GEOSYNTHETICS ENGINEERING: IN THEORY AND PRACTICE

Prof. J. N. Mandal

Department of civil engineering, IIT Bombay, Powai, Mumbai 400076, India.
Tel. 022-25767328
email: cejnm@civil.iitb.ac.in

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Recap of previous lecture.....

- Introduction
- Mechanism of filtration function
- Geosynthetics filtration and drainage criteria
- Geosynthetic drainage applications
- Subsurface drainage
Example: Site conditions: Less critical condition. Stone riprap slope protection with geotextile needed.

Step 1: Determine grain size distribution of soil

\[ D_{60} = 0.18, \ D_{10} = 0.040, \ D_{85} = 0.40, \ D_{15} = 0.05 \]

Step 2: Determine retention criteria

\[
C_u = \frac{D_{60}}{D_{10}} = \frac{0.18}{0.04} = 4.5
\]

\[
4 \leq C_u \leq 8; \quad B = \frac{8}{C_u} = \frac{8}{4.5} = 1.78
\]

\[
B \ D_{85} = 1.78 \times 0.40 = 0.712 \ mm
\]

For retention criteria in steady flow condition to be satisfied, A.O.S or \( O_{95} \leq 0.712 \ mm \)

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Step 3: Determine permeability criteria

\[ k_{soil} = (D_{10})^2 = (0.04)^2 = 1.6 \times 10^{-3} \text{ cm/sec} \]

For less critical and less severe applications, \( k_{geotextile} \geq 1k_{soil} \)

Therefore, \( k_{geotextile} \geq 1.6 \times 10^{-3} \text{ cm/sec} \)

Step 4: Determine permittivity criteria

For percent in-situ passing 0.075 mm sieve < 15%,

Permittivity \( (Ψ) \geq 0.5 \text{ sec}^{-1} \) (AASHTO T88)
**Step 5:** Selection of drainage aggregates

Range of Coefficient of Permeability ($k_s$) for materials of different sizes

<table>
<thead>
<tr>
<th>Type</th>
<th>Size (mm)</th>
<th>Permeability ($k_s$) (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Gravel</td>
<td>20 - 63</td>
<td>$\sim 5 \times 10^{-1}$</td>
</tr>
<tr>
<td>Medium Gravel</td>
<td>6.3 - 20</td>
<td>$\sim 1 \times 10^{-1}$</td>
</tr>
<tr>
<td>Fine Gravel</td>
<td>2.0 – 6.3</td>
<td>$\sim 5 \times 10^{-2}$</td>
</tr>
<tr>
<td>Coarse Sand</td>
<td>0.63 – 2.0</td>
<td>$\sim 1 \times 10^{-2}$</td>
</tr>
</tbody>
</table>
Step 6: Determine clogging criteria

For less critical and less severe conditions,

\[ O_{95} \text{ (geotextile)} \geq 3 \ D_{15} \text{ (soil)} \text{ for } C_u > 3 \]

Here, \( C_u = 4.5 > 3 \)

Therefore, \( O_{95} \geq 3 \ D_{15} \geq 3 \times 0.05 \geq 0.15 \text{ mm} \)

Nonwoven geotextile: Porosity \( \geq 50 \% \)

Woven geotextile: Percent open area \( \geq 5\% \)
Geosynthetics can effectively perform the filtration function in different Civil engineering applications like retaining walls, pavement, erosion control, silt fence etc.

In a conventional rigid concrete retaining wall, water can pass through the vertical drainage layer to the under drain system or weep holes and consequently, development of hydrostatic pressure behind the retaining wall can be reduced. However, drainage sand layer can become clogged after a passage of time causing the wall to collapse due to generation of high hydrostatic pressure.

The problem can be overcome by providing geosynthetics behind reinforced concrete wall or using gabion wall (consisting of wire baskets filled with stones of 100 mm size).

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Geosynthetic design for filtration:
The major criteria for filtration is the cross-plane permeability and apparent opening size of geosynthetic.

**Step 1:** Draw the flow nets behind retaining wall. Determine quantity of flow using the following equation,

\[ q = k \times \Delta h \times \frac{N_f}{N_d} \]

$q =$ Flow rate (m³/sec/m), $k =$ Permeability of soil (m/sec)

$\Delta h =$ head lost (m), $N_f =$ Number of flow lines, and

$N_d =$ Number of potential lines

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
**Step 2:** Determine required permittivity or cross plane permeability

When water passes perpendicular or across the plane of the candidate geosynthetics, it is called permittivity or cross plane permeability.

**Concept of cross plane permeability**

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
From Darcy’s equation,

\[ q = k_n \cdot i \cdot A = k_n \cdot (\Delta h/t_g) \cdot A \]

Permittivity (\(\psi\)) = \[
\left( \frac{k_n}{t_g} \right) = \frac{q}{A \cdot \Delta h}
\]

\(\Psi\) = permittivity (sec\(^{-1}\))

\(q\) = flow rate calculated using flow net (m\(^3\)/sec),

\(k_n\) = hydraulic conductivity (Normal to geosynthetic) (m/s),

\(A\) = area of geosynthetics = W \times L (m\(^2\)),

\(\Delta h\) = head lost (m), and

\(t_g\) = thickness of geosynthetic (m)
Slope representation of permittivity

\[ \Psi = \frac{q}{\Delta h \ A} \]

Permittivity = \( \Psi \) (sec\(^{-1}\))

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Step 3: Determine the ultimate permittivity of geosynthetic ($\Psi_{ult}$) from laboratory tests.

\textit{a) Constant head method}

Permittivity ($\psi$) = \( \frac{k_n}{t_g} \) = \( \frac{q}{A \cdot \Delta h} \)

Q = total water collected after time $\Delta t$

Hence, flow rate = $q = Q/ \Delta t$

A = cross-sectional area of geosynthetic = ($W \times L$)

$k_n$ = cross-plane permeability of geosynthetic

$t_g$ = thickness of geosynthetic

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
b) **Falling head method**

\[
\frac{K_n}{t_g} = \psi = 2.3 \frac{a}{A \Delta t} \log_{10} \frac{h_0}{h_f}
\]

- \(a\) = area of stand pipe (m\(^2\))
- \(A\) = area of geosynthetic (m\(^2\))
- \(\Delta t\) = time change between \(h_0\) and \(h_f\) (sec)
- \(h_0\) = head at beginning of the test (m)
- \(h_f\) = head at end of the test (m)

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Step 4: Determine the allowable permittivity of geosynthetic ($\Psi_{\text{allow}}$) using the following equation in case of flow related problems (Koerner, 1995),

$$\Psi_{\text{allow}} = \frac{\Psi_{\text{ult}}}{\text{cumulative reduction factors}}$$

The range of recommended reduction factors depends on the type of application (Koerner, 1995) such as,

- retaining wall,
- erosion control,
- pavement,
- landfill,
- gravity drainage, and
- pressure drainage etc
**Step 5**: Determine the factor of safety (FS)

\[
F.S. = \frac{\text{Allowable permittivity of candidate geosynthetic}}{\text{Required permittivity of candidate geosynthetic}} = \frac{\psi_{\text{allow}}}{\psi_{\text{reqd}}}
\]

**Step 6**: If the factor of safety is adequate, the candidate geosynthetics is acceptable, otherwise try a different candidate geosynthetic.
Step 7: Determine all parameters such as,

- Effective diameter of soil, $d_{10}$ (mm)
- Coefficient of uniformity of the soil, $C_u$
- Coefficient of permeability of the soil (m/sec)
- Relative density of soil (DR)$\%$, and
- $d_{85}$ (mm) from the grain size distribution curve of the site specific soil
**Step 8:** Check the required apparent opening size of candidate geosynthetics \( (AOS \text{ or } O_{95\text{reqd}}) \) to prevent the soil loss based on the soil retention criteria.

Four methods can be used for soil retention criteria:

- Task force 25 (1991)
- Carroll method, (1983)
- Giroud method (1982), and
- Luettich et al. (1992)

Carroll method can be used for non-critical cases, whereas Giroud method can be used for critical case.
Task force 25 (AASHTO, 1991)

a) For particles ≤ 50 % passing the No. 200 sieve (0.075 mm),

\[ O_{95} \geq \text{No. 30 sieve (0.60 mm)} \]

b) For particles > 50 % passing the No. 200 Sieve,

\[ O_{95} \geq \text{No. 50 Sieve (0.30 mm)} \]
Carroll Method (1983)

This method can be used for noncritical cases.

\[ O_{95} < (2 \text{ or } 3) \, d_{85} \]

i.e. \[ O_{95} < 2.5 \, d_{85} \]

\[ d_{85} = \text{particle size at percentage finer of 85\%} \]
The required apparent opening size of geotextile varies for different relative densities of soil as reported in the Table.

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Relative density of the soil ($D_R$)</th>
<th>Liner coefficient of uniformity of the soil ($C_u$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose granular soil</td>
<td>$D_R &lt; 50 %$</td>
<td>$O_{95} &lt; C_u d_{50}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$O_{95} &lt; (9 d_{50})/C_u$</td>
</tr>
<tr>
<td>Medium granular soil</td>
<td>$D_R &lt; 80 %$</td>
<td>$O_{95} &lt; 1.5 C_u d_{50}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$O_{95} &lt; (13.5 d_{50})/C_u$</td>
</tr>
<tr>
<td>Dense granular soil</td>
<td>$D_R &gt; 80 %$</td>
<td>$O_{95} &lt; 2 C_u d_{50}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$O_{95} &lt; (18 d_{50})/C_u$</td>
</tr>
<tr>
<td>Plasticity Index (PI)</td>
<td>&lt; 5</td>
<td></td>
</tr>
</tbody>
</table>
Luettich et al. (1992)

Soil retention criteria for geotextile filter design under steady-state flow conditions

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
\( d_x \) = the particle size of which \( x \) percent is smaller

\( I_D \) = relative density of the soil

\( PI \) = plasticity index of the soil

\( DHR \) = double-hydrometer ratio of the soil

\( O_{95} \) = geotextile opening size

\( C_u' = \frac{d'_{100}}{d'_0} \)

\( C_c = \frac{(d_{30})^2}{d_60 \times d_{10}} \)

\( d'_{100} \) and \( d'_0 \) are the extremities of a straight line drawn through the particle size distribution as directed above and \( d'_{50} \) is the midpoint of this line.
Soil retention criteria for geotextile filter design under dynamic flow conditions. (After Luettich et al., 1992)

\[ C_u = \frac{d_{60}}{d_{10}} \]

- **FROM SOIL PROPERTIES TESTS**
  - **NON-DISPERSIVE SOIL**
    - \( d_{20} < 0.002 \text{ mm} \)
    - \( d_{10} < 0.07 \text{ mm} \)
  - **DISPERSSIVE SOIL**
    - \( d_{20} > 0.002 \text{ mm} \)
    - \( d_{10} > 0.07 \text{ mm} \)
  - **LESS THAN 20% CLAY AND MORE THAN 10% SILT**
  - **MORE THAN 90% GRAVEL**
    - \( d_{10} > 4.8 \text{ mm} \)
  - **LESS THAN 10% SILT AND MORE THAN 10% SAND**
  - **SEVERE WAVE ATTACK**
    - \( O_{95} < d_{50} \)
    - \( c_u > 5 \)
  - **MILD WATER CURRENTS**
    - \( c_u < 5 \)
    - \( d_{50} < O_{95} < d_{90} \)
  - **PLASTIC SOIL**
    - \( PI > 5 \)
  - **NON-PLASTIC SOIL**
    - \( PI < 5 \)
  - **USE 3 TO 6 INCHES OF VERY FINE SAND BETWEEN SOIL AND GEOTEXTILE, THEN DESIGN THE GEOTEXTILE AS A FILTER FOR THE SAND**
  - **Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay**
Step 9: Determine the allowable apparent opening size of geosynthetics \( (O_{95 \text{allow}}) \) from the laboratory sieve test.

Step 10: Determine the factor of safety of geosynthetic against apparent opening size.

\[
F.S. = \frac{O_{95 \text{reqd}}}{O_{95 \text{act}}}
\]

Step 11: If the FOS is not adequate (i.e. opening size of the candidate geosynthetic is larger enough and fails to retain soil), try with another candidate geosynthetics. It must satisfy the permittivity and soil retention criteria.

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Step 12: Clogging criterion (long-term flow compatibility)

Gradient ratio test (GRT) should be conducted.

Check that gradient ratio ≤ 3.

In that case, the geosynthetic is free from clogging.
Applications:

I. Geosynthetics behind retaining walls

- In a conventional reinforced concrete retaining wall, granular soil is used as vertical drainage layer to allow the water from backfill soil to the under drains or weep holes.

- Over the passage of time, sand drain may become excessively clogged due to the retained backfill soil. As a result, excessive hydrostatic pressure builds up in the backfill zone causing failure of the structure.

- A layer of geosynthetic filter, introduced at the back of the retaining wall, will retain the backfill soil and allow only water to filter into the granular drainage layer.
Geosynthetics behind retaining wall for filtration

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
A gabion wall is made of galvanized wire baskets filled with stones of size nearly 100 mm or larger stones. It is a flexible wall with its free draining system. It also requires a geosynthetic filter at the back as shown in Figure below.
Giroud (1988) reported the typical hydraulic gradients:

1) If the drainage is for embankment, road and slope etc, the hydraulic gradient will be less than one.

2) If the drainage is for wall and trenches, the hydraulic gradient will be 1.5.
Example:

A flexible retaining wall of 4.5 m height is made of gabion which consists of 1 m × 1 m × 4 m baskets. It rests on a 0.5 m × 2 m × 4 m mattress as shown below.
Properties of silty sand

Particle size finer than 85% = $d_{85} = 0.12\text{mm}$,
Particle size finer than 50% = $d_{50} = 0.06\text{mm}$
Effective particle size = $d_{10} = 0.02\text{mm}$
Relative density = $R_D = 85\%$
Coefficient of uniformity = $C_u = 2.7$
Coefficient of permeability of soil ($k$) = 0.0065 m/sec

**Candidate Geotextile:** (Non woven needle punched)

Apparent opening size (A.O.S.) = 0.25 mm
Permittivity of geotextile = $\Psi = 1.1$/sec
Cumulative reduction factor (R.F.) = 12

Check suitability of geotextile.
Solution: Two stages of design

- Flow factor of safety
- Opening size of geotextile, i.e. retention criteria

**Flow factor of safety**

**Step 1:** Calculate actual flow rate using flow net.

\[ q = k \times \Delta h \times \frac{N_f}{N_d} \]

\[ q = \text{Flow rate, } k_{\text{soil}} = 0.0065 \text{ m/sec, } \Delta h = 4.5, N_f = 4, N_d = 5 \]

\[ q = 0.0065 \times 4.5 \times \frac{4}{5} = 0.0234 \text{ m}^3/\text{sec/m} \]
Step 2: Required permittivity of geotextile ($\Psi_{reqd}$)

$$\Psi_{reqd} = \frac{k_n}{t_g} = \frac{q}{\Delta h \cdot A_L}$$

$q = 0.0234 \text{ m}^3/\text{sec/m},$

$k_n = \text{Coefficient of permeability normal to the geotextile}$

$\Delta h = \text{Hydraulic head} = 4.5,$

$t_g = \text{Thickness of the geotextile, and}$

$A_L = \text{Area of geotextile per meter length} = (4.5 \times 1) \text{ m}^2$

$$\Psi_{reqd} = \frac{0.0234}{4.5 \times (4.5 \times 1)} = 1.16 \times 10^{-3} \text{ sec}^{-1}$$
Step 3: Allowable permittivity of geotextile

\[ \Psi_{ult} = 1.1 \text{ /sec (Given)} \]

\[ \Psi_{allow} = \frac{\Psi_{ult}}{R.F.} = \frac{1.1}{12} = 0.092 \text{ /sec} \]

Step 4: Factor of safety

\[ F.S = \frac{\Psi_{allow}}{\Psi_{Reqd}} \]

\[ F.S = \frac{0.092}{0.00116} = 78.44 \text{ (Ok)} \]

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
**Step 5: Geosynthetics opening size, i.e. retention criterion**

As it is not critical, apply Carroll’s criteria $O_{95} < 2.5 \, d_{85}$.

$O_{95} = 0.25 \, \text{mm}$

$2.5 \, d_{85} = 2.5 \times 0.12 = 0.3 \, \text{mm}$

Hence, $O_{95} < 2.5 \, d_{85}$

Therefore, soil retention criterion is satisfied.
II. Geosynthetic filters around under-drains in highway

- Generally, crushed stones and/or perforated pipes are conventionally used as under-drains for filtration in highways, railways and airfields. However, after a passage of time the under-drain systems become clogged due to seepage of water through native soil to the crushed stones.

Therefore, layers of geosynthetics surrounding the stones/aggregates are to be provided to protect the aggregates from fine soil contamination.

- Some applications of geosynthetics in under-drains without and with perforated pipe are shown here.

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Conventional aggregate drain with perforated pipe

Geosynthetics around aggregates with perforated pipe

Geosynthetic wrapped aggregate without pipe

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Use of geosynthetics in different pavement under-drains:

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Installation procedure of geosynthetics in under drain:

Sequential procedure for under drain construction with geosynthetic

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Step 1: Excavate the sub grade soil to form a required size of trench as shown in Figure (a).

Step 2: Place the geosynthetic such as there should not be any void space behind the geosynthetic. Avoid any kind of folding or wrinkling on the geosynthetic as shown in Figure (b).

Step 3: Place granular aggregates at the bottom of trench as a bedding layer up to minimum 10 cm height before the placement of perforated pipe or collector pipe (if required) as shown in Figure (c).
**Step 4:** Remaining portion of the trench should be filled up with granular material under proper compaction as shown in Figure (d).

Generally, compaction is done by vibratory equipment. The minimum compaction should be 95% standard proctor.

**Step 5:** When compaction is over to the required depth of the trench, overlap the geosynthetic on the top of the granular materials as shown in Figure (e).

The minimum overlap should be 30 cm to 60 cm for drain. The overlap helps to protect the drainage aggregate from surface contamination.

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Step 6: The remaining part (minimum 30 cm) of the trench should immediately be filled up with loosely excavated materials and compacted [Figure (f)].

It is preferable not to expose the geosynthetic to sunlight, dirt or any kind of damage.

Geosynthetics will prevent the soil from migrating into the aggregates while allow the water to flow. As transmissivity of open graded stones is adequate, there is no need for a perforated pipe in the drainage system.

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Example: A geotextile filter is provided around the under-drain in a highway. Design the geotextile filter.
Size of drain = (350 mm x 550 mm)

Δh = 500 mm

**Soil Properties:**
Coefficient of curvature, $C_c = 1.8$,
Coefficient of uniformity, $C_u = 4$,
Particle size finer than 50%, $d_{50} = 0.03$ mm
Relative density, $R_D = 75$

**Geotextile properties:**
Apparent opening size, A.O.S. = 0.20 mm
$q_{ult} = 12$ m$^3$/day/m
Permittivity = $\Psi = 1.2$/sec
Cumulative reduction factor, R.F. = 20
Solution:

Permittivity criterion

Step 1: Calculate required permittivity ($\Psi_{\text{reqd}}$)

$$
\Psi_{\text{reqd}} = \frac{k_n}{t_g} = \frac{q}{\Delta h \cdot A_L}
$$

$$
\Psi_{\text{reqd}} = \frac{12}{0.5 \times 0.35 \times 1} = 68.57 \text{/day} = 0.00079 \text{/sec}
$$

$q = \text{Maximum flow rate coming from the top aggregates} = 12 \text{ m}^3\text{/day/m},$

$\Delta h = 0.5 \text{ m},$

$A_L = \text{Area of geotextile per meter length} = (0.35 \times 1) \text{ m}^2$
Step 2: Calculate allowable permittivity of geotextile

Given, $\Psi_{ult} = 1.2 / \text{sec}$

$\Psi_{allow} = (1.2 / \text{R.F.}) = 1.2 / 20 = 0.06 / \text{sec}$

Step 3: Factor of safety

$$F.S = \frac{\Psi_{allow}}{\Psi_{Reqd}}$$

$$F.S = \frac{0.06}{0.00079} = 75.96$$

(Ok)

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Retention criterion

**Step 4:** Apparent opening size of geotextile

According to Luettich et al. (1992), under steady-state flow conditions for $R_D = 75\%$ and $C_u = 4$, we can write,

$$O_{95} = \text{Apparent opening size} < 18 \frac{d_{50}}{C_u}$$

$$18 \frac{d_{50}}{C_u} = 18 \times 0.03/4 = 0.135$$

Given, Apparent opening size (A.O.S.) = $O_{95} = 0.20$

Therefore, $F.S. = \frac{0.135}{0.2} = 0.675$ (Not acceptable)
The candidate geosynthetic is not acceptable. Soil will not be retained as opening size is too big. So, alternative geosynthetics with tight pore structure is needed.

As the permittivity factor is too high, tighter geosynthetics can reduce the factor of safety for permittivity.

Then both permittivity and retention criteria will be satisfied.

Similarly, we can apply geosynthetics in the following areas:

- Geosynthetics as silt fences
- Geosynthetics beneath erosion control structure
Please let us hear from you

Any question?
Prof. J. N. Mandal

Department of civil engineering, IIT Bombay, Powai, Mumbai 400076, India.
Tel. 022-25767328
email: cejnm@civil.iitb.ac.in

THANKS FOR LISTENING