GEOSYNTHETICS ENGINEERING: IN THEORY AND PRACTICE

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Module - 4
LECTURE- 19
Geosynthetics for filtrations, drainages and erosion control systems
Recap of previous lecture.....

- Geocomposite drains are preferable behind retaining walls
- Geocomposite sheets drains/ geomats/ geospacers
- Compressive strength of geocomposite sheet drains
- Geocomposite prefabricated highway edge drains
- Geosynthetics wrapped french drain
- Horizontal drainage blanket in combination with french drain
- Drawdown of ground water level (partly covered)
Example:

The depth of ground water above impervious layer is 8 m. It is required to lower the ground water level 1 m to protect a building foundation. It is decided to employ a geotextile wrapped French drain. Calculate the volume of aggregates and the required amount of geotextile.

Given,

\[ Z_t = 30 \text{ cm}, \ Z = 8 \text{ m}, \ Z_{dw} = 1 \text{ m}, \]
\[ Z_d = (8 - 1) \text{ m} = 7 \text{ m}, \]
\[ y = 80 \text{ m}, \ R = 50 \text{ m}, \ i = \text{slope of drain (1%)} = 0.01 \text{ m/m}, \]
\[ k_{\text{soil}} = 7 \times 10^{-5} \text{ m/sec} \quad k_w = 0.8 \text{ m/sec} \]
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Solution:

Step 1: Calculate required $Z_0$

$$Z_d = Z_0 \left[ \frac{1.48}{R} (Z - Z_0) + 1 \right]$$  
$Z = 8\ m, \ R = 50\ m, \ Z_d = 7\ m$

$$7 = Z_0 \left[ \frac{1.48}{50} (8 - Z_0) + 1 \right]$$  
$$-0.0296Z_0^2 + 1.2368Z_0 - 7 = 0$$

By solving the quadratic equation,

$Z_0 = 6.75\ m$, or $Z_0 = 35.03\ m$

Therefore, $Z_a = Z - Z_0 = 8 - 6.75 = 1.25\ m$
Step 2: Calculate flow \( (q_d) \)

\[
q_d = \left\{ 0.73 + \frac{0.27(Z - Z_0)}{Z} \right\} \frac{k_s y}{2R} (Z^2 - Z_0^2)
\]

\[
q_d = \left\{ 0.73 + \frac{0.27(8 - 6.75)}{8} \right\} \frac{7 \times 10^{-5} \times 80}{2 \times 50} (8^2 - 6.75^2)
\]

\[
q_d = 0.772 \times 1.0325 \times 10^{-3} = 7.97 \times 10^{-4} \text{ m}^3 / \text{sec}
\]

Step 3: Calculate \( Z_w \) in terms of \( d_w \)

\[
Z_w = \frac{q_d}{k_w i d_w}
\]

\[
Z_w = \frac{7.97 \times 10^{-4}}{0.8 \times 0.01 \times d_w} = \frac{0.1}{d_w}
\]
Now selecting $d_w = 0.6 \text{ m}$, $Z_w = 0.166 \text{ m}$
(It is a practical combination)

### Step 4: Calculate volume of aggregates required

$$V = y \cdot d_w \cdot (Z_a + Z_w) = 80 \times 0.6 \times (1.25 + 0.166) = 67.97 \text{ m}^3$$

### Step 5: Calculate amount of geotextile

Geotextile required

$$= y \left[ 2(Z_a + Z_w) + 3 \cdot d_w \right] = 80 \left[ 2 \times (1.25 + 0.166) + 3 \times 0.6 \right]$$
$$= 370.56 \text{ m}^2$$
Climate change, population growth and soil erosion are the greatest problems in the world. Almost 75 billion tones of soil are lost annually while eighty percent of land is eroded. So, it is necessary to control the soil loss from erosion.

In erosion control system, geosynthetics can effectively be used in place of conventional graded granular filters. It may prevent erosion in various applications such as slope protection in coastal areas, roadways, bank protection, scour protection in bridge piers and abutments and stream canals or channels.

Basically, geosynthetic acts for filtration as well as prevents the fines that may migrate through the riprap or armor materials.

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More than 100 million hectares soil eroded in India

Geosynthetic erosion control system at stream bank

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Slopes and Channels

Hard Armor

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Geocell Confinement Systems:

Geocell is filled with soil.
Large Geotextile Tubes are used for beach erosion control.

Tubes filled with a soil slurry to hold back water.

Tube placed on the ground surface for a barrier to sediment.
Stream bank revetment

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Wave protection revetments and key trenches for under-water construction


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Wave protection revetments and key trenches for dry construction


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Scour protection for bridge abutment


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Cross section and placement details of geotextile in stream bank protection
(After Task force 25 report, AASHTO-AGC-ARTB Joint Committee, 1990)

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The adjacent rolls of geosynthetics should be overlapped (0.3 m), sewed or seamed keeping a minimum offset of 1.5 m. However, minimum one meter overlap should be provided when those are placed under water.

The threads used for sewing should be high strength polyester or polypropylene but not the nylon thread.

Steel pins of diameter 5 mm and 0.5 m long fitted with 40 mm diameter washer should be spaced along the overlap alignment at a spacing of 1 m center to center.

The placement of armor (riprap, block, sandbags) should start from the toe and proceed up the slope. Heavy riprap should not fall from a height more than 300 mm.
The bedding layer is to be placed within two weeks to protect the geosynthetic from ultraviolet light. It also acts as a cushion to avoid tearing or puncturing of the geosynthetic.

In case of geocell or jute and coir geotextile, seeds can be placed for new vegetation.

- Its root structure provide strength to the soil to hold in place.
- The vegetation provides shelter from the wind and rain over the long terms.
- As the vegetation matures, it degrades leaving completely natural environment.
Design Steps:

**Step 1:** Determine the characteristics of the field soil

a) **Draw** grain size distribution curve and calculate $D_{10}$, $D_{50}$, $D_{60}$, $D_{85}$ and $D_{90}$.

b) **Calculate** coefficient of uniformity ($C_u$)

$$C_u = \frac{D_{60}}{D_{10}}$$

c) **Perform** laboratory tests to determine the coefficient of permeability.
Step 2: Calculation of slope angle (\( \beta \)) if not provided.

River bank geometry

\[ H_s = \text{height of slope}, \ H_w = \text{Height of water level} \]
\[ \beta = \text{slope angle} \]

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Hoek (1973) reported the following equations,

\[ Y = 1.1 \times \gamma \times \frac{H_s}{C} \]

\[ X = \beta - \left[ 1.2 - \frac{H_w}{2H_s} \right] \phi \]

\( \gamma \) = unit weight of soil,
\( C \) = cohesion of soil,
\( \phi \) = Angle internal friction of soil
\( X, Y \) = auxiliary factors

Variation of \( X \) and \( Y \) with FOS (After Hoek, 1973)

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Step 3: Determine the weight of armors

(a) The minimum acceptable weight of armor stone (W) can be expressed according to Hudson’s formula (1959),

\[ W = \frac{350 H^3 \gamma_s \tan \beta}{(\gamma_s - 10)^3} \]

(No damage and no over toppling)

\( W \) = weight of armor (kN),
\( H \) = wave height (m),
\( \gamma_s \) = unit weight of rock (kN/m\(^3\)), and
\( \beta \) = slope angle (Degree)
Wave height versus armour weight graph based on Hudson’s formula (1959)

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(b) Determine armor weight based on the velocity of water either turbulent flow or laminar flow.

Riprap weight based on the flow velocity
(After Blake, 1975 From Don and Low Ltd., 1988)

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Step 4: Calculate the equivalent diameter of armor stone.

\[ D_e = \sqrt[3]{(7 \times W \times 10^{-4})} \]

- \( D_e \) = equivalent diameter (m)
- \( W \) = armor weight (kg)

Minimum thickness of stone layer = \((2 \times D_e)\)

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Equivalent diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89</td>
</tr>
<tr>
<td>10</td>
<td>191</td>
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<tr>
<td>70</td>
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</tr>
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<td>519</td>
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<tr>
<td>250</td>
<td>559</td>
</tr>
<tr>
<td>300</td>
<td>594</td>
</tr>
</tbody>
</table>
Step 3: Determine the required bedding

A protective or bedding layer is recommended to provide between the geosynthetic and riprap.

Protective layer for rip-rap installation

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Size of the protective layer should satisfy the following conditions,

- \( d_{100} < 0.5 \times D_e \)

- \( d_{100} = \) Grain size of protective layer at 100% passing finer

- Thickness of the protective layer \( \geq (D_e) \)

- The protective layer should not wash through the riprap.

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Step 4: Determine the required flow rate \( (q_{\text{reqd}}) \) in field condition

Step 5: Determine the required permittivity \( (\psi_{\text{reqd}}) \)

\[
\psi_{\text{reqd}} = \frac{k_n}{t_g} = \frac{q_{\text{reqd}}}{\Delta h \times A}
\]

\( \Delta h \) = hydraulic head

\( A \) = area of geosynthetic perpendicular to flow

\( k_n \) = cross-plane permeability of geosynthetic

\( t_g \) = thickness of geosynthetic
**Step 6:** Determine ultimate permittivity of the candidate geosynthetic ($\psi_{ult}$) in laboratory

**Step 7:** Determine allowable permittivity ($\psi_{allow}$) of the candidate geosynthetic

\[ \psi_{allow} = \frac{\psi_{ult}}{\text{cumulative reduction factor}} \]

$RF_{SCB} =$ Reduction factor for soil clogging and blinding,

$RF_{CR} =$ Reduction factor for creep of void space,

$RF_{IN} =$ Reduction factor for materials intruding into geotextile’s voids space,

$RF_{CC} =$ Reduction factor for chemical clogging, and

$RF_{BC} =$ Reduction factor for biological clogging.

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Step 8: Determine the factor of safety (FS)

\[ FS = \frac{\psi_{allow}}{\psi_{reqd}} \]

Step 9: Determine apparent opening size (AOS) of the candidate geosynthetic
### Universal Soil Loss Equation (USLE) for Slope Erosion

Wischmeier and Smith (1960) reported the universal soil loss equation (USLE) for slope erosion,

\[ E = R \times K \times (LS) \times C \times P \]

- \( E \) = Soil loss
- \( R \) = Rainfall factor (dimensionless)
- \( K \) = Soil erodibility factor (dimensionless)
- \( LS \) = Length of slope or gradient factor (dimensionless)
- \( C \) = Vegetative cover factor (dimensionless)
- \( P \) = Conservation practice factor (dimensionless)
Channel Erosion

- The velocity approach for channels can be expressed as,

\[ V_{reqd} = \frac{1.0}{n} \left( \frac{R^{2/3}}{S_f^{1/2}} \right) \]

- \( V_{reqd} \) = flow velocity (m/sec),
- \( n \) = manning coefficient (dimensionless),
- \( R \) = hydraulic radius = \( A/P \),
- \( A \) = cross sectional area (m\(^2\)),
- \( P \) = wetted perimeter (m), and
- \( S_f \) = slope of channel (dimensionless)
The shear stress approach for channels can be expressed as:

$$T_{\text{reqd}} = \gamma_w \cdot d \cdot S_f$$

Where,

- $T_{\text{reqd}} = \text{required shear stress (kN/m}^2\text{)}$
- $\gamma_w = \text{unit weight of water (kN/m}^3\text{)}$
- $d = \text{depth of flow (m)}$
- $S_f = \text{slope of channel (dimensionless)}$
Example: Design proper geotextile for placing at river bank in view to control the erosion. Soil properties and river bank geometry are given below:

\[ d_{50} = 0.06 \text{ mm}, \quad d_{85} = 0.4 \text{ mm}, \]

Height of slope \((H_s) = 8 \text{ m}, \) Height of water level \((H_w) = 5 \text{ m}, \)

Cohesion of soil \((C) = 5 \text{ kN/m}^2,\)

Coefficient of uniformity \((C_u) = 9, \) CBR = 4\%,

\(\phi = \) Angle internal friction of soil = 27°,

Unit weight of soil \((\gamma) = 19 \text{ kN/m}^3, \) and

Wave height \((H) = 1 \text{ m}\)

Unit weight of block placed over geotextile \((\gamma_s) = 25 \text{ kN/m}^3\)
River bank geometry

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Solution:

Given data:

\( d_{50} = 0.06 \text{ mm}, \)
\( d_{85} = 0.4 \text{ mm}, \)
Height of slope (H) = 8 m,
Height of water level (\( H_s \)) = 5 m,
Soil cohesion (C) = 5 kN/m\(^2\),
Coefficient of uniformity (\( C_u \)) = 9, and
CBR value = 4%
Step 1: Calculation of slope angle

Hoek (1973) reported the following equations,

\[ Y = 1.1 \times \gamma \times \left( \frac{H_s}{C} \right) \]

\[ X = \beta - \left[ 1.2 - \frac{H_w}{2H_s} \right] \phi \]

\[ \gamma = 19 \text{kN/m}^3, \ H_s = 8 \text{ m}, \ C = 5 \text{kN/m}^2, \ H_w = 5 \text{ m}, \ \phi = 27^\circ \]

\[ X, \ Y = \text{auxiliary factors}, \ \beta = \text{slope angle}, \]

Therefore, \[ Y = 1.1 \times 19 \times 8/5 = 33.44 \]

Assume rotational factor of safety (FOS) = 1.5

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Variation of X and Y with FOS (Aftre Hoek, 1973)

From the graph for \( Y = 33.44 \) and FOS = 1.5, we get the value of \( X = 4.5 \)

Therefore,

\[
4.5 = \beta - \left[ 1.2 - \frac{5}{2 \times 8} \right] \times 27
\]

\[
\beta = 28.46^\circ
\]

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Step 2: Calculation of block weight

\[ W = \frac{350 H^3 \gamma_s \tan \beta}{(\gamma_s - 10)^3} \]

\( H = \) wave height = 1 m, \( \gamma_s = 25 \text{ kN/m}^3 \), and \( \beta = 28.46^\circ (\approx 1:2) \)

For \( \beta = 28.46^\circ \) and wave height (H) = 1 m, the weight (W) comes out to be 1.5 kN = 150 kg

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Step 3: Calculation of equivalent armor diameter and minimum total layer thickness

Equivalent armor diameter ($D_e$),

$$D_e = \frac{3}{4} \sqrt[3]{7 \times W \times 10^{-4}}$$

$$D_e = \frac{3}{4} \sqrt[3]{7 \times 150 \times 10^{-4}} = 0.47 \text{ m}$$

The armor layer should be laid in two courses to a minimum total thickness $= 2 \times D_e = 2 \times 0.47 = 0.94 \text{ m}$

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Step 4: Calculation of bedding (protective) layer

Size of the stones in protective layer \( (d_{100}) < 0.5 \, D_e \)

Hence, \( d_{100} < (0.5 \times 0.47 \, m = 0.235 \, m = 235 \, mm) \)

Thickness of the protective layer should be greater than or equal to equivalent diameter of the riprap \( (D_e) \).

Hence, thickness of the protective layer \( \geq 470 \, mm \)

The protective layer should not wash through the riprap.

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Step 5: Calculation of opening size ($O_{95}$)

Apparent opening size of geotextile can be selected from the following Table (After Giroud, 1982).

<table>
<thead>
<tr>
<th>$C_u$</th>
<th>$(d_{85} / d_{50}) &lt; 2$</th>
<th>$(d_{85} / d_{50}) &lt; 4$</th>
<th>$(d_{85} / d_{50}) &gt; 4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 3$</td>
<td>$O_{95} \leq 1(d_{50})$</td>
<td>$O_{95} \leq 1.5(d_{50})$</td>
<td>$O_{95} \leq 1.5(d_{50})$</td>
</tr>
<tr>
<td>$&lt; 6$</td>
<td>$O_{95} \leq 1.5(d_{50})$</td>
<td>$O_{95} \leq 1.8(d_{50})$</td>
<td>$O_{95} \leq 1.8(d_{50})$</td>
</tr>
<tr>
<td>$&gt; 6$</td>
<td>$O_{95} \leq 1(d_{50})$</td>
<td>$O_{95} \leq 1.6(d_{50})$</td>
<td>$O_{95} \leq 2(d_{50})$</td>
</tr>
</tbody>
</table>

For $C_u = 9$ and $d_{85}/d_{50} = 0.4/0.06 = 6.67$,

$O_{95} \leq 2 \times d_{50}$, \hspace{1cm} $d_{50} = 0.06$ (Given)

Therefore, $O_{95} = 2 \times 0.06 = 0.12$
Please let us hear from you

Any question?
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THANKS FOR LISTENING