Geosynthetics Engineering: In Theory & Practice

Prof. J. N. Mandal
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Lecture No - 30
GEOSYNTHETICS ENGINEERING: IN THEORY AND PRACTICE

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Module - 6
LECTURE - 30
Geosynthetics for reinforced soil retaining walls
Recap of previous lecture.....

Example: Design of geogrid reinforced soil wall under static loading
II) Check for seismic loading:

\[ q = q_c + q_D \]

\[ 0.7H = 10.5 \text{ m} \]

\[ 0.5H = 7.5 \text{ m} \]

\[ 0.7H = 10.5 \text{ m} \]

\[ H = 15 \text{ m} \]

\[ z = 10.5 \text{ m} \]

\[ d_i = 4.5 \text{ m} \]

\[ (45^\circ + \Phi/2) \]

\[ 0.7H = 10.5 \text{ m} \]

\[ F_D \text{ (Seismic load)} \]

\[ q_h \]

\[ P_{ab \sin \theta_h} \]

\[ P_{ab \cos \theta_h} \]

\[ 0.6H \]

\[ V \tan \theta + C_{af} x L \]

\[ C_f = 0.6 \]

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Seismic thrust \( (P_{\text{AE}}) = 0.375 \times \alpha_m \times \gamma_b \times H^2 \)

\[ \alpha_m = (1.45 - \alpha_o) \alpha_o \]

\( \alpha_o = \text{Basic horizontal seismic co-efficient} \quad = 0.05 \text{ (given for zone II)} \)

\( \gamma_b = \text{unit weight of the backfill soil} = 17.5 \text{ kN/m}^3 \)

\( H = \text{height of the reinforced wall} = 15 \text{ m} \)

Therefore,

\[ \alpha_m = (1.45 - 0.05) \times 0.05 = 0.07 \]

\[ P_{\text{AE}} = 0.375 \times \alpha_m \times \gamma_b \times H^2 = 0.375 \times 0.07 \times 17.5 \times 15^2 \]
\[ = 103.36 \text{ kN/m} \]
Horizontal inertia force \( (P_{IR}) = \alpha_m \times \gamma_r \times H \times L_{\text{max}} \)

- 50% of \( P_{IR} \) should be considered.

\[ \gamma_r = \text{unit weight of the reinforced soil} = 18.5 \text{ kN/m}^3 \]

\[ L_{\text{max}} = 10.5 \text{ m} \]

Hence, \( P_{IR} = 0.07 \times 18.5 \times 15 \times 10.5 = 203.96 \text{ kN/m} \)
Total dynamic force on the retaining wall \( (F_D) \)
\[
= P_{AE} + 50\% \ P_{IR}
\]
\[
= (103.36 + 0.5 \times 203.96) \text{ kN/m}
\]
\[
= 205.34 \text{ kN/m}
\]

- \( F_D \) will act at a distance 0.6H from the bottom of the wall.

Overturning moment due to dynamic force \( (M_{OD}) \)
\[
= F_D \times 0.6 \ H
\]
\[
= (205.34 \times 0.6 \times 15)
\]
\[
= 1848.07 \text{ kN/m}
\]
A) Check for sliding:

Total driving force including dynamic force \((F_{\text{total}})\)
\[ = F_{\text{static}} + F_D = (727.44 + 205.34) \text{ kN/m} \]
\[ = 932.78 \text{ kN/m} \]

Total resisting force \((R)\)
\[ = 1578.815 \text{ kN/m (previously calculated)} \]

Factor of safety against sliding
\[ = \frac{R}{F_{\text{total}}} \]
\[ = \frac{1578.815}{932.78} \]
\[ = 1.693 > (0.75 \times 1.5 = 1.125) \text{ (Safe)} \]
B) Check for overturning:

Total overturning moment including overturning moment due to dynamic force $(M_o)_{total}$

\[
(M_o)_{static} + M_{OD} = 4105.35 + 1848.07 = 5953.416 \text{ kN/m}
\]

Total resisting force $(M_r)$

\[
M_r = 20855.09 \text{ kN/m (previously calculated)}
\]

Factor of safety against resisting moment

\[
= \frac{M_r}{(M_o)_{total}} = \frac{20855.09}{5953.416} = 3.5 > (0.75 \times 2 = 1.5) \text{ (Safe)}
\]
C) Check for bearing capacity:

As the wall is safe against bearing capacity failure for static case, it is safe even considering the seismic condition.
Example:

Design a pre-cast segmental block retaining wall of height 8 m with geogrid as reinforcement.

- Coverage ratio ($C_r$) = 1
- Length to height ratio ($L/H$) ≥ 0.7 (i.e., $L \geq 5.6$ m)
- Surcharge load ($q$) = 18 kN/ m$^2$
- Allowable tensile strength of geogrid ($T_a$) = 38 kN /m
- For connection of geogrid with segmental block, connection strength ($T_c$) = 34 kN/m
- Interaction coefficient ($C_i$) = 0.85
- Foundation bearing pressure = 700 kN /m$^2$
Properties of backfill soil
- Angle of internal friction of backfill soil ($\phi_b$) = 33°
- Unit weight of backfill soil ($\gamma_b$) = 18 kN/m$^3$

Properties of reinforced soil
- Angle of internal friction of reinforced soil ($\phi_r$) = 24°
- Unit weight of reinforced soil ($\gamma_r$) = 20 kN/m$^3$

Foundation soil properties:
- Angle of shearing resistance between soil and reinforcement ($\delta_f$) = 26°
- Cohesion = 0 kPa,
- Bearing capacity = 700 kPa
Precast concrete segmental retaining wall

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Solution:

A) External Stability

Step 1: Calculation of Coefficient of Earth pressure for backfill soil.

\[ K_{ab} = \frac{1 - \sin \phi_b}{1 + \sin \phi_b} \]

\( K_{ab} = \text{Coefficient Earth pressure of backfill soil.} \)

\( \phi_b = \text{Angle of internal friction of backfill soil} = 33^\circ \)

\[ K_{ab} = \frac{1 - \sin 33^\circ}{1 + \sin 33^\circ} = 0.294 \]
Step 2: Calculation of horizontal driving force due to backfill soil and surcharge.

Distribution of horizontal Earth pressure due to backfill and Surcharge

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Horizontal driving force due to backfill soil \((P_1)\)

\[
P_1 = 0.5 K_{ab} \gamma_b H^2
\]

- \(K_{ab} = \text{Coefficient of earth pressure for backfill soil} = 0.294\)
- \(\gamma_b = \text{Unit weight of backfill soil} = 18 \text{ kN/m}^3\)
- \(H = \text{Height of the retaining wall} = 8 \text{ m}\)

\[
P_1 = 0.5 \times 0.294 \times 18 \times 8^2 = 169.34 \text{ kN /m}
\]
Horizontal driving force due to surcharge ($P_2$)

$$P_2 = q \times K_{ab} \times H$$

$q = \text{surcharge load} = 18 \text{ kN/m}^2$

$K_{ab} = \text{Coefficient of earth pressure for backfill soil} = 0.294$

$H = \text{Height of the retaining wall} = 8 \text{ m}$

$$P_2 = 18 \times 0.294 \times 8 = 42.33 \text{ kN/m}$$
Step 3: Calculation of total horizontal driving force

Total horizontal force \((P) = P_1 + P_2\)

\(P_1 = \text{Horizontal force due to backfill soil} = 169.34 \text{ kN/m}\)

\(P_2 = \text{Horizontal force due to surcharge} = 42.33 \text{ kN/m}\)

Total horizontal driving force \((P)\)

\[= 169.34 + 42.33\]

\[= 211.67 \text{ kN/m}\]
Step 4: Calculation of resisting force

\[ \mu = \text{static co-efficient of friction} \]

\[ W = \text{total weight of the reinforced soil} \]

\[ \text{Total resisting force} = \mu \times W \]

\[ L = \text{Length of geogrid} \]
\[ \mu = \tan \delta_f = \tan 26^\circ = 0.4877 \]

\[ W = \gamma_r \times H \times L = 20 \times 8 \times L \]

\[ \delta_f = \text{Angle of shearing resistance between soil and reinforcement} \ 26^\circ \]

\[ \gamma_r = \text{Unit weight of reinforced soil} = 20 \text{ kN/m}^3 \]

\[ H = \text{Height of the retaining wall} = 8\text{m} \]

\[ L = \text{Length of geogrid.} \]

**Total Resisting force**

\[ = \mu \times W = 0.487 \times 20 \times 8 \times L = (77.92 \times L) \text{ kN/m} \]
Step 5: Check for Factor of safety against sliding.

Minimum Factor of safety against sliding = 1.5

\[ FOS = \frac{\text{Resisting force}}{\text{Sliding force}} \]

Resisting force = \((77.92 \times L)\) kN/m

Driving force = 211.67 kN/m

Hence, \(1.5 = \frac{77.92 L}{211.67}\)

\(L = 4.068 m < 5.6 m (0.7H)\) (OK)

Therefore, adopt the length of geogrid = 5.6 m
Step: 6 Calculation of length of geogrid based on overturning criterion

Minimum factor of safety against overturning = 2

\[(F.S.)_{\text{Overturning}} = \frac{\text{Stabilizing moment}}{\text{Overturning moment}}\]

\[W = \text{weight of reinforced soil}\]

\[L = \text{length of geogrid in reinforced soil zone}\]
Stabilizing moment ($M_s$):

$$M_s = \frac{W \times L}{2}$$

$$W = H \times \gamma_r \times L$$

$H = \text{height of retaining wall} = 8 \text{ m}$

$\gamma_r = \text{unit weight of reinforced soil} = 20 \text{ kN/m}^3$

$L = \text{length of geotextile in reinforced soil zone}$

$$M_s = \frac{H \times \gamma_r \times L \times L}{2} = \frac{8 \times 20 \times L^2}{2} = 80L^2 \text{ kNm / m}$$

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Overturning moment \((M_o)\):

\[M_o = (P_1 \times h_1) + (P_2 \times h_2)\]

- \(P_1\) = horizontal force due to backfill soil
- \(P_2\) = horizontal force due to surcharge soil
- \(h_1\) = distance of horizontal force \((P_1)\) from the base of wall
  = \(H/3 = 8/3\) m
- \(h_2\) = distance of horizontal force \((P_2)\) from the base of wall
  = \(H/2 = 8/2\) m

Hence,

\[M_o = \left(169.34 \times \frac{8}{3}\right) + \left(42.33 \times \frac{8}{2}\right) = 620.8\ \text{kNm} / \text{m}\]
Factor of safety against overturning,

\[(F.S.)_o = \frac{M_s}{M_o}\]

\[2 = \frac{80 \times L^2}{620.8}\]

\[L = 3.93 \text{ m}\]

\[L = 3.93 \text{ m} < 5.6 \text{ m} (0.7H)\]

Therefore, adopt the length of geogrid = 5.6 m

**Step: 7 Check for bearing pressure**

\[ (F.S.)_{B.C.} = \frac{\text{Allowable bearing pressure}}{\text{Actual bearing pressure}} \]

Allowable bearing pressure = 700 kN/m\(^2\) (Given)
Bearing capacity

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Actual bearing pressure = \[
\frac{(\gamma_r \times H \times L) + (q \times L)}{L - 2e}
\]

H = height of retaining wall = 8 m
\(\gamma_r\) = unit weight of reinforced soil = 20 kN/m\(^3\)
L = length of geotextile in reinforced soil zone = 5.6 m
q = surcharge pressure = 18 kN/m\(^2\)

**eccentricity** (e) = \[
\frac{\text{Overturning moment}}{\text{Total vertical load}}
\]

\[e = \frac{M_o}{(W) + (q \times L)}\]

\(M_o\) = overturning moment = 620.80 kN-m/m

W = weight of reinforced soil behind the retaining wall
\[= 8 \times 20 \times 5.6 = 896\ \text{kN/m}\]
Since, eccentricity $e < L/6$, no tension will develop (Ok)

Actual bearing pressure = \[
\frac{(\gamma_r \times H \times L) + (q \times L)}{L - 2e}
\]

\[
= \frac{(20 \times 8 \times 5.6) + (18 \times 5.6)}{(5.6) - (2 \times 0.62)}
\]

\[
= \frac{996.8}{4.36} = 228.62 \text{ kN/m}^2
\]

Allowable bearing pressure = 700 kN/m$^2$ ..... (Given)
(F.S.)_{B.C.} = \frac{\text{Allowable bearing pressure}}{\text{Actual bearing pressure}}

(F.S.)_{B.C.} = \frac{700}{228.62} = 3.08 > 2 \text{ (OK)}
(B) Internal Stability

Step 1: Calculation of horizontal pressure ($\sigma_{hf}$) at any depth

Maximum horizontal earth pressure ($\sigma_{h,max}$) on the back of the retaining wall at any depth “h” due to surcharge load (q) and backfill (Meyerhof’s distribution),

$$\sigma_{h,max} = \frac{K_{ar} (\gamma_r h + q)}{K_{ab} (\gamma_b h + 3q) \left(\frac{h}{L}\right)^2 \left[1 - \frac{1}{3(\gamma_r h + q)}\right]}$$

$$K_{ar} = \frac{1 - \sin \phi_r}{1 + \sin \phi_r}$$

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q = surcharge pressure = 18 kN/m²

\( K_{ar} = \) active earth pressure coefficient for the reinforced soil

\( \phi_r = \) internal friction angle of the reinforced soil = 34°

\( \gamma_b = \) unit weight of backfill soil = 18 kN/m³

\( K_{ab} = \) active earth pressure coefficient for backfill soil = 0.294

\( \gamma_r = \) unit weight of the reinforced soil = 20 kN/m³

\( L = \) length of the retaining wall = 5.6 m

\[
K_{ar} = \frac{1 - \sin \phi_r}{1 + \sin \phi_r}
\]

\[
K_{ar} = \frac{1 - \sin 34°}{1 + \sin 34°} = 0.28
\]
At any depth \((h)\), the actual horizontal earth pressure \((\sigma_{hf})\) at the facing,

\[
\sigma_{hf} = \sigma_{h,\text{max}} \times \text{R.F.}
\]

R.F. = Reduction factor = \[
1 - \frac{0.25(H - h)}{H}
\]

\(H = \text{height of retaining wall} = 8 \text{ m.}\)
Calculated $\sigma_{h,\text{max}}$ and $\sigma_{hf}$ at different depths

<table>
<thead>
<tr>
<th>Depth h (m)</th>
<th>$\sigma_{h,\text{max}}$ kN/m$^2$</th>
<th>RF</th>
<th>$\sigma_{hf}$ kN/m$^2$</th>
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</tr>
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</table>
Variation of horizontal pressure with depth

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Step 2: Calculation for vertical spacing

\[ S_v = \text{Vertical spacing between geogrids} \]
Allowable tensile strength of geogrid ($T_a$) = 38 kN/m (Given)

However,

$$T_a = \frac{\sigma_{h,\text{max}} \times S_{v1}}{C_r}$$

$\sigma_{h,\text{max}}$ = Maximum horizontal pressure (kN/m²)

$S_{v1}$ = Vertical spacing based on tension in geogrid (m)

$C_r$ = Coverage ratio = 1

Therefore, $s_{v1} = \frac{38}{\sigma_{h,\text{max}}}$
Connecting pressure between geogrid and segmental block \((T_c) = 34 \text{ kN/m} \) (Given)

\[ T_c = \frac{\sigma_{hf} \times S_{v2}}{C_r} \]

\( \sigma_{hf} = \text{actual horizontal pressure (kN/m}^2) \)

\( S_{v2} = \text{Vertical spacing based on tension in connection (m)} \)

\( C_r = \text{Coverage ratio} = 1 \)

Therefore, \( s_{v2} = 34/ \sigma_h \)

- Spacing = minimum \((s_{v1}, s_{v2}) \leq 1 \text{ m}\)
Calculation of spacing at different depths

<table>
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<tr>
<th>Depth, h (m)</th>
<th>$\sigma_{h,\text{max}}$ (kN/m²)</th>
<th>RF</th>
<th>$\sigma_{hf}$ (kN/m²)</th>
<th>$S_{v1}$ (m)</th>
<th>$S_{v2}$ (m)</th>
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</table>

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Variation of spacing with depth

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Step 3: Calculation of anchorage length or embedded length
For embedded length,

\[ s_v \times \sigma_h \times FS_{pullout} = 2 \times L_e \times C_i \times \sigma_v \tan \phi' \times C_r \]

\[ \therefore L_e = \frac{s_v \times \sigma_h \times FS_{pullout}}{2 \times C_i \times \sigma_v \tan \phi' \times C_r} \]

\( S_v \) = spacing between geogrids  
\( \sigma_h \) = Horizontal stress in kN/m\(^2\)  
\( FS \) = factor of safety for pullout = 1.5  
\( C_i \) = Interaction coefficient = 0.85  
\( C_r \) = Coverage ratio = 1  
\( \phi' = \phi_r \) = Internal friction angle of the reinforced soil = 34°  
\( \sigma_v \) = vertical stress in kN/m\(^2\) = \( \gamma_r h \)  
\( L_e \) = embedded length in m \( \geq 1 \) m
\[ L_r = (H - z) \tan \left(45 - \frac{\phi}{2}\right) \]

\( L_r = \) Non acting Rankine length (m)

\( z = \) depth of layer from top

\[ L = L_e + L_r \]

<table>
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<tr>
<th>No. of layers</th>
<th>depth (m)</th>
<th>Spacing (m)</th>
<th>( L_e ) (m)</th>
<th>( L_{e,\text{min}} ) (m)</th>
<th>( L_r ) (m)</th>
<th>( L ) (m)</th>
<th>( L_{\text{reqd}} ) (m)</th>
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<td>5.6</td>
</tr>
</tbody>
</table>

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Reinforcement details

- Also check for seismic loading conditions.

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Example:

Calculate the horizontal stresses with depth on a wall of 8 m high under 200 kN tandem axle truck with eight wheels.

Calculate the horizontal stresses at 1m increment and plot the variation of maximum wheel load stress along the depth.
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(1) If \((m = X/ H) \leq 0.4\)
\[ n = \frac{Z}{H} \]
\[
\sigma_H \left( \frac{H^2}{Q_p} \right) = \frac{0.28n^2}{(0.16 + n^2)^3}
\]

(2) If \(m > 0.4\)
\[
\sigma_H \left( \frac{H^2}{Q_p} \right) = \frac{1.77m^2n^2}{(m^2 + n^2)^3}
\]

\(Q_p\) = Point load of wheels,

\(\sigma_H' = \sigma_H \cos^2(1.1\theta)\)

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Calculations:

(a) Stress due to wheels 1 and 2

<table>
<thead>
<tr>
<th>( Z (m) )</th>
<th>( \frac{n}{Z/H} )</th>
<th>( X (m) )</th>
<th>( \frac{m}{X/H} )</th>
<th>( \sigma_H \left( \frac{H^2}{Q_p} \right) )</th>
<th>Wheel 1 ( \sigma_H ) (kPa)</th>
<th>Wheel 2 ( \sigma'_H ) (kPa)</th>
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Please let us hear from you

Any question?
THANKS FOR LISTENING