Design methods for geosynthetics used for erosion control in channel and river banks

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Erosion in channels, rivers, estuaries
Some solutions – working against nature
Industry Strategy: Government and Industry in Partnership

Construction 2025

Executive Summary......
Our vision for 2025

Working together, industry and Government have developed a clear and defined set of aspirations for UK construction.

It begins with a clear vision of where UK construction will be in 2025:

- **PEOPLE** An industry that is known for its talented and diverse workforce
- **SMART** An industry that is efficient and technologically advanced
- **SUSTAINABLE** An industry that leads the world in low-carbon and green construction exports
- **GROWTH** An industry that drives growth across the entire economy
- **LEADERSHIP** An industry with clear leadership from a Construction Leadership Council

This vision will provide the basis for the industry to exploit its strengths in the global market.

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**Lower costs**

33% reduction in the initial cost of construction and the whole life cost of built assets

**Faster delivery**

50% reduction in the overall time, from inception to completion, for newbuild and refurbished assets

**Lower emissions**

50% reduction in greenhouse gas emissions in the built environment

**Improvement in exports**

50% reduction in the trade gap between total exports and total imports for construction products and materials

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The global construction market is forecast to grow by over 70% by 2025.

*Global Construction 2025: Global Construction Perspectives and Oxford Economics (July 2013)*
Environmental Impact

Quarrying revetment stone

This.....

Or this.....

Delivering revetment stone

Disturbing the public

Damaging roads
Definitions and design

• Two main design categories

  • “Dry” slope erosion - design influence - surface susceptible to rainfall impact, surface flow and rivuleting leading to channel flow

  • “Wet” slope erosion – design influence – surface receives permanent or temporary inundation such as drainage channels, spillways, river lake and sea margins. Flow and wave impact.
Soil erosion in the UK

+off-site impacts!
Erosion types and impact

Highway Construction erosion/sediment rates in UK – 338 - 480 t/ha/yr

Urbanisation – 226 t/ha/yr
## Threats to soils: erosion rates - unprotected engineered slopes

<table>
<thead>
<tr>
<th>Site description</th>
<th>Erosion / sediment rates</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine spoils</td>
<td>102 - 500 t/ha/yr 46,400 p.p.m. sediment concentrations in runoff 2.1 – 5.9 mm / yr ground loss</td>
<td>Renner, 2002; Bright, 1991; Curtis, 1971; Haigh, 1979; US EPA, 1973</td>
</tr>
<tr>
<td>Highway construction</td>
<td>338 - 480 t/ha/yr</td>
<td>Diseker and Richardson, 1962; Vice et al., 1969</td>
</tr>
<tr>
<td>Urbanisation</td>
<td>226 t/ha/yr</td>
<td>Yorke and Herb, 1976</td>
</tr>
<tr>
<td>Construction</td>
<td>17,000 t/km²/yr</td>
<td>US EPA, 1973</td>
</tr>
<tr>
<td>Off road recreation</td>
<td>5.52 t/ha/yr</td>
<td>Snyder et al, 1976</td>
</tr>
</tbody>
</table>

**Transport delays**

**Embankment failure**

**Dead Fish caused by soil choked gills**
## Total costs of soil degradation (Graves et al., 2011)

<table>
<thead>
<tr>
<th>Ecosystem service</th>
<th>Provisioning</th>
<th>Regulating</th>
<th>Cultural</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agricultural production</td>
<td>Flooding</td>
<td>Water quality</td>
<td>GHG emissions</td>
</tr>
<tr>
<td>Errosion</td>
<td>30 - 50</td>
<td>46 - 80</td>
<td>55 - 62</td>
<td>8 - 10</td>
</tr>
<tr>
<td>Compaction</td>
<td>180 - 220</td>
<td>120 - 200</td>
<td>60 - 80</td>
<td>30 - 40</td>
</tr>
<tr>
<td>TOTAL</td>
<td>212 - 270</td>
<td>166 - 280</td>
<td>115 - 142</td>
<td>398 - 750</td>
</tr>
<tr>
<td>%</td>
<td>20%</td>
<td>19%</td>
<td>11%</td>
<td>49%</td>
</tr>
</tbody>
</table>
“Dry” slope erosion protection

A selected, well established, well maintained vegetated surface is a sound engineering solution

....if only it would stay that way!
Particle transport – “stopping it starting”

Surface friction and transport

TRM preventing rivuletting

![Graph showing water velocity vs. average particle size](image)

- Erosion matting required
- No erosion matting required

- clay
- silt
- sand
- gravel
- stones
“Dry” slope erosion protection - reinforcement

Examples of Types of Surface Erosion Control mats

Biodegradable (temporary)  

Biodegradable/polymer net (temp/perm?)

Non-Biodegradable (permanent)  
- Turf Reinforcement Mats
Pinned cellular webs for topsoil containment

Cellular webs prevent soil block movement below surface until grass is established
Anchored cellular webs - reinforced
Anchored cellular webs - reinforced
“Wet” slope erosion – overtopping – flow design

Change in overall design philosophy

- from “defending against” nature to tolerating and working with nature
- Designing for overtopping and “managing” the flood. (e.g. Flood proof housing)

Willows or reeds
Natural erosion protection

- Well developed root zone highly resistant to flow

- Weaknesses
  - time limited
  - localised die back
  - localised contamination
Design Guidelines - CIRIA
Pinning - good surface contact – shear resistance

Pinning pattern depends on slope, roll width, flow

Pinning cellular webs

Helical pin

Helical pin with Webgrip
CASE STUDY: Somerset 2014 floods
Turf reinforcement mats

• Case Study: Somerset UK - 2014 Floods

• Overtopping
  • 62 days of overtopping
  • Max recorded flow 4.3m/s

• After flood
  • Majority turf in tact
  • Kept hydraulic shape
    • No cavities
  • Completely self healed
Overtopping – wave surging - EuroTop Report
Tests lead to design limits

• Design detail available
  • Limiting velocities
  • Roughness coefficients
  • Anchorage and pinning
  • Edge details

• Design guidance sources
  • CIRIA
  • EurOtop
  • Rostock University
  • European methods being developed
Transitions

• Any change in shape, texture and alignment is a potential for erosion
• Geosynthetics are versatile and can be shaped or preformed to assist with the design of flexible hydraulic transitions
Transitions – edge details

• Anchorage on total perimeter
• Anchorage with change of material or shape
Alternative Revetments

- Fascine mattressing
- Sand mattress / concrete filled mattress
- Concrete block revetments
- Turf Reinforcement mattressing – open / asphalt filled
  Cementitious mattressing
  Sand mattress
“Wet” slope erosion – wave and flow filter design

• Design of geotextiles in a wave environment in river applications
  - Erosion under rock armour
    – flexible porous filter design

• 50 year design evolution in use of geosynthetics in rock armour erosion control
• Much work on filter design for most types of soil
• Practical experience leads to pragmatism
  • Better a design than no design at all!
  • Is it buildable without damage?
  • Attention to edge details
• Accessible design guides for engineers – New guide (pub. 2017)
• Some geosynthetic alternatives to rock – design considerations
Some fine particles migrate.

Very few medium particles migrate.

Coarse particles cannot migrate.

High energy water can move soil particles.

Terzaghi Filter principle.
Typical filter/seperator geotextiles used
Typical filter/separator geotextiles used
Typical geotextiles used

Soil particles
Embankment Slopes - Revetments

• Basic design requirements of a filter/separater geotextile

• must have sufficient
  a) permeability to avoid undue stress on textile or embankment
  b) filter capability to prevent loss of fines
  c) Survivability during construction and design life
Hydraulic Properties

- The balance between filter and permeability
- Relative permeability
- Getting it wrong!
Mechanical Properties

• Specify site testing
  • Simulate actual site conditions
  • More damage when primary armour dropped onto bedding layer
Latest Design Guidelines

- “Guideline for the design of geotextiles under stone coverings” – SBRCUR (Dutch) (2017)
Latest Design Guidelines

- Early Dutch designs based on woven experience
- Recent shift to non woven with appropriate use of woven
- Collect best practice from designers, clients, contractors and manufacturers
- Site failure analysis

“State of the art” 1986
4 Drivers for new guidelines

• Minimum information on geosynthetics in Rock Manual

• Site failure analysis
  • Majority caused by holes caused by installation

• Numerous filter rules –
  • was confusing for engineers
  • tended to no design or copy old design

• Engineers often unable to obtain soils analysis on river and estuarial sites
Three Methods

- **Simple Method** – majority of designs
  - Installation damage – arising from known rock armour sizing
  - Assumed typical simple classifications of soil

- **Detailed Method**
  - Superior soils knowledge …type and variation of type along the revetment
  - Allowable variations for different revetment shapes and types eg concrete blocks

- **Advanced Method** – Large scale projects
  - Laboratory analysis of soils available
  - Modelling and performance of soil filter behaviour
  - Site trials modelling installation (sometimes complex with special equipment) and long term behaviour of the structure
  - Need for reinforcing function in installation or geotechnical performance
  - Use all available published information
Simple Method – Key conditions

• SOIL TYPE: Estimate ground density and water permeability of soil at site location

• CURRENT FLOW or WAVES: Determine direction of flow through geotextile: one or two (reversing);

• GEOTECHNICS: The slope itself is geotechnically stable determined by slope angle and toe detail. Typical 1 in 3 max.

• TWO LAYER REVETMENT: specification for the lower (secondary) layer of 90/250mm, 5-40kg, 10-60kg, 40-200kg. Stone density 2300kg/m³

• PLACEMENT: Maximum drop height on site 2m (secondary and primary).

• PLACEMENT: Maximum of 15 tonnes site plant tracking over minimum 300mm of cover

• DESIGN: Factory of Safety throughout is 1.5

• DESIGN: Design life is minimum 50 years
Simple Method - look up tables

### Table 2: Opening size for different soils in single and reversing flows

<table>
<thead>
<tr>
<th>Soil</th>
<th>Opening size $O_{90}$ (mm)</th>
<th>Stationary (single direction flow)</th>
<th>Dynamic (reversing flows)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy clay</td>
<td>0.10</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Sandy clay</td>
<td>0.30</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>sand</td>
<td>0.34</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>0.50</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>gravel</td>
<td>0.50</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Required minimum permeability of geotextile

<table>
<thead>
<tr>
<th>Soil</th>
<th>$D_{50}$ (mm)</th>
<th>Range $k_b$ (m/s)</th>
<th>Chosen notional value $k_b$ (m/s)</th>
<th>$C_m$</th>
<th>Required $k_g$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy clay</td>
<td>0.010</td>
<td>$10^{-10} - 10^{-8}$</td>
<td>$10^{-8}$</td>
<td>100</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>0.038</td>
<td>$10^{-8} - 10^{-6}$</td>
<td>$10^{-6}$</td>
<td>100</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>sand</td>
<td>0.17</td>
<td>$10^{-6} - 10^{-3}$</td>
<td>$10^{-4}$</td>
<td>10</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>3.0</td>
<td>$10^{-3} - 10^{-1}$</td>
<td>$10^{-3}$</td>
<td>10</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>gravel</td>
<td>9.3</td>
<td>$10^{-3} - 10^{-1}$</td>
<td>$10^{-2}$</td>
<td>10</td>
<td>$10^{-1}$</td>
</tr>
</tbody>
</table>

### Table 4: Energy Absorption Levels for typical stone grades

<table>
<thead>
<tr>
<th>Stone class</th>
<th>Energy Absorption Level (EAL) (kJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90/250 mm</td>
<td>3</td>
</tr>
<tr>
<td>5-40 kg</td>
<td>3.5</td>
</tr>
<tr>
<td>10-60 kg</td>
<td>7</td>
</tr>
<tr>
<td>40-200 kg</td>
<td>9</td>
</tr>
</tbody>
</table>
Detailed Method additions

- Reduction factors
  - durability, UV, compressive creep, installation damage, chemical blocking, biological blocking, chemical degradation
Detailed – Estimating Elongation

• Modelling

Rounded

Sharp cornered
### Key features of the geotextile filter/separator

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Characteristics geotextiles</th>
<th>Unit</th>
<th>Requirement / reason</th>
<th>Norm</th>
<th>Section in guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening size</td>
<td>mm</td>
<td></td>
<td>Prevent leaching of the base layer</td>
<td>EN ISO 12956</td>
<td>5.2.1, table 5.4</td>
</tr>
<tr>
<td>Permeability</td>
<td>m/s</td>
<td></td>
<td>Caring for good water permeability to prevent water overpressure and subpressure</td>
<td>EN ISO 11058</td>
<td>5.2.2, table 5.5</td>
</tr>
<tr>
<td>Lifetime</td>
<td>jaar</td>
<td></td>
<td>Minimum service life &gt; 50 year, to prevent failure during life time</td>
<td>EN ISO 13438</td>
<td>5.2.3</td>
</tr>
<tr>
<td><strong>Robustness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength, at break</td>
<td>kN/m²</td>
<td></td>
<td>Absorbing forces during the installation phase</td>
<td>EN ISO 10319</td>
<td>Minimum breaking strength: 5.3.2, table 5.6</td>
</tr>
<tr>
<td>Minimum elongation</td>
<td>%</td>
<td></td>
<td>Elongation of the geotextile to be able to follow the deformation of the underlying soil as result of the energy absorption of the falling stone</td>
<td>EN ISO 10319</td>
<td>Minimum elongation at break: 5.3.3, table 5.7</td>
</tr>
<tr>
<td><strong>Additional requirements at installation using a mattress</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum elongation at required tensile strength</td>
<td>ε</td>
<td>When using a mattress, the strain in the geotextile may not exceed a certain value at the maximum strength level, during installation</td>
<td>EN ISO 10319</td>
<td>Maximum elongation at required strength: 5.4.1, table 5.8</td>
<td></td>
</tr>
<tr>
<td>Energy Absorption Level</td>
<td>kJ/m²</td>
<td></td>
<td>The Energy Absorption capability of the geotextile (EAL) is the relationship between tensile strength and elongation at break, which with each other multiplied, give an indication of the deformation capacity</td>
<td>EN ISO 10321</td>
<td>5.4.2, table 5.9</td>
</tr>
<tr>
<td>Seam strength</td>
<td>kN/m</td>
<td></td>
<td>Strength over the sewing seam, if applicable</td>
<td></td>
<td>5.4.3, table 5.10</td>
</tr>
</tbody>
</table>
Geotextile Alternatives to Rock
Design considerations

• Geobags
  • Weight filled
  • Fabric and Stitching withstand impact load
  • Damage resistance for handling
  • Filter criteria with fill material and underlying soil
Geotube – pumped fill

<table>
<thead>
<tr>
<th>Extraction</th>
<th>Delivery</th>
<th>Filling</th>
<th>Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic extraction of filling sand by means of suction dredger or dredge pump. Alternatively: Liquefaction of sand through addition of water in mixing tank and filling by means of slurry pump.</td>
<td>Hydraulic delivery of sand/water mix to place of installation.</td>
<td>In-situ filling of SoilTain tube: water drains out while sand is retained in tube.</td>
<td>Possibilities for integration in landscape setting by covering with sand or overlaying with revetment system; optional stacking of tubes.</td>
</tr>
</tbody>
</table>
Geotextile Alternatives to Rock
Design considerations

- Geotubes
  - Fill porosity
  - Tensile properties & stitch strength
    - During filling
    - In service
  - Maximum fill levels to
    - Prevent bursting
    - Reach design shape
- Geotechnical stability
  - External and internal
Geotextile Alternatives to Rock
Additional design considerations

- Geo containers
  - Loading on container as it slips though opening jaws of ship
  - Drop direction and orientation in currents
Conclusions – Flexible permeable solutions

GRASS SLOPES – “dry” and “wet”

• Work with nature, not against it – protected vegetation and root structures are very strong – LESS STONE more VEGETATION
• Create the right conditions for grasses to establish
• Edge detailing essential

REVETMENTS

• Wave environments are often a harsh and crude
• A lot of academic information - somewhat confusing
• Testing and site experience invaluable
• Recent joining of the two has produced accessible realistic design methods
• Flexible geosynthetics methods provide alternative revetments