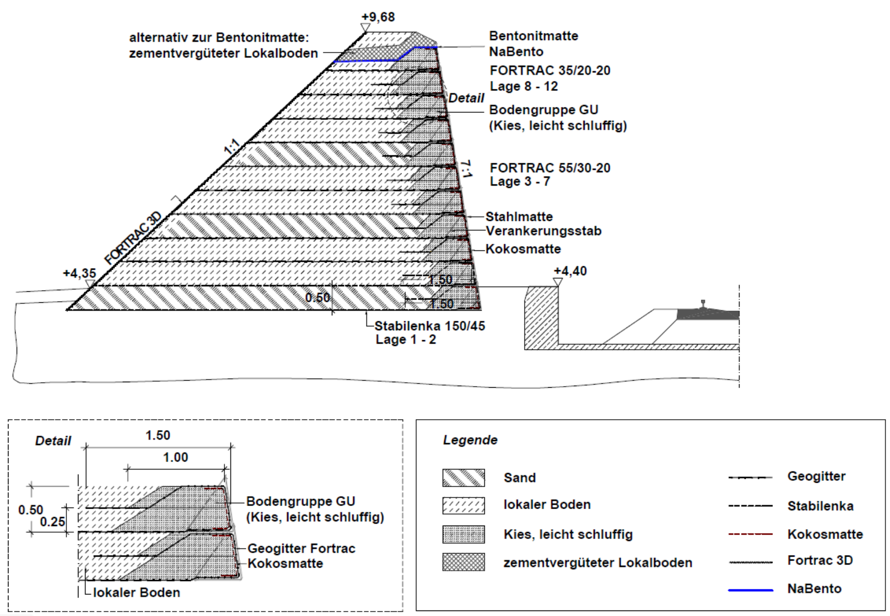


GRS with Silt als fill material: ULS ok but SLS?
Without additional measures deformation are very likely to happen

Design

How to construct with marginal cohesive fill?

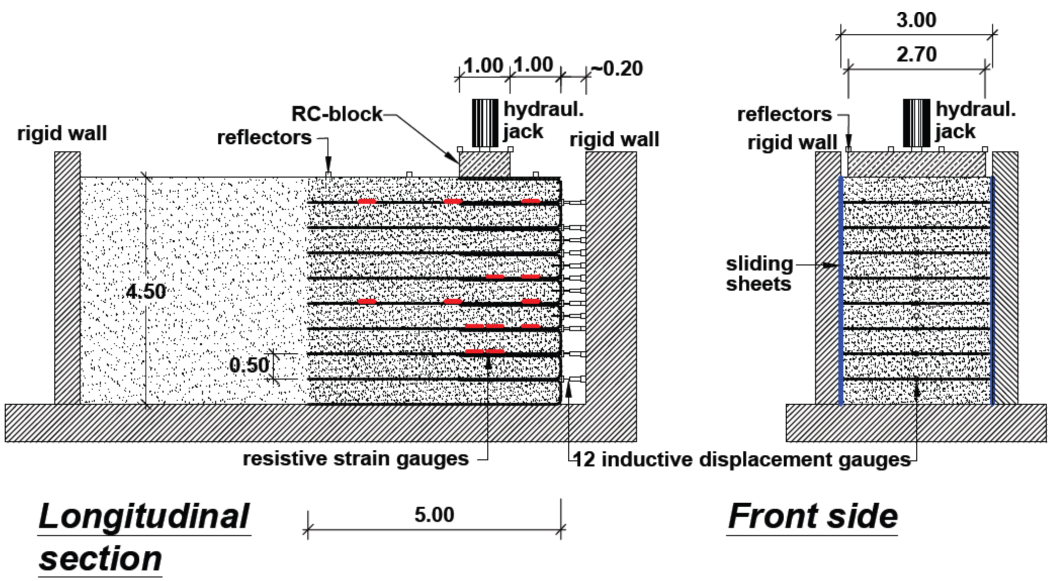
- Arrangement of intermediate frictional layers
  - Increase shear strength
  - Drainage for consolidation and rain events
- Use of high frictional material in the front
- Use of stable front elements like bended steel meshes
- Prevent water infiltration
- Use of cement to improve the properties of the marginal fill



Load bearing behaviour

High loads

- Large-scale test LGA, Nürnberg
- 4.5 m high GRS loaded by max. 600 kPa (3 x usual loads for bridge super structures and traffic)



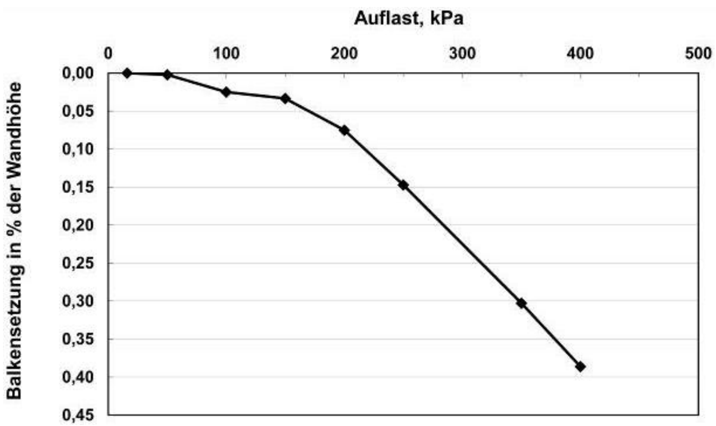
Load bearing behaviour

High loads

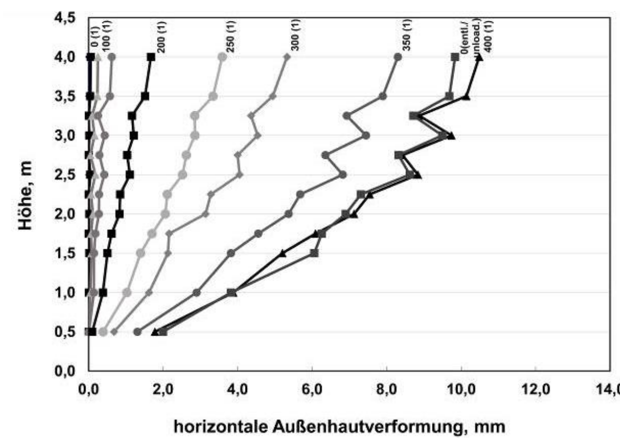
Load bearing behaviour

High loads

- Large-scale test LGA, Nürnberg
- Max. vertical settlements 18 mm
- Max. horizontal deformation 10 mm



Results, settlements of concrete beam



Results, horizontal deformation at the GRS face

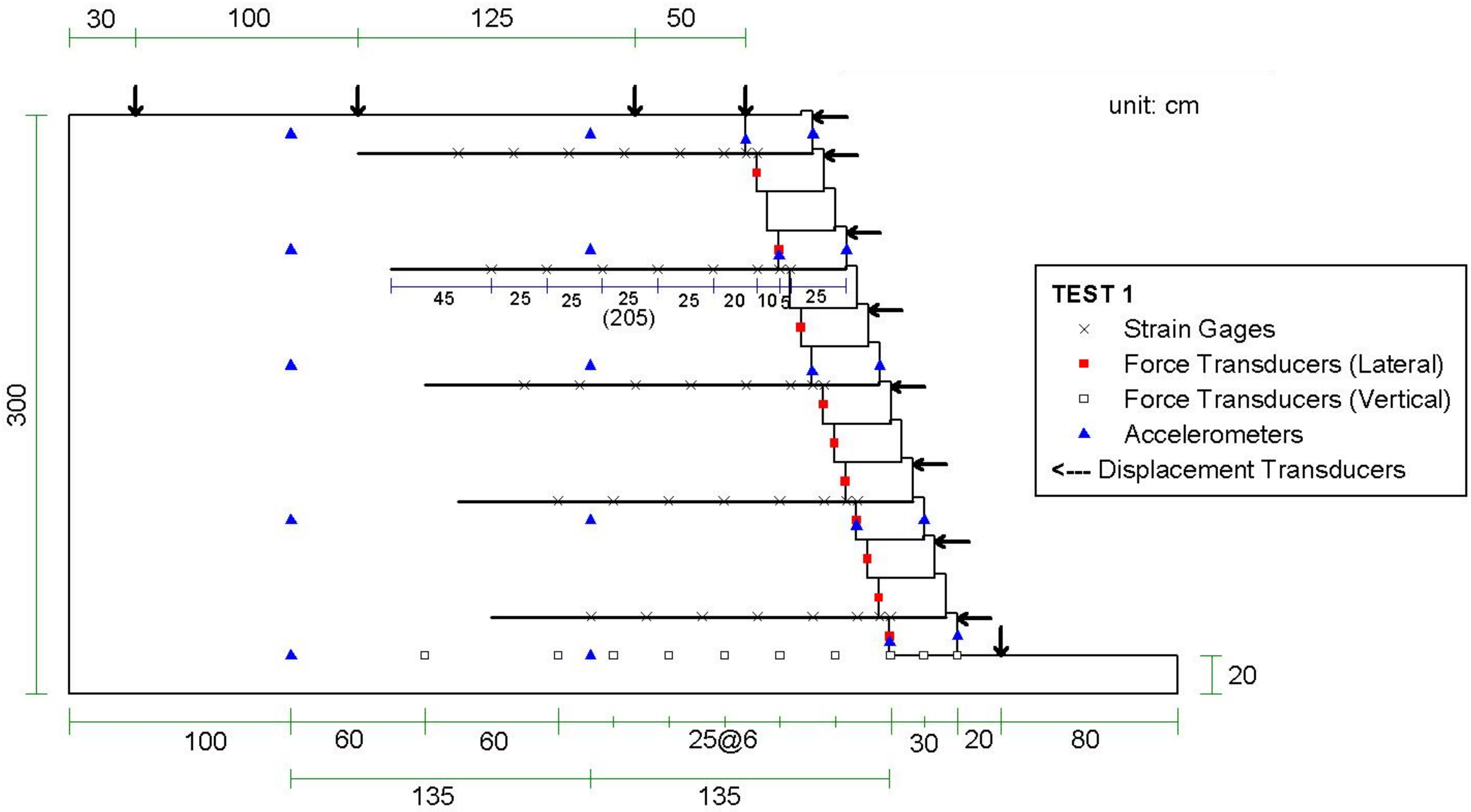
Load bearing behaviour

Seismic loads

- Series of Seven Tests
- Wall Height of 2.8 m
- Tests 1-4 Sand
- Tests 5-7 Silt
- Horizontal Accelerations 0.4g and 0.8g (Kobe Earthquake)

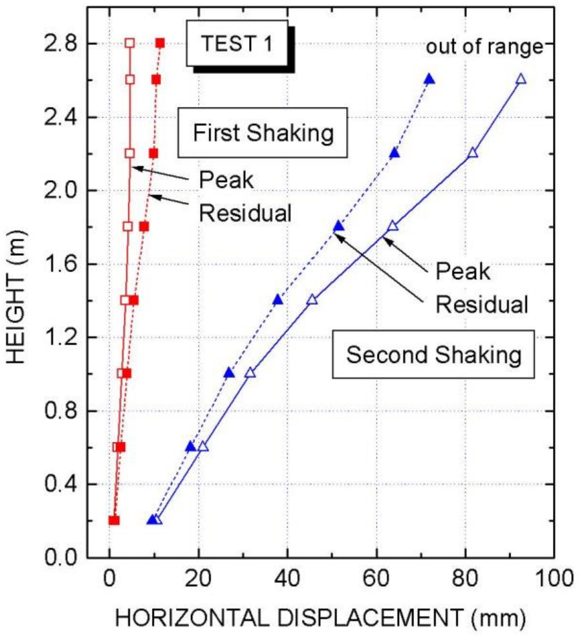
Load bearing behaviour

Seismic loads



Load bearing behaviour

Seismic loads



Load bearing behaviour

Seismic loads

Load bearing behaviour

Seismic loads

Case studies

Rehabilitation DB Section Heidenau – Altenberg "Müglitztalbahn", 2002 (Germany)

Case studies

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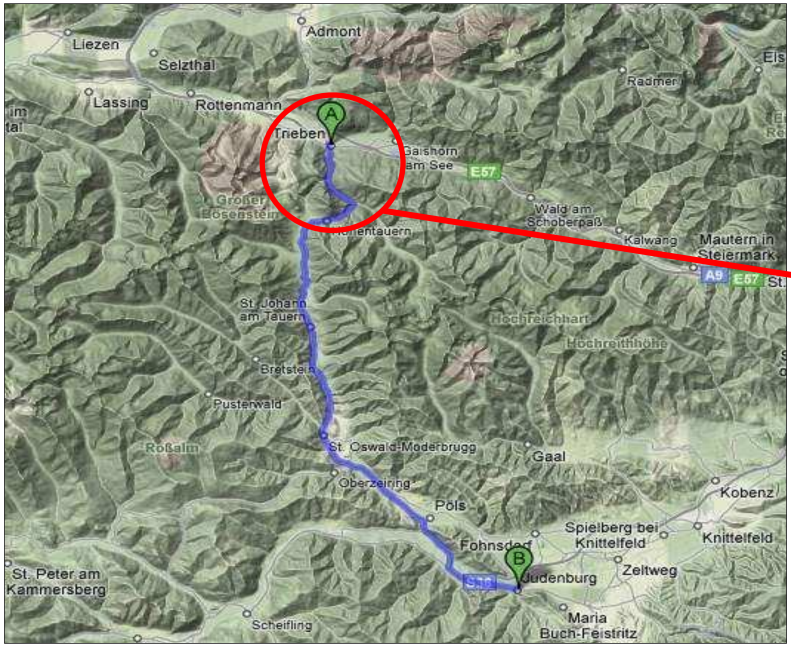
Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

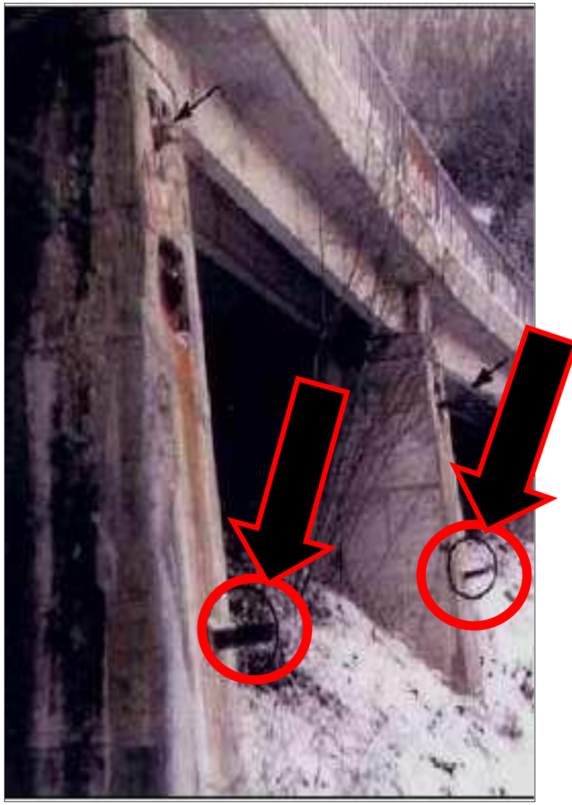


Focus on this section close to Trieben

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

- Permanent slope movement
  - Damage on retaining structures
  - Rupture of anchors to back-anchor bridges
  - Complex and cost-intensive maintenance works
  - 2 m asphalt layer due to compensation of settlements



Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

- Up to 20% road inclination → dangerous, especially in the winter time
- 1991 bad bus accident with several dead people

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

- Acute danger of large-scale landslide
  - GPS monitoring of the road → Blocking possible at anytime
- Due to the situation at that time different options have been investigated
  - Continuation of maintenance works on existing road
  - Construction of new road
    - tunnel
    - supported on embankments on the other side of the valley

Case studies

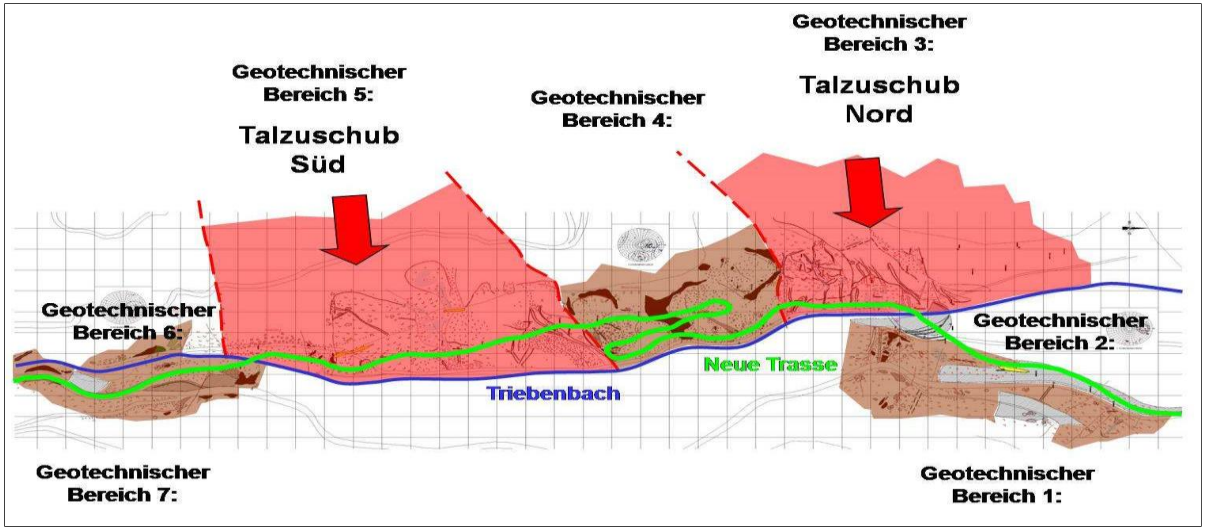
New construction of the B114 to connect Trieben and Judenburg (Austria)

- Problematic area
  - Steep terrain
  - Avalanches and landslides
  - Creep-prone slopes
- Estimated Traffic (2008)
  - 2000 vehicles/24h
  - 9% heavy-goods vehicles

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

- New road to be built
- Construction on opposite hillside (slopes are also prone to creep)
- Reduction of inclination by serpentines
- Direct crossing of creep prone areas
- Traffic can run during construction on old road



Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Cut areas

- Rock areas
  - Shotcrete plus anchors in a „2 m x 2 m“ pattern
- Loss rock areas
  - Temporary securement by shotcrete
  - Permanent back-anchored by up to 28 m long anchors for working loads of 400 kN

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

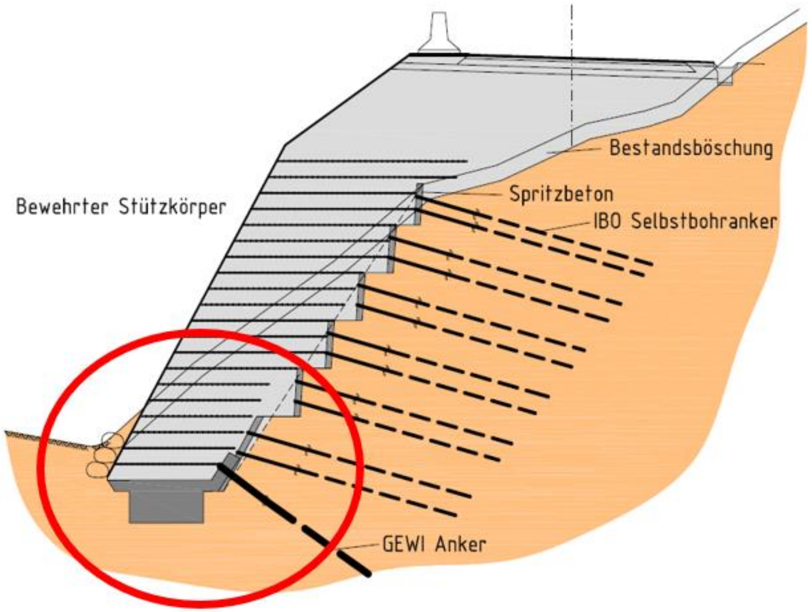
Geogrid reinforced embankments in fill areas

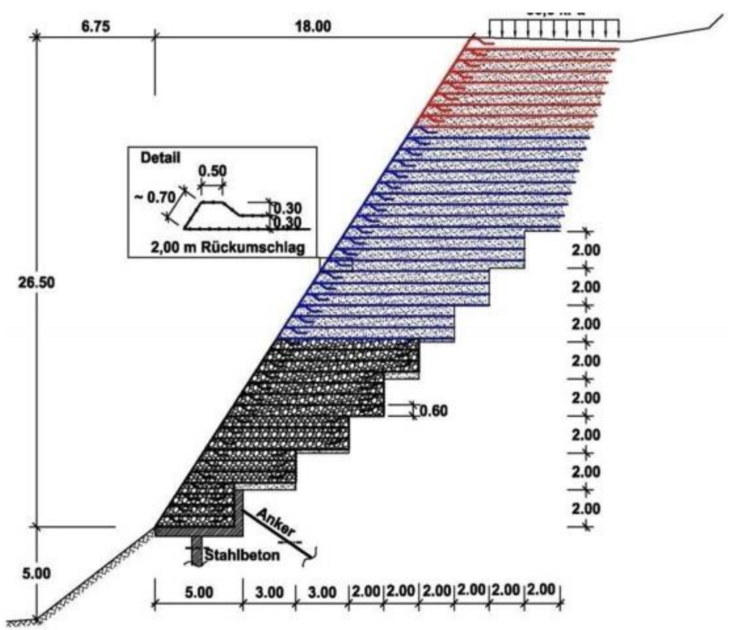
- Due to previous experience a flexible solution was preferred
  - Geotextile reinforced embankments
  - Able to compensate deformation to a certain extent without damage
- Highest Embankments at that time in Austria with this technology (max. 28 m)

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

- Stable base construction to secure global stability

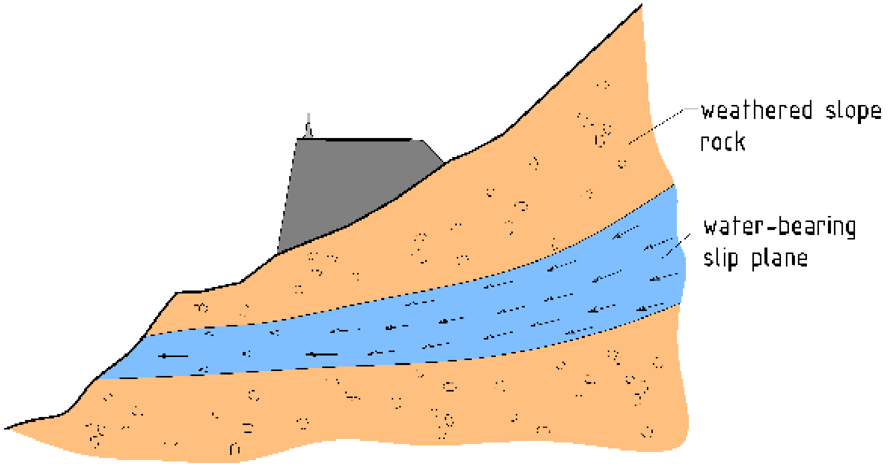




Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

- Drainage of water-bearing potential slip plane



Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Construction sequence

Preparation of stable base by means of back anchored concrete blocks

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Construction sequence

Preparation of reinforcement at central place. Easy and space-saving transportation of folded reinforcements.

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Construction sequence

Placement of lost formwork, reinforcement and erosion protection in the front.

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Construction sequence

Use of local material for wall construction.

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Construction sequence

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Construction sequence

Case studies

New construction of the B114 to connect Trieben and Judenburg (Austria)

Construction sequence

Conclusion

- Geosynthetic reinforced structures are used to construct steep slopes and vertical walls

- Design of GRS in Europa is regulated acc. to EC 7 with several national guidelines (CUR, BS, EBGEO, Nordic Guideline,…)

- Adaption for special and individual requirements possible
  - Facing, high loads, rock operations, pipes or culverts, seismic impact, geometry, sealing, renovation, etc…

- Ecological friendly → reduced C02-footprint in comparison to alterantiv solutions

Thank you!

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