Geoguide 6
The New Guide to Reinforced Fill Structure and Slope Design in Hong Kong

Geotechnical Engineering Office
Civil Engineering Department
The Government of the Hong Kong Special Administrative Region
Scope

- Geoguide 6 is a companion to Geoguide 1 – Guide to Retaining Wall Design (1993)
- Presents a recommended standard of good practice for
  - design
  - construction supervision of new permanent structures
- Included are:
  - Walls and slopes
  - bridge abutments
  - segmental block walls
- (Does not cover soil nailing, reinforced fill dams, maritime structures or embankments on soft ground)
Classification of Common Earth Retention Systems

(a) Externally Stabilised System
- Cantilever wall
- Gravity elements (interlocking cribs)
- In-situ bored pile wall

(b) Internally Stabilised System
- Facing panels
- Reinforced fill wall
- Reinforced fill slope
- Interlocking concrete wall blocks
- Gabion
- Segmental block wall
- Reinforced gabion structure

(c) Hybrid System
- Geogrids
The Use of Reinforcement Fill in Highway and Railway Application
The Use of Reinforced Fill in Housing Development
Other common usage

(a) River Training Structures

(b) Rock Crushing Plant

(c) Material Storage Facility
Rationale for the use of Reinforced Fill

- Reinforced fill structures can offer technical and economic advantages over conventional forms of construction
- Savings of 20-50% of initial capital cost are possible
- Particularly suited to sloping terrain
- Largely immune to earthquake
- Compatible with the concept of sustainable development
Examples of Economic and Technical Advantages of Reinforced Fill
Ecological Parameters for a 6m High Reinforced Fill Structure and an Equivalent Reinforced Concrete Structure
Philosophy

- The philosophy followed in the Geoguide is to design against the occurrence of a limit state (ultimate or serviceability) – expressed in terms of limit modes of failure.
Ultimate Limit States - External Instability

- (a) Overall Slope Instability
- (b) Sliding Failure
- (c) Overturning Failure
- (d) Bearing Failure
Ultimate Limit States - Internal Instability
Ultimate Limit States - Compound Instability
Serviceability Limit States
Philosophy (cont’d)

- Factors of Safety
  - Overall stability based upon global-safety-factor approach after the Geotechnical Manual for Slopes (GCO, 1984)
  - External and internal stability based upon partial safety factors:
    - partial consequence factors $\gamma_n$
    - material factors $\gamma_m$
    - load factors $\gamma_f$
Philosophy (cont’d)

Thus \( R_D = \frac{R}{\gamma_n \gamma_m} \), \( G_D = \frac{G}{\gamma_m} \), \( F_D = F \cdot \gamma_f \)

where

\( R_D = \) design value of reinforcement parameters \( R \)
\( G_D = \) design value of geotechnical parameters \( G \)
\( F_D = \) design value of loading, \( F \)

Example: \( \phi_d'_{des} = \tan^{-1} \left( \frac{\tan \phi'}{\gamma_m} \right) \)
### Recommended Partial Material Factors for the Design of Reinforced Fill Structures and Slopes

<table>
<thead>
<tr>
<th>Material Parameter</th>
<th>Ultimate Limit State</th>
<th>Serviceability Limit State</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fill:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- unit weight, $\gamma$</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>- effective shear strength, $\tan \phi'$</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Ground:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- effective shear strength ($^2$)</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>- base friction, $\tan \delta_b$</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Granular fill and drainage materials:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Permeability, $k$</td>
<td>10.0</td>
<td>-</td>
</tr>
<tr>
<td><strong>Structural elements:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Reinforcement strength</td>
<td>1.5($^3$)</td>
<td>-</td>
</tr>
<tr>
<td>- facing strength</td>
<td>as per relevant structural code</td>
<td>-</td>
</tr>
<tr>
<td><strong>Fill-to-reinforcement interaction:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- sliding resistance</td>
<td>1.2($^4$)</td>
<td>-</td>
</tr>
<tr>
<td>- pullout resistance</td>
<td>1.2($^4$)</td>
<td>-</td>
</tr>
<tr>
<td><strong>Facing units interaction:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- unit-to-unit resistance</td>
<td>1.2</td>
<td>-</td>
</tr>
<tr>
<td>- unit-to-reinforcement resistance</td>
<td>1.2</td>
<td>-</td>
</tr>
</tbody>
</table>

Partial Material Factor, $\gamma_m$
Recommended Partial Load Factors for the Design of Reinforced Fill Structures and Slopes

<table>
<thead>
<tr>
<th>Loading</th>
<th>Ultimate Limit State</th>
<th>Serviceability Limit State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load due to weight of the reinforced fill</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Dead load due to weight of the facing</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>External dead load (e.g. line or point loads)</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>External live load (e.g. traffic loading)</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Seismic load</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Water pressure</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Recommended Partial Load Factors for Load Combinations for Reinforced Fill Retaining Walls and Bridge Abutments

<table>
<thead>
<tr>
<th>Loading</th>
<th>Load Combination</th>
<th>Partial Load Factors $\gamma_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A^{(1)}$</td>
<td>$B^{(2)}$</td>
</tr>
<tr>
<td>Dead load due to weight of reinforced fill</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Dead load due to weight of facing</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>External dead load on top of structure</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>External live loads:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) on reinforced fill block</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>(ii) behind reinforced fill block</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Temperature effects on external loads (e.g. thermal expansion)</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Basic Theory

- The action of reinforcement placed horizontally in a reinforced fill wall or steep slope increases the resistance to shear failure by:
  - Directly resisting the disturbing force
  - Increasing the normal component of force which mobilises additional frictional resistance
Effects of reinforcement on Equilibrium and Action in Direct Shear
Basic Theory (cont’d)

- Factors affecting the behaviour of reinforced fill include:
  - Reinforcement properties (durability, form, strength, stiffness…)
  - Strain compatibility
  - Creep
  - Reinforcement distribution (location, orientation, spacing)
  - Fill properties
  - Fill state (density, state of stress, temperature…)
  - Construction (compaction of fill, construction technique…)
  - Foundation
Influence of Foundation Condition on Reinforced Fill Structures

(a) Wall Displacement on a Weak Foundation

(b) Potential for Arching on Stepped Foundation
Condition of Strain Compatibility
Construction Materials

Reinforcement (sheets, bars, strips, grids or anchors)

- Steel reinforcement must be galvanised 610-1000g/m², sacrificial thickness included
- Polymeric reinforcement usually polyester or high density polyethylene accommodating the potential effects of:
  - photo-oxidation
  - thermo-oxidation
  - hydrolysis (of polyester)
  - creep and stress rupture
  - installation damage
Construction Materials (cont’d)

- Facings and connections:
  - Hard or soft depending upon use and purpose including segmental block and gabion facings

- Fill:
  - Natural or processed material
  - Restrictions on electrical and chemical limits

- Filter and drainage materials:
  - Conforming to Geoguide 1 (GEO, 1993)
Investigation and Testing

Sampling and testing of fill materials:
- The source and properties of the fill may not be known at the design stage
- Use conservative values and undertake compliance tests on a regular basis (detailed in the Model Specification)

Testing of reinforcements and connections:
- Number reflects the size of the structure
- Required to verify design assumptions:
  - tensile test on reinforcing materials
  - tensile test on joints and connections
  - reinforcement pull out
  - direct shear, fill-to-reinforcement, facing-unit-to-reinforcement, facing-unit-to-facing-unit
## Design Consideration for Reinforced Fill Structures and Slopes

<table>
<thead>
<tr>
<th>Selection of Reinforced Fill System</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space for construction</td>
<td>Tolerances and serviceability limits</td>
</tr>
<tr>
<td>Acceptable deformation limits</td>
<td>Details and procedures</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Protection of reinforcements</td>
</tr>
<tr>
<td>Construction and maintenance costs</td>
<td>Compliance testing</td>
</tr>
</tbody>
</table>

### Design Situations

<table>
<thead>
<tr>
<th>Function and design life</th>
<th>Loading conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction conditions</td>
<td>Ground conditions</td>
</tr>
<tr>
<td>Loading conditions</td>
<td>Consequence of failure</td>
</tr>
</tbody>
</table>

### Construction

- Tolerances and serviceability limits
- Details and procedures
- Protection of reinforcements
- Compliance testing

### Maintenance

- Drainage
- Vegetation
- Structural elements

### Factor of Safety

- Consequence factors
- Material factors
- Load factors

### Design Loading

- Dead loads
- Live loads
- Seismic loads

### Design Strength

- Reinforcement and facing
- Fill and foundation materials
- Fill-reinforcement interaction

### Design Stiffness

- Deformation moduli
- Poisson ratio

### Design Permeability

- Ground
- Fill
- Filter and drainage materials

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**GEOGUIDE 6**
Design procedure for reinforced fill structures

- Define wall geometry, fill properties and reinforcement
  - Initial sizing (Section 7.3)
  - External stability check (Section 7.4)
- Determination of tensile forces to be resisted by individual layers of reinforcement (Section 7.5.3)
  - Checking rupture and pullout of individual layers of reinforcement (Section 7.5.4)
  - Wedge stability check (Section 7.5.5)
  - Compound stability check (Section 7.6)
  - Serviceability check (Section 7.7)
  - Spacing of reinforcement (Section 7.8)
- Design of connections and facing (Section 7.9 and 7.10)
  - Drainage provisions (Section 7.11)
  - Detailing/Drawings (Section 7.17)
External stability

- Use limit equilibrium methods, Geotechnical Manual for Slopes (GCO, 1984)
- Stability of reinforced block, Geoguide 1 (GEO, 1993)
- Bearing pressure, Meyerhof distribution assumed; if L/H > 0.6 use trapezoidal pressure distribution
- Sliding resistance, based upon the weakest material fill or ground
Internal Stability

- Assumptions:
  - Design tension based upon assumption of vertical loads distributed using Meyerhof pressure (or trapezoidal if L/H < 0.6)
  - Resistance to pull out based upon uniform normal stresses and unfactored loads – pore water pressures should be considered
Analytical models

The design state of stress within a reinforced fill structure determines the design tensile load in the reinforcement.

The state of stress inside the reinforced fill block is determined by the quantity and axial stiffness of the reinforcement:

- Axial strain > 1%: the analytical model recommended is the Tie Back Method – the lateral earth pressure in the reinforced block is in the active state, $k_{des} = k_a$
- Axial strain < 1%: the Coherent Gravity Method is assumed to apply, where $k_{des} = k_o$ reducing to $k_a$ at a depth of 6m
Design Methods for Internal Stability Analysis of Reinforced Fill Structures
Internal Stability (cont’d)

- The design checks for:
  - Tension in the reinforcement
    - rupture of reinforcement
    - pull out
  - Wedge stability
  - Compound stability (i.e. failure planes located within and outside the reinforced fill block)
    - sliding on planes between the reinforcement
    - sliding along the reinforcement
Design of Connections

- Designed for maximum tension in the reinforcement
- Checked for failure in tension, shear and combined shear and tension
Serviceability Considerations

- Identify the serviceability limits
- Most movements take place during construction
- Consideration is given to:
  - creep of polymeric reinforcement
  - creep of fine grained fill
  - additional loading
  - foundation settlement
  - deterioration of the reinforcement
Specific Structures and Details

Geoguide 6 covers:

- Superimposed walls
- Segmental block walls
- Walls with a stepped base
- Back-to-back walls
- Bridge abutments
  - spread footings
  - piled
  - integral
- Design detailing
  - corner and wall joints
  - connections to cast-in-place structures
Specific Structures and Details

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  - piled
  - integral
- Design detailing
  - corner and wall joints
  - connections to cast-in-place structures
Special Conditions Relating to Design and Construction Control in Hong Kong

Temperature:
- Creep test temperature is usually 20-23°C
- Mean soil temperature in Hong Kong is 26 °C
- 0.5m behind the face temperature can reach 35°C
Design temperature of 30°C is recommended

Drainage:
- The stability of reinforced fill structures relies upon good drainage. Geoguide 6 provides examples of good drainage. Checks should be made on the adequacy and efficacy of all drainage during construction, in particular during/after periods of intense rainfall.
Typical Drainage Layouts for Reinforced Fill Structures and Slopes
Typical Drainage Layouts for Highway and River Training Applications
Special Conditions Relating to Design and Construction Control in Hong Kong

- Seismic events:
  - Reinforced fill structures are tolerant of earthquakes and structures need not generally be designed for seismic loads

- Proprietary products:
  - Certified products can be used
  - Proprietary products not covered by a CED certificate are not approved for use in permanent works
Design of Reinforced Fill Slopes

- Slopes defined as having face inclination > 20°C from vertical
- External stability
- Internal stability
  - Local stability of individual reinforcing elements
  - Stability of the yielding reinforced fill mass
- Assumptions:
  - Similar to walls
  - Uniform normal stress distribution with unfactored loads
  - Increase in stress due to compaction considered (except for pull out check)

Slopes defined as having face inclination > 20°C from vertical
Design of Reinforced Fill Slopes

- Slopes defined as having face inclination > 20° from vertical
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  - Increase in stress due to compaction considered
    (except for pull out check)
Aesthetics and Landscaping

- The aesthetics of reinforced fill is emphasised in the Geoguide

- Use of proven details recommended
  - joints
  - parapets
  - drainage
  - concrete finishes
  - cracking of facing units
  - joints between reinforced fill and cast-in-place structures

- Long term aesthetic appearance:
  - leaking joints
  - cracking and staining of facing
  - unplanned vegetation
Procurement and Specification

- Types of contract:
  - Conventional
  - Design and build

- Model Specification:
  - Appendix A

- Suitability of contractors:
  - Competence

- Patents and Client’s indemnification
Construction Control

- Assumptions critical to the design (e.g. foundation or ground water levels) should be reviewed during construction by the designer

- Construction supervision:
  - Pre-construction review
  - Method and sequence
  - Preparation of the foundation
  - Temporary drainage
  - Storage of materials
  - Compaction
  - Testing of materials (including tensile tests, carbon black etc.)
Comparison with Other Codes

- **BS 8006 and FHWA**

- **Walls**
  - 5m and 15m in height
  - Extensible and inextensible reinforcement
  - Low and high consequence of failure (i.e. $\gamma_n=1.0$ or 1.1)

- **Slopes**
  - 6m and 15m high
  - 65° slopes
Comparison of Different Design Standards
15 m Wall with Inextensible Reinforcement (Low Consequence)

Wall Height $H = 15$ m  
Peak Friction Angle $\phi' = 38^\circ$

Wall Width $B = 10.5$ m  
Unit Weight $\gamma = 19$ kN/m$^3$

Reinforcement Spacing = 750 mm

Design Tension (kN)  
Depth (m)

Ratio of Design Tension  
(Other Design Guide / Geoguide 6)
Comparison of Different Design Standards
15 m Wall with Extensible Reinforcement (Low Consequence)

Wall Height $H = 15\text{m}$  
Peak Friction Angle $\phi' = 38^\circ$
Wall Width $B = 10.5\text{ m}$  
Unit Weight $\gamma = 19\text{ kN/m}^3$
Reinforcement Spacing = 750 mm

![Graph showing comparison of different design standards](image)
Comparison of Different Design Standards
5 m Wall with Inextensible Reinforcement (Low Consequence)

Wall Height $H = 5$ m
Wall Width $B = 3.5$ m
Peak Friction Angle $\phi_p = 38^\circ$
Unit Weight $\gamma = 19$ kN/m$^3$
Reinforcement Spacing = 500 mm

- **Geoguide 6**
- **FHWA**
- **BS 8006**
Comparison of Different Design Standards
5 m Wall with Extensible Reinforcement (Low Consequence)

Wall Height $H = 5$ m  Peak Friction Angle $\phi'_p = 38^\circ$
Wall Width $B = 3.5$ m  Unit Weight $\gamma = 19$ kN/m$^3$
Reinforcement Spacing $= 500$ mm

![Graph comparing design tensions of Geoguide 6, FHWA, and BS 8006 for different depths and ratios of design tension.](image)
Comparison of Different Design Standards
15 m Wall with Inextensible Reinforcement (High Consequence)

Wall Height H = 15m  Peak Friction Angle $\phi'_p = 30^\circ$
Wall Width B = 10.6 m  Unit Weight $\gamma = 19$ kN/m$^3$
Reinforcement Spacing = 750 mm

![Graph showing comparison of different design standards](image)
Comparison of Different Design Standards
15 m Wall with Extensible Reinforcement (High Consequence)

Wall Height $H = 15\text{m}$
Peak Friction Angle $\phi' = 38^\circ$
Wall Width $B = 10.5\text{m}$
Unit Weigh $\gamma = 19\text{kN/m}^3$
Reinforcement Spacing $= 750\text{mm}$
Comparison of Different Design Standards
5 m Wall with Inextensible Reinforcement (High Consequence)

Wall Height $H = 5$ m
Peak Friction Angle $\phi_p' = 30^\circ$
Wall Width $B = 3.5$ m
Unit Weight $\gamma = 19$ kN/m$^3$
Reinforcement Spacing = 500 mm

![Graph comparison of different design standards](image)
Comparison of Different Design Standards
5 m Wall with Extensible Reinforcement (High Consequence)

Wall Height $H = 5$ m  
Peak Friction Angle $\phi_p = 30^\circ$
Wall Width $B = 3.5$ m  
Unit Weight $\gamma = 19$ kN/m$^3$
Reinforcement Spacing = 500 mm

![Graph showing comparison of different design standards for a 5 m wall with extensible reinforcement.](image)
Comparison of Different Design Standards
6m High & 65 Degrees Slope

![Graph showing Design Tension vs Depth and Ratio of Design Tension (Other Design Guide / Geoguide 6)]

- Design Tension vs Depth (6m, 65 degrees)
  - Depth (m)
  - Design Tension (kN)
  - Geoguide 6
  - BS8006

- Ratio of Design Tension (Other Design Guide / Geoguide 6)
  - Depth (m)
  - Ratio
  - BS8006
  - Geoguide 6
Comparison of Different Design Standards
15m High and 65 Degrees Slope

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Design Tension vs Depth (15m, 65 degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>80.0</td>
</tr>
<tr>
<td>1</td>
<td>40.0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

- Geoguide 6

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Ratio of Design Tension (Other Design Guide / Geoguide 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- BS8006

- Geoguide 6