GEOSYNTHETICS ENGINEERING: IN THEORY AND PRACTICE

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Module - 1
LECTURE - 5
INTRODUCTION TO REINFORCED EARTH

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RECAP of previous lecture.....

- Standard Analysis of Reinforced Earth
  - Internal local stability
  - Critical slip surface for inextensible reinforcement
  - Critical slip surface for extensible reinforcement
  - Calculation of maximum tensile forces in the reinforcement layers
  - Design an inextensible steel reinforced soil retaining wall (partly covered)
**Calculation of eccentricity at base (e):**

\[
e = \frac{L}{2} - \frac{M_R - M_o}{W_r}
\]

\[
M_R = W_r \times L/2 = 1077.3 \times (6.3/2) = 3393.495 \text{ kN-m/m}
\]

\[
M_o = F_a \times H/3 + F_q \times H/2
\]

\[
= (256.5 \times 9/3 + 30 \times 9/2) \text{ kN-m/m}
\]

\[
= 904.5 \text{ kN-m/m}
\]

\[
e = \frac{6.3}{2} - \left(\frac{3393.495 - 904.5}{1077.3}\right) = 0.839599 < \left(\frac{L}{6} = 1.05\right) \quad \text{(OK)}
\]

Factor of safety against overturning,

\[
FS_{\text{overturning}} = \frac{M_R}{M_o} = \frac{3393.495}{904.5} = 3.75 > 2 \quad \text{(OK)}
\]
Geosynthetics Engineering: In Theory and Practice

Stresses on Foundation Soil

Forces Acting on Reinforced Soil Wall

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Calculation of bearing pressure at base

Effective length = (L - 2e)

Total vertical pressure over the foundation soil = $\sigma_v$

$$\sigma_v = \frac{\sum V}{L - 2e} = \frac{W_r + W_q}{L - 2e}$$

$$\sigma_v = \frac{1077.3 + 63}{6.3 - 2 \times 0.84} = 246.78 \text{ kPa} < 300 \text{ kPa}$$ (OK)

Given allowable bearing capacity of foundation soil = 300 kPa
Step 3: Check internal stability

The complete calculations along the entire height at each reinforcement level are presented in a tabular form at the end.

The hand calculations for internal stability are performed at a depth, $z = 4.875$ m.

$$K_{ar} = \tan^2(45^\circ - \phi_r / 2) = \tan^2(45^\circ - 32^\circ / 2) = 0.307$$

As $z < 6$ m ($z = 4.875$ m), from interpolation,

$$K_r = K_{ar} \left[ 1.2 + 0.5 \times \frac{(6-z)}{6} \right] = 0.398$$
Variation of stress ratio with depth

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Calculation for $K_r$ when $z < 6$ m:

\[
\frac{x}{6-z} = \frac{0.5}{6}
\]

\[
x = 0.5 \times \frac{6-z}{6}
\]

\[
\frac{K_r}{K_{ar}} = 1.2 + 0.5 \times \frac{6-z}{6}
\]

\[
K_r = K_{ar} \left[ 1.2 + 0.5 \times \frac{6-z}{6} \right]
\]

Therefore, at $z = 4.875$ m,

\[
K_r = 0.307 \left[ 1.2 + 0.5 \times \frac{6-4.875}{6} \right] = 0.398
\]
Now, at this level vertical pressure ($\sigma_v$)

$$\sigma_v = \gamma_r \times z + q = 19 \times 4.875 + 10 = 102.625 \text{ kPa}$$

Horizontal pressure ($\sigma_h$)

$$\sigma_h = K_r \times \sigma_v = 0.398 \times 102.625 = 40.795 \text{ kPa}$$

Consider tributary area ($A_t$) over twice the panel width to determine the horizontal spacing among reinforcements and check the pull-out criteria.

$$A_t = 2 \times \text{panel width} \times S_v = 2 \times 1.5 \times 0.75 = 2.25 \text{ m}^2$$

The maximum horizontal force on this tributary area ($T_{\text{max}}$)

$$= \sigma_h \times A_t = 40.795 \times 2.25 = 91.789 \text{ kN}$$
Considering factor of safety against pull-out failure \((FS_{\text{pull-out}}) \geq 1.5\),

Pull-out resistance \((P_R) \geq 1.5 \times T = 1.5 \times 91.789 = 137.683\ kN\)

If the minimum number of reinforcements required in the tributary area to achieve the pullout resistance = \(N\)

\[
N = \frac{P_R}{2 \times b \times F^* \times L_e \times \sigma'_v}
\]

\(b = \text{width of reinforcement strip} = 50\ mm\)
\(L_e = \text{embedded length of reinforcement} = L - L_a\)
\(\sigma'_v = \text{vertical pressure ignoring the surcharge pressure}\)

\(F^* = 1.2 + \log C_u\ \text{at the top of the structure} = 2\ \text{(maximum)}\)
\(= \tan\phi'\ \text{(at } z \geq 6\ m)\)
Variation of friction factor ($F^*$) with depth

As $z < 6$ m, From interpolation

$$F^* = \tan \phi_r + \frac{(2 - \tan \phi_r)(6 - z)}{6}$$

$$F^* = \tan 32^\circ + \frac{(2 - \tan 32^\circ)(6 - 4.875)}{6} = 0.883$$

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As $z > H/2 = 4.5$ m,

$L_a = \text{length of reinforcement in active zone}$
$= 0.6(H - Z) \quad \text{[From interpolation]}$
$= 0.6 \times (9 - 4.875)$
$= 2.475 \text{ m}$

$L_e = L - L_a = 6.3 - 2.475 = 3.825 \text{ m}$

$\sigma_v' = \text{vertical pressure at this level ignoring the surcharge pressure} = (102.625 - 10) = 92.625 \text{ kPa}$

$N = \frac{P_R}{2 \times b \times F^* \times L_e \times \sigma_v'} = \frac{137.683}{2 \times 0.05 \times 0.883 \times 3.825 \times 92.625} = 4.403$

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For $z > H/2$

$y = (z - H/2)$

$(0.3\ H)/(H/2) = L_a/(H/2 - y)$

$0.6 = L_a/[(H/2) - y]$

$L_a = 0.6[(H/2) - y]$

$L_a = 0.6[(H/2) - (z - (H/2))]$

$L_a = 0.6(H-z)$
Hence, \( N_{\text{actual}} = 5 \) (it should be an integer)
In the tributary area 5 numbers of strips should be provided in a row.

Approximate horizontal spacing \( (S_h) \) can be

\[
= \frac{(2 \times \text{panel width})}{N} = \frac{(2 \times 1.5)}{5} = 0.6 \text{ m}
\]

Now, the corrected pull-out resistance \( P_{R(\text{actual})} \)

\[
= 2 \times b \times F^* \times L_e \times \sigma_v' \times N_{\text{actual}}
\]

\[
= 2 \times 0.05 \times 0.883 \times 3.825 \times 92.625 \times 5
\]

\[
= 156.367 \text{ kN}
\]

Therefore, factor of safety against pull-out failure,

\[
FS_{\text{pull-out}} = \frac{P_{R(\text{actual})}}{T} = \frac{156.367}{91.789} = 1.704
\]

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Step 4: Calculation of stress in metallic strip during design life

Initial thickness of the metallic strip reinforcement made of steel including the zinc coating of 0.086 mm = 5 mm

According to FHWA (1990), the thickness losses per year are as follows:

- zinc loss = 0.015 mm/year (first 2 years)
  = 0.004 mm/year (thereafter)
- steel loss = 0.012 mm/year/ side (thereafter)
Time for complete zinc loss
= 2 years + \([0.086 - 2 \times 0.015]/0.004]\) = 16 years

Steel loss will be for \((75 - 16) = 59\) years during design life.

Total thickness loss during design life \((t_{\text{loss}})\)
= \(2 \times 0.012 \times 59 = 1.416\) mm

Remained thickness \((t_{\text{remained}})\)
= \(5 - 1.416 = 3.584\) mm = 0.003584 m

Remained cross-section after design life of 75 years \((A_c)\)
= \(0.003584 \times 0.05 = 0.0001792\) m²
f_y = 413.7 MPA (60 grade steel)

f_{allowable} = 0.55 (f_y) = 227.5 MPA

The tensile stress (f_s) in each strip,

\[
f_s = \frac{T}{N \times A_c} = \frac{91.789}{5 \times 0.0001792} = 102.44 \text{ MPA} < 227.5 \text{ MPA}
\]

(OK)
<table>
<thead>
<tr>
<th>Depth (z) (m)</th>
<th>Vertical pressure (kPa)</th>
<th>( K_a )</th>
<th>( K_r )</th>
<th>Horizontal Pressure (kPa)</th>
<th>( F^* )</th>
<th>( L_a ) (m)</th>
<th>( L_e ) (m)</th>
<th>Max. hor. force/trib. area (( T_{max} )) (kN)</th>
<th>( P_R ) (kN)</th>
<th>( N ) strips per trib. area</th>
<th>( N_{actual} )</th>
<th>Approx hor. spacing (( S_h )) (m)</th>
<th>( P_{R(actual)} ) (kN)</th>
<th>Tensile stress, ( f_s ) (MPA)</th>
<th>FS pullout</th>
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<td>201.24</td>
<td>1.725</td>
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</tbody>
</table>

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Conventional systems

Gravity Retaining Wall

Cantilever Retaining Wall

Sheet Pile Wall

Braced Excavation

Soil Nailing

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Mechanically stabilized reinforced earth using metal strips

- High Cost
- Long term susceptibility to corrosion.
- Sustainability depends on the correct choice of Backfill material (i.e. gradation, chemical properties etc.)
- Cannot be used with many indigenous materials.
- Back fill material cost is about 30 to 40% of the total cost of the reinforced soil wall.

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It is preferable to use non corrosive materials like polymer geosynthetics as a reinforcement.

- Polymer does not corrode,
- Economical, and
- Used with many other indigenous materials
Please let us hear from you

Any question?

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