Reinforced Fills with Geosynthetics

Design and application overview

Jeroen Smet
Dave Woods
Reinforced Fills with Geosynthetics

- Introduction to reinforced soil concept
- Eurocodes and design guidance
- Principles of design
  - Finishing options
  - Soil selection
  - Loading
  - Design Parameters
  - External Stability
  - Internal Stability
- Design Software
- Materials Testing
- Structural Monitoring
Soil is strong in compression and weak in tension so the addition of a thin tensile layer helps to disperse the lateral strain generated in the soil by the compressive force.

The tension within the reinforcement is mobilised by a combination of skin friction, granular interlock and potentially bearing on cross members.

For reinforcement to work optimally the soil needs to strain to a similar degree to the reinforcement at peak force: Strain Compatibility
Basics - Natural slope angle of a material

<table>
<thead>
<tr>
<th>soil</th>
<th>$\Phi$ (phi)</th>
<th>Slope (V : H )</th>
</tr>
</thead>
<tbody>
<tr>
<td>fine sand</td>
<td>26.5</td>
<td>1 : 2</td>
</tr>
<tr>
<td>coarse sand</td>
<td>30°</td>
<td>1 : 1.7</td>
</tr>
<tr>
<td>sandy gravel</td>
<td>34°</td>
<td>1 : 1.5</td>
</tr>
<tr>
<td>Clay</td>
<td>17.5°</td>
<td>1 : 3.2</td>
</tr>
<tr>
<td>Peat</td>
<td>15°</td>
<td>1 : 3.5</td>
</tr>
</tbody>
</table>
Scope of designed structures

- Natural slopes: $\beta < \phi$
  
  No need of soil reinforcement

- Reinforced structures
  
  Steep slopes: Slope angle of $\phi < \beta \leq 76^\circ$

  Retaining walls: Slope angle $= 76^\circ < \beta \leq 90^\circ$
Conventional gravity structures are externally stabilised solutions which work against the soil’s self weight. Reinforced soil solutions are internally stabilised using the soil’s self weight to generate the tensile forces in the reinforcement which bond the hybrid mass together.
A Simple Concept
A Simple Concept
Principle of soil reinforcement

- Casagrande: Modern reinforced soil techniques in 1938
  - Layering strong tensile materials

- Henri Vidal: “Terre Armé” in the 1960s
  - Horizontal tensile elements in frictional soil
  - Weight of material provides friction
Modern reinforced earth started in the late 60s “invented” by Henri Vidal who patented the term.
New Materials / Old Techniques

- Early construction used steel strips and meshes and reinforced concrete panels, materials familiar to all Engineers.

- Familiar problems too
The Earliest Man made Structures?

Ziggurats of ancient Babylon, Iraq
The Earliest Man made Structures?
Brief history of Enka-brand products in earth walls

1977 - Ht = 10 m, L = 50 m - Huesker / Akzo Nobel (Stabilenka)

33 years later...
Eurocodes (EC)

Eurocodes are the basis of structural design, published as separate European standards:

- Applied to all building materials: concrete (EC2), steel (EC3), wood (EC5), masonry (EC6), geotechnical design (EC7), Earthquake resistance (EC8)...

- Thanks to these common rules for European Community, it is easier for all engineering offices to compare and check the designs proposed by the contractors and their suppliers.

- Member states consider these rules as basis documents to prove the compliance of the construction works with essential requirements of the directive 89/106/EEC of the Council of European Communities, particularly the requirement n°1 – Mechanical resistance and stability.

- The Eurocodes therefore replaced the existing national building codes published by national standard bodies, although many countries had a period of co-existence until 2010.

- Some other countries like Moroccan authorities specify these European rules.

Eurocodes are based on a Limit States Design (ULS & SLS) method taking into account reduction factors as defined in the EC0 (EN 1990/A1).
Preliminary Design Decisions:

Which Design Code?

In Europe all Geotechnical design must comply with EC 7 but gives no design recommendations for Reinforced Soil. At present the choice of the design approach defers to the national application documents and is often down to the designer.

Many design guides exist:

FHWA (US), EBGEO (Germany), BS8006 (UK), NF P 94-270 (France), CUR (Netherlands), NORGEOSPEC (Norway), Geoguide 6 (Hong Kong)
Preliminary Design Decisions

CEN TC 250 are attempting to rationalize all the design guidance to produce a single European design approach within EC 7. EG5 aim to have their framework document on reinforced soil finalised in Q1 2016 for the Project Teams to draft sections for inclusion in EC 7. Publication expected in 2019.

ISO TC 221 are also drafting a guide for “Design Using Geosynthetics”.

Enka®solutions
Preliminary Design Decisions

What do you want the structure to look like?

Face angle: Wall or Slope

A tricky issue in design guides >70° UK, >76° NL, no difference D

Face finish: Blocks, Gabions, Panels, Vegetation

Loading: Traffic loads, bridge abutments, traffic barriers, seismic loading
Temporary facings

Used in situations where space constraints and existing embankment geometry require a full height retaining solution to support road / rail / bridge abutment prior to construction of a permanent solution.
Temporary Facings
Temporary Facings
Gabions, or galvanised mesh with 200-300mm of gabion stone fill.
Modular Blockwork
Modular Blockwork
Modular Blockwork

- With proper design and detailing anything is possible
Discrete concrete panel facings
Discrete concrete panels
Full Height Concrete Panels

- Full height props needed
- Construction can be tricky
Natural Slope Repairs
Shallow Reinforced Slopes
Steep Reinforced Slopes
Steep Reinforced Slopes
Steep Reinforced Slopes
### Preliminary Design Decisions:

#### What Soil?

**Fill Material Requirements to BS8006**

<table>
<thead>
<tr>
<th>Fill materials</th>
<th>Walls and abutments</th>
<th>Steep slopes ($\leq 70$, $&gt; 45^\circ$)</th>
<th>Shallow slopes ($\leq 45^\circ$)</th>
<th>Foundations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class or type</strong></td>
<td>Selected granular fills (Classes 6IIJ), Selected cohesive fills (Classes 7B/C/D) and Chalk (see Note 3)</td>
<td>Selected granular fills (Classes 6IIJ), Selected cohesive fills (Classes 7B/C/D), General granular fill (Class 1), General cohesive fill (Class 2)(see Note 4) and Chalk (see Note 3)</td>
<td>Selected granular fills (Classes 6IIJ), Selected cohesive fills (Classes 7B/C/D), General granular fill (Class 1), General cohesive fill (Class 2), and Chalk (see Note 3)</td>
<td>Classes 6F2 and 6F3</td>
</tr>
</tbody>
</table>
Soil Design parameters

\( \Phi' \) is used in walls where strain is \(<1\%\), \( \Phi'_c \) is used in slopes and cohesive materials where higher strains are expected.
Preliminary Design Decisions

Loading: Bridge Bank Seats and Traffic Barriers
Design reinforced soil

- EC 7: Ultimate Limit State & Serviceability limit state
  - ULS: Possible and probable failures are considered
  - SLS: Relevant working conditions are identified

- Method of partial factors:
  - Load factor
  - Material factor
  - Soil/reinforcement interaction factors
### BS8006 Partial Factors

<table>
<thead>
<tr>
<th>Partial factors</th>
<th>Ultimate limit state</th>
<th>Serviceability limit state</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil unit weight density e.g.</td>
<td>The appropriate value of $f_{ms}$ to be chosen</td>
<td></td>
</tr>
<tr>
<td>wall fill</td>
<td>according to Table 12 and Table 13 for the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>particular load combinations</td>
<td></td>
</tr>
<tr>
<td>External dead loads e.g. line or</td>
<td>The appropriate value of $f_q$ to be chosen</td>
<td></td>
</tr>
<tr>
<td>point loads</td>
<td>according to Table 12 and Table 13 for the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>particular load combinations</td>
<td></td>
</tr>
<tr>
<td>External live loads e.g. traffic</td>
<td>According to Table 12 and Table 13 for the</td>
<td></td>
</tr>
<tr>
<td>loading</td>
<td>particular load combinations</td>
<td></td>
</tr>
<tr>
<td><strong>Soil material factors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to be applied tan $\phi'_{p}$</td>
<td>$f_{ms} = 1.0$</td>
<td>$f_{ms} = 1.0$</td>
</tr>
<tr>
<td>to be applied to $c'$</td>
<td>$f_{ms} = 1.6$</td>
<td>$f_{ms} = 1.0$</td>
</tr>
<tr>
<td>to be applied to $c_u$</td>
<td>$f_{ms} = 1.0$</td>
<td>$f_{ms} = 1.0$</td>
</tr>
<tr>
<td><strong>Reinforcement material factor:</strong></td>
<td>The value of $f_m$ should be consistent with the</td>
<td></td>
</tr>
<tr>
<td>to be applied to the</td>
<td>type of reinforcement to be used and the design life over</td>
<td></td>
</tr>
<tr>
<td>reinforcement base strength</td>
<td>which the reinforcement is required (see 5.3.3 and Annex A)</td>
<td></td>
</tr>
<tr>
<td>**Soil/reinforcement interaction</td>
<td>$f_s = 1.3$</td>
<td>$f_s = 1.0$</td>
</tr>
<tr>
<td>factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sliding across surface of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reinforcement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pull-out resistance of</td>
<td>$f_p = 1.3$</td>
<td>$f_p = 1.0$</td>
</tr>
<tr>
<td>reinforcement</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Partial factors of safety</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation bearing capacity: to</td>
<td>$f_{ms} = 1.35$</td>
<td>NA</td>
</tr>
<tr>
<td>be applied to $q_{ult}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sliding along base of structure or</td>
<td>$f_s = 1.2$</td>
<td>NA</td>
</tr>
<tr>
<td>any horizontal surface where there</td>
<td></td>
<td></td>
</tr>
<tr>
<td>is soil-to-soil contact</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### BS8006 Load Combinations

**Table 13: Partial load factors for load combinations associated with abutments**

<table>
<thead>
<tr>
<th>Effects</th>
<th>Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Dead load of the structure</td>
<td>$f_{fs} = 1.5$</td>
</tr>
<tr>
<td>Dead load of the fill on top of the structure</td>
<td>$f_{fs} = 1.5$</td>
</tr>
<tr>
<td>Dead load of bridge and bank seat</td>
<td>$f_{t} = 1.2$</td>
</tr>
<tr>
<td>Backfill pressure behind the bank seat</td>
<td>$f_{fs} = 1.5$</td>
</tr>
<tr>
<td>Backfill pressure behind the structure</td>
<td>$f_{fs} = 1.5$</td>
</tr>
<tr>
<td>Horizontal loads due to creep and shrinkage</td>
<td>$f_{t} = 1.2$</td>
</tr>
<tr>
<td>Traffic loading</td>
<td>Over the entire structure, $f_{q} = 1.5$</td>
</tr>
<tr>
<td>Bridge vertical live load</td>
<td>HA</td>
</tr>
<tr>
<td></td>
<td>$f_{q} = 1.5$</td>
</tr>
<tr>
<td></td>
<td>$f_{q} = 1.3$</td>
</tr>
<tr>
<td>Braking dynamic load</td>
<td>HA</td>
</tr>
<tr>
<td></td>
<td>$f_{q} = 1.25$</td>
</tr>
<tr>
<td></td>
<td>$f_{q} = 1.1$</td>
</tr>
<tr>
<td>Temperature effects</td>
<td>$f_{q} = 1.3$</td>
</tr>
</tbody>
</table>
BS8006 Load Combinations

Figure 17  Load combinations showing partial load factors (see Table 12)

a) External and internal stability
b) External and internal stability
c) Settlement and serviceability
### Design Life

<table>
<thead>
<tr>
<th>Design working life category (BS EN 1990:2002+A1)</th>
<th>Category</th>
<th>Typical service life years</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Temporary works</td>
<td>1 to 5</td>
<td>Contractors site structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Piling platforms</td>
</tr>
<tr>
<td>1</td>
<td>Short term</td>
<td>5 to 10</td>
<td>Contractors site structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basal reinforced platforms for settlement control or in association with ground improvement</td>
</tr>
<tr>
<td>3/4</td>
<td>Industrial</td>
<td>10 to 50</td>
<td>Structures at mines</td>
</tr>
<tr>
<td>4/5</td>
<td>Long term</td>
<td>60</td>
<td>Marine structures in accordance with BS 6349</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Highway embankments</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Railway embankments (NR/SP/CIV071 [17])</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basal reinforcement in association with Piles or other supports under embankments</td>
</tr>
<tr>
<td>5</td>
<td>Long term</td>
<td>120</td>
<td>Highway and railway retaining walls and highway structures and bridge abutments</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basal reinforcement in association with piles or other supports under retaining walls and structures</td>
</tr>
</tbody>
</table>
## Consequence of Failure

Table 9  Category of structure depending upon ramification of failure

<table>
<thead>
<tr>
<th>Category</th>
<th>Partial factor $f_n$</th>
<th>Examples of structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (low) A)</td>
<td>1.0 if analysis is undertaken</td>
<td>Retaining walls and slopes less than 1.5 m in retained height above finished ground level in front where failure would result in minimal damage and loss of access</td>
</tr>
<tr>
<td>2 (medium)</td>
<td>1.0</td>
<td>Embankments and structures where failure would result in moderate damage and loss of services</td>
</tr>
<tr>
<td>3 (high)</td>
<td>1.1</td>
<td>Abutments, structures directly supporting motorway, trunk and principal roads or railways or inhabited buildings, dams, sea walls and slopes, river training walls and slopes</td>
</tr>
</tbody>
</table>

**NOTE** See Figures 10 to 14 for examples of structures in categories 1, 2 and 3.

A) Structures in category 1 should be restricted to small and relatively simple structures, with negligible risk, which may be designed by experience without analysis as described in BS EN 1997-1:2004.
Initial Sizing of Structures

Ref figures 19 & 20 of BS8006
## Initial Sizing of Structures

**Table 15** Determination of the minimum embedment as a function of the mechanical height \( H \) in metres and the factored bearing pressure \( q_r \) in kN/m\(^2\)

<table>
<thead>
<tr>
<th>Slope of the ground at toe ( \beta_s )</th>
<th>Minimum embedment ( D_m ) m</th>
<th>Minimum embedment factor ( D_m/q_r ) m(^3)/kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta_s = 0 )</td>
<td>Walls ( H/20 )</td>
<td>( 1.35 \times 10^{-3} )</td>
</tr>
<tr>
<td>( \beta_s = 0 )</td>
<td>Abutments ( H/10 )</td>
<td>( 1.35 \times 10^{-3} )</td>
</tr>
<tr>
<td>( \beta_s = 18^\circ ) (( \cot \beta_s = 3/1 ))</td>
<td>Walls ( H/10 )</td>
<td>( 2.7 \times 10^{-3} )</td>
</tr>
<tr>
<td>( \beta_s = 27^\circ ) (( \cot \beta_s = 2/1 ))</td>
<td>Walls ( H/7 )</td>
<td>( 4.0 \times 10^{-3} )</td>
</tr>
<tr>
<td>( \beta_s = 34^\circ ) (( \cot \beta_s = 3/2 ))</td>
<td>Walls ( H/5 )</td>
<td>( 5.9 \times 10^{-3} )</td>
</tr>
</tbody>
</table>

**NOTE 1** For definition of notation see Figure 21.

**NOTE 2** \( D_m \approx 0.45 \) m.
Design Criteria

External Stability

1. Sliding along base of reinforced soil block
Design Criteria

External Stability

1. Sliding along base of reinforced soil block
2. Bearing capacity
Reinforced Soil Wall Design

Design Criteria

External Stability

1. Sliding along base of reinforced soil block
2. Bearing capacity
3. Overturning
Design Criteria

External Stability

1. Sliding along base of reinforced soil block
2. Bearing capacity
3. Overturning
4. Overall stability
Reinforced Soil Wall Design

Design Criteria

External Stability

1. Sliding along base of reinforced soil block

2. Bearing capacity

3. Overturning

4. Overall stability

5. Settlement
Flexibility of the systems make them better over poor ground

BS8006 suggests the following limitations to differential settlement

<table>
<thead>
<tr>
<th>Maximum differential settlement</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 1000</td>
<td>Not normally significant</td>
</tr>
<tr>
<td>1 in 200</td>
<td>Full height panels may be affected by joints closing or opening. Normal safe limit for segmental blockwalls.</td>
</tr>
<tr>
<td>1 in 100</td>
<td>Normal safe limit, without special measures, for discrete concrete panel facings</td>
</tr>
<tr>
<td>1 in 50</td>
<td>Normal safe limit for semi-elliptical steel face elements. Discrete concrete panels may suffer closed joints if special measures not included</td>
</tr>
<tr>
<td>1 in &lt; 50</td>
<td>Soft facings might suffer distortion affecting their retaining ability</td>
</tr>
</tbody>
</table>

**NOTE** There is no intended firm limit between categories. This is a preliminary guide only.
Flexibility of the systems make them better over poor ground
Reinforced Soil Wall Design

Design Criteria

Internal Stability

1. Tensile failure of reinforcement
Reinforced Soil Wall Design

Design Criteria
Internal Stability

1. Tensile failure of reinforcement
2. Reinforcement pullout
Tie Back Wedge analysis for use with polymeric reinforcement
Tension Generated by surcharge, self weight and backfill pressure in each layer of reinforcement

\[ T_{sj} = K \sigma_{vj} \]
Tension Generated by vertical pressure from strip load

\[ T_{pj} = K P_L / b_e \]
Tension generated by horizontal loading to strip

\[ T_{fj} = \frac{2F_p \tan\left(45^\circ - \frac{\varphi}{2}\right)}{c_f + b_f} \left(1 - \frac{h_j \tan\left(45^\circ - \frac{\varphi}{2}\right)}{c_f + b_f - 2e'_{\text{parapet}}} \right) \]
Seismic loading designed to Mononobe-Okabe pseudo-static method

Additional tension generated by seismic loading

\[ T_{md} = P_l L_{ej} \]

\[ \sum L_{ej} \]

Additional force checked against tensile capacity of reinforcement based on 75% of the static FoS
Reinforced Soil Wall Design

Connection Loads

Checked for both ULS & SLS

<table>
<thead>
<tr>
<th>Tie back wedge method</th>
</tr>
</thead>
<tbody>
<tr>
<td>All facings with movement capacity or movement capacity at connections</td>
</tr>
<tr>
<td>$T_{conn} = 75% T_j$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Toe</th>
</tr>
</thead>
</table>

| Stiff face, e.g. segmental block walls and full height panels with no movement capacity at connections |
| $T_{conn} = 100\% T_j$ |

| Toe |
Reinforced Soil Wall Design

System Dependent checks

1. Bulging or overturning of facing
2. Failure of connection
Simple Excel Spreadsheet Checks

Enka-solutions

Données et hypothèses

Hauteur du mur: 7.00 m
Inclinaison (tan i): 0.25
Remblai technique: \( y_{w} = 20 \text{ kN/m}^3 \)
Frottement interne \( \varphi_{u} = 35^\circ \)
Coef. \( a = 0.74 \)
Coefficient de poussée du remblai \( K_{u} = 0.21 \)
Remblai du parement \( K_{u} = 0.75 \)
Talus de surcharge \( \beta = 0^\circ \)
Surcharge routière \( a = 10 \text{ kN/m}^3 \)
Choix de véhicules sur dispositif solitaire d’une dalle de treatment en tête de massif: non
Terrain sol: \( y = 20 \text{ kN/m}^3 \)
Frottement interne \( \varphi_{u} = 35^\circ \)
Inclinaison écart fictif \( 
\begin{aligned} 25^\circ \ \text{si} \ \beta = 0^\circ \\ 20^\circ \ \text{si} \ \beta \geq 2^\circ 
\end{aligned} 
\)
Coefficient de poussée du terrain \( K_{u} = 0.30 \)

Remblais à poussée \( K_{u} = 0.20 \)

Paramètres sismiques (cf. EN 1998-1)

Aceleracão máxima de referência para la zona do terrão \( a_{0} = 2.0 \text{ m/s}^2 \)
Coefficient d’importance \( \gamma = 1.0 \)
Spectre type 1: \( \gamma = 1.0 \)
Spectre type 2: \( \gamma = 1.0 \)
Spectre type 3: \( \gamma = 1.0 \)
Spectre type 4: \( \gamma = 1.0 \)

S = 1

Paramètres du sol (cf. NF P 94-270)

\( V_{s} \) la composante verticale de la charge transmise au sol par le mur
\( H_{u} \) le paramètre de calcul de la résistance vitale au glissement du mur

Stabilité au glissement en conditions drainées

Quantités

Relief plateau: cul-de

\( V_{h} = 42.8 \text{ m/mi} \)
\( y_{h} = 40.9 \text{ m/mi} \)

Séisme desc.

\( V_{h} = 858 \text{ km/h} \)
\( y_{h} = 388 \text{ km/h} \)

Séisme asc.

\( V_{h} = 779 \text{ km/h} \)
\( y_{h} = 363 \text{ km/h} \)

Enabilité Check

Load level:

\( h = 11.600 \text{ m} \)

墙

\( D_{m} = 1.000 \text{ m} \)

Column

\( D_{b} = 2.000 \text{ m} \)

Panel

\( D_{p} = 6.000 \text{ m} \)

Tension

\( T_{om} = 0.640 \text{ m} \)

Bonar - Pour une performance.

116, 01, 49, 46, 24, 50, fax. 01, 49, 46, 24, 35.
DC-Geotex software
Design Criteria
Compound Stability

1. Combination of global and internal stability checking circular or planar failure surfaces passing partially through the reinforced block.

2. Essential check for complex wall geometries and loadings.

Commercial packages include: Geo5 MSEW & Slope, SlopeW, TALREn, DC Geotex, etc.
Types of reinforcement material

- **High strength Wovens**
- **Uniaxial Geogrids** made from straps up to 350 kN/m or more?
- **HS Wovens** up to 1250 kN/m or more?
Product related specifications

\[ LTDS = \frac{UTS}{RF_{CR} \cdot RF_{ID} \cdot RF_{CN} \cdot RF_{DU} \cdot SF} \]

- A1: reduction factor for creep
- A2: reduction factor for installation damage
- A3: reduction factor for connection
- A4: reduction factor for durability
Product related specifications

Determination of the tensile strength in accordance with EN ISO 10319:
Creep data tested on continuous samples for over 25 years.
Results are plotted for creep as linear deformation vs log time.
For creep rupture linear or log load vs log time.
From creep curves at different stress grades isochronous stress strain curves may be derived and extrapolated for prediction of structural deformation at a given time.
Installation damage reduction factor (A2)

Field test at La Grave
Product related specifications

Direct physical testing of connection strength.
Product related specifications

Durability Testing:
- Hydrolysis
- Oxidation
- UV Degradation
- Weathering

Used to determine design reduction factors and application specific exposure limits (pH values of soil, storage & installation procedures, exposure limitation and protection)
**Product related specifications**

- **Interaction:**
  
  ![Diagram showing direct shear resistance and pull out resistance](image)
Product related specifications

- Pull out resistance:
  - Summarizes the friction behaviour of both the top and the bottom surface and the soil or fill material.
  - Geogrid as anchorage layer
  - Anchorage force depends on interaction behaviour
  - Mobilize tensile forces from the active part => stable part
Product related specifications

- Pull out resistance test EN 13738:
  Apply a horizontal force to a specimen embedded between two layers of soil under different normal stresses. The pullout force is recorded.

<table>
<thead>
<tr>
<th>soil</th>
<th>type</th>
<th>$c_l$</th>
<th>Test reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>PRO</td>
<td>0.86</td>
<td>GeoSyntec GLI0856</td>
</tr>
<tr>
<td>gravel</td>
<td>PRO</td>
<td>0.78</td>
<td>tBU 2003</td>
</tr>
<tr>
<td>sandy gravel</td>
<td>MAX</td>
<td>1.00</td>
<td>GeoSyntec GLI0856</td>
</tr>
</tbody>
</table>
Product related specifications

- **Direct shear resistance:**
  - The angle of friction
  - Shear resistance is critical for the direct sliding resistance
  - The test velocity is 1 mm/min. The tests should be carried out with 3 normal stresses
Monitoring
Extensometers and strain gauges on reinforcement & pressuremeters within the fill.

- A more academic approach to structures which is seldom performed but which has proven the approximations of peak load positions, working strains and pressure distribution used within the designs.

Survey points on wall profile, inclinometer with pore pressure measurement behind/within structure, sacrificial reinforcement samples for durability verification over time.

- Practical approach to monitor structural movement, particularly after concerns are raised and guarantee confidence.
Thank you for your attention
Any Questions?