Geosynthetics Engineering: In Theory & Practice

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Lecture No - 11
GEOSYNTHETICS ENGINEERING: IN THEORY AND PRACTICE

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Module - 3
LECTURE- 11
Geosynthetic properties and test methods

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RECAP of previous lecture…..

- When to test geosynthetics?
- Physical Properties
- Mechanical Properties (Partly Covered)
Puncture Resistance Test
(ASTM D6241 and ISO 12236)

Inside diameter of CBR mold = 150 mm.

Load is applied with a 50 mm diameter steel cylinder flat-tipped rod.

Unit of CBR puncture strength = Newton

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\[ T_g = \frac{P_p}{2 \pi R} \]  
(Cazzuffi and Venesia, 1986)

\[ T_g = \text{Tensile strength of geotextile (kN/m)} \]
\[ P_p = \text{Puncture strength (kN)} \]
\[ R = \text{Radius of puncturing rod (m)} \]

\[ \varepsilon_g = \frac{(d - h)}{h} \times 100 \]  
(DIN standard)

\[ \varepsilon_g = \text{Strain at failure (%)} \]
\[ d = \text{Diagonal of the geosynthetics at failure (m)} \]
\[ h = \text{Horizontal distance between outer edge of the plunger and inner edge of the mould} \]
Analytical analysis of puncture resistance:

The geotextile may puncture due to the presence of sharp stones or roots during backfilling of soil and compaction by rollers and/or traffic loads.

Vertical forces exerted on the geotextile

\[
T_{\text{vertical}} = (\pi \cdot D_a \cdot D_h) \cdot P_g \cdot S' 
\]

- \(D_a\) = Average diameter of the puncturing object
- \(D_h\) = Protrusion height = \(D_a\)
- \(P_g\) = Pressure on geotextile from tire
- \(S'\) = Shape factor = 1 – \(S\)
- \(S\) = Sphericity of the object

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Now, the vertical force can be converted into tensile force of the geotextile.

\[
\frac{T_{\text{vertical}}}{T_{\text{required}}} = \frac{D_a}{D_i}
\]

\[T_{\text{required}} = \text{required tensile strength of the geotextile}\]
\[D_i = \text{apparent opening size of geotextile}\]
\[D_a = \text{Average diameter of the puncturing object}\]

Hence,

\[
T_{\text{required}} = \frac{T_{\text{vertical}}}{\left(\frac{D_a}{D_i}\right)} = \frac{\pi D_a D_a g S'}{D_a} \times D_i = \pi D_a g S' D_i
\]
Design chart for required puncture resistance due to the application of pressure at geotextile-stone interface (Factor of safety= 2.5) is shown here.

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Example: Determine the required puncture resistance of a geotextile when apparent opening size of geotextile is 0.40 mm. Size of rock = 30 cm. Sphericity of rock = 0.24, Tire pressure = 800 kPa and F.O.S. = 2.5

Solution:

\[ D_i = 0.40 \text{ mm} = 0.040 \text{ cm}, \quad S = 0.24, \quad D_a = 30 \text{ cm}, \quad P_g = 800 \text{ kPa} \]

Shape factor (\( S' \)) = 1 - S = 1 - 0.24 = 0.76

\[ T_{\text{reqd}} = \pi \cdot D_a \cdot P_g \cdot S' \cdot D_i \]
\[ = \pi \times 0.30 \times 800 \times 0.76 \times 0.00040 \]
\[ = 0.229211 \text{ kN} = 229.2 \text{ N} \]

F.O.S = 2.5, Hence, \( T_{\text{reqd}} = (229.2 \times 2.5) = 573 \text{ N} \)
Penetration resistance test (drop test) / drop cone (impact strength) (ISO 13433)/ tear (impact) resistance

This test method can simulate the stresses in geosynthetic when a rock falls on it.

Field problem and laboratory simulation of penetration resistance test

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The container is filled up with water to simulate the very soft soil and it ensures more practical result.

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Cone to measure diameter of the hole

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Analytical analysis of tear (impact) resistance:

When a rock falls freely on the geotextile from a height, geotextile resists the impact and/or damage and consequently, gravitational energy gets developed.

Energy \((e) = m \cdot g \cdot z \)

\[
= (\pi \times \rho \times g \times z)
\]

\[
= \left( \frac{4}{3} \pi r^3 \times \rho \right) \cdot g \cdot z
\]

\[
= \left( \frac{4}{3} \pi \frac{D^3}{8} \times \rho \right) \cdot g \cdot z
\]

\[
= \left( \pi \frac{D^3}{6} \times \rho w G_s \right) \cdot g \cdot z
\]  
(D in meter)

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When D in mm,

\[
e = \left( \frac{\pi (D/1000)^3}{6} \times \rho_w G_s \right) \cdot g \cdot z = 13.87 \times 10^{-6} \times D^3 \times z
\]

\(e\) = energy (Jules)
\(m\) = mass of rock (kg)
\(z\) = height of fall (m)
\(g\) = acceleration due to gravity (m/sec\(^2\)) = 9.81 m/sec\(^2\)
\(V\) = volume of rock (m\(^3\))
\(\rho_r\) = density of rock (kg/m\(^3\)) = \(\rho_w \times G_s\)
\(\rho_w\) = unit weight of water (kg/m\(^3\)) = 1000 kg/m\(^3\)
\(G_s\) = specific gravity of rock (dimensionless) = 2.7
\(r\) = radius of rock (m) = \(D/2\)
\(D\) = diameter of rock (mm)
Design chart for energy mobilization due to free fall of a rock on a geotextile

- The above design chart is only applicable when the geotextile is placed on a firm sub-grade.

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When the rock falls on a geotextile laid on soft sub-grade soil, the geotextile deforms and also resists higher amount of impact energy. Therefore, it is necessary to determine the modification factor as given by Koerner (2005).

\[
e_{\text{required}} = \frac{e}{\text{Modification factor (MF)}}
\]

\( e = \text{max energy developed if the geotextile is on a hard surface} \)

\( e_{\text{required}} = \text{required impact energy of geotextile} \)

\[
F.S. = \frac{e_{\text{allow}}}{e_{\text{required}}}
\]

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**Example:** Calculate mobilized energy due to free failing of a rock of 350 mm diameter from a height of 2 m on the geotextile. If C.B.R of subsoil = 3 and allowable impact strength of geotextile = 35 Jules, calculate the factor of safety.

**Solution:**

\[ D = 350 \text{ mm}, \quad Z = 2 \text{ m} \]

Mobilized energy (\( e \)) = \[ 13.87 \times 10^{-6} \times D^3 \times z \]
= \[ 13.87 \times 10^{-6} \times (350)^3 \times 2 \]
= 1189.35 Jules

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Energy required (\( e_{\text{reqd}} \)) = \( \frac{1189.35}{15} = 79.29 \) Jules

For C.B.R. = 3, Modification factor = 15

\[
F.S. = \frac{e_{\text{allow}}}{e_{\text{required}}}
\]

Factor of safety = \( \frac{35}{79.29} = 0.04 \)

(Not ok, the geotextile will damage)

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Size of tensile test specimens by single and multi-rib
(a) Specimen dimensions for method A (b) Specimen
dimensions for methods B and C

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For geogrid wide width method B and C, minimum width of the sample contains 5 ribs or is 200 ± 3 mm and length of the sample contains 2 apertures/ 3 junctions or is 300 mm.

The test is to be conducted in a tensile testing machine at a strain rate of 10 ± 3 % per minute.

Using hydraulic clamping grips, tensile strength of geosynthetic can be measured in between 30 and 120 kN/m.

If the tensile strength is more than 120 kN/m, roller grips are generally used.
Multi-rib geogrid tests using hydraulic clamping grips (ASTM D 6637 - 01)

Multi-rib geogrid tests using roller grips (ASTM D 6637 - 01)

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The tensile strength of geogrid = Observed breaking load \times C

C = \frac{N_m}{N_s},

N_m = \text{Minimum number of tensile elements within one meter width of the product}

N_s = \text{Number of tensile elements within the test specimen.}

Test results of a geogrid wide width method

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## Tensile strength test results of some geogrids

<table>
<thead>
<tr>
<th>Type of geogrids</th>
<th>Direction of test</th>
<th>Ultimate tensile strength, (kN/m)</th>
<th>Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>MD</td>
<td>38.30</td>
<td>12.86</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>32.50</td>
<td>13.56</td>
</tr>
<tr>
<td>G2</td>
<td>MD</td>
<td>51.96</td>
<td>13.68</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>33.45</td>
<td>13.37</td>
</tr>
<tr>
<td>G3</td>
<td>MD</td>
<td>71.63</td>
<td>13.57</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>32.81</td>
<td>13.68</td>
</tr>
<tr>
<td>G4</td>
<td>MD</td>
<td>99.90</td>
<td>12.50</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>30.00</td>
<td>14.60</td>
</tr>
<tr>
<td>G5</td>
<td>MD</td>
<td>122.30</td>
<td>10.60</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>39.44</td>
<td>11.25</td>
</tr>
<tr>
<td>G6</td>
<td>MD</td>
<td>130.77</td>
<td>11.25</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>31.60</td>
<td>12.23</td>
</tr>
<tr>
<td>G7</td>
<td>MD</td>
<td>172.30</td>
<td>11.94</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>33.32</td>
<td>14.23</td>
</tr>
<tr>
<td>G8</td>
<td>MD</td>
<td>206.00</td>
<td>13.06</td>
</tr>
<tr>
<td></td>
<td>CMD</td>
<td>34.32</td>
<td>13.86</td>
</tr>
</tbody>
</table>

**Note:** MD = Machine direction and CMD = Cross machine direction.
Determine geogrid rib tensile strength (GRI GG1-87)

- Test sample should contain three junctions in the concerned direction.
- For a biaxial geogrid, the tests are to be done for both longitudinal and transverse rib.

Rate of extension of the test machine = 50 mm per min.

Unit of rib tensile strength is kN
\[ T_{\text{rib}} = \frac{\Sigma T_i}{N} \]

\( T_i = \) Ultimate test strength of each rib (kN), and

\( N = \) Total number of test specimens (minimum of 10)

\[ T_{\text{grid}} = \frac{(T_{\text{rib}}) (n_{\text{rib}})}{L} \]

\( T_{\text{grid}} = \) Ultimate strength of geogrid (kN/m)

\( n_{\text{rib}} = \) Number of ribs in length \( L \) (Typically taken over one meter length)

\( L = \) length used to determine number of ribs in a meter.
Determination of geogrid junction (node) strength (GRI GG2)

Unit of junction or node strength is kN

- Junction strength efficiency (%) is evaluated as the ratio of junction strength to the rib strength. It may vary from 7% to 100% (Koerner, 2005).

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### Junction strength, rib strength and junction efficiency of some geogrids

<table>
<thead>
<tr>
<th>Geogrid designations</th>
<th>Junction strength (kN)</th>
<th>Rib strength (kN)</th>
<th>Junction efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geogrid-1</td>
<td>0.825</td>
<td>0.91</td>
<td>90.65</td>
</tr>
<tr>
<td>Geogrid-2</td>
<td>1.01</td>
<td>0.99</td>
<td>102.02</td>
</tr>
<tr>
<td>Geogrid-3</td>
<td>0.87</td>
<td>0.88</td>
<td>98.86</td>
</tr>
<tr>
<td>Geogrid-4</td>
<td>0.86</td>
<td>0.80</td>
<td>107.5</td>
</tr>
<tr>
<td>Geogrid-5</td>
<td>0.93</td>
<td>0.91</td>
<td>102.2</td>
</tr>
</tbody>
</table>
Junction strength of geocell

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Tensile strength of Gabions [ASTM A 975- 97 (Reapproved 2003)]

- Metallic-coated steel wire meshes require two types of test.
  - Load is to be applied parallel to the axis of the twist.
  - Load is to be applied perpendicular to the axis of twist.

- Failure must occur at least one mesh away from the gripping point; otherwise the sample will be rejected.

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Testing zinc coatings on galvanized mild steel wire
(BS 443: 1982)

- Firstly, clean the test specimen with the aid of methylated spirit and wipe it with a dry soft cloth.

- Take initial weight of the dry zinc coated steel wire sample = \( W_1 \)

- Immerge the specimen into a solution made of 5 ml antimony chloride solution and 100 ml hydrochloric acid of density between 1.16 and 1.18. After action is over, take out the wire from the acid, wash it thoroughly with water and make it dry.

- Weight of the dry steel wire after immersion into the acid = \( W_2 \)
Mass of the zinc coating wire \( (\text{g/m}^2) = \frac{(W_1 - W_2)}{\pi \cdot d \cdot l} \)

d = Diameter of steel wire = 3 mm

l = Length of steel wire \( \leq 100 \text{ mm} \)

Surface area of the wire is \( \pi \cdot d \cdot l \)

**Test results of a double twisted hexagonal wire mesh gabion (metallic coated steel wire gabion):**

- Tensile strength of gabion mesh parallel to twist = 40 kN/m
- Tensile strength of gabion mesh perpendicular to twist = 22.95 kN/m
- Tensile strength of wire = 465.50 kN/mm\(^2\)
- Weight of zinc = 464.31 gm/mm\(^2\)

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Direct shear test (ASTM D5321 AND ISO 12957)

Direct shear test (soil-to-soil)

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Large scale direct shear test of soil-to-geosynthetic

Size of test box
= 300 mm x 300 mm

Displacement rate
= 0.05 mm/min

Small scale direct shear test box

Size of test box
= 60 mm x 60 mm
Shear strength:

\[ \tau_s = c + \sigma_n \tan \phi \quad (\text{soil - to - soil}) \]

\( \tau_s = \) shear strength of soil

\( c = \) cohesion of soil

\( \sigma_n = \) normal stress

\( \phi = \) angle of friction (soil - to - soil)

\[ \tau_g = c_a + \sigma_n \cdot \tan \delta \]

\( \tau_g = \) shear strength of soil-to-geosynthetic

\( c_a = \) adhesion between soil and geosynthetic

\( \delta = \) Angle of wall friction between soil and geosynthetic
Geosynthetic efficiency due to cohesion and friction can be written as follows:

\[ \eta_c = \frac{c_a}{c} \times 100 \]  
(Efficiency due to cohesion)

\[ \eta_\phi = \frac{\tan \delta}{\tan \phi} \times 100 \]  
(Efficiency due to friction)

Direct shear test results (peak strength) on various geogrids

<table>
<thead>
<tr>
<th>Type of tests</th>
<th>Friction angle</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil-to-soil</td>
<td>36°</td>
<td>100</td>
</tr>
<tr>
<td>Soil-to-uniaxial geogrid-40</td>
<td>34°</td>
<td>94</td>
</tr>
<tr>
<td>Soil-to-uniaxial geogrid-60</td>
<td>34.5°</td>
<td>96</td>
</tr>
<tr>
<td>Soil-to-uniaxial geogrid-80</td>
<td>35°</td>
<td>97</td>
</tr>
</tbody>
</table>

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Minimum width of geogrid \((W_g)\) should be as follows to obtain the highest efficiency,

\[
W_g > 3.5 \, d_{50} \quad \text{(Sarsby, 1985)}
\]

\(d_{50}\) = average size of the backfill material
Please let us hear from you

Any question?
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THANKS FOR LISTENING