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
Module-12
LECTURE- 55
DESIGN OF GEOSYNTHETICS FOR LANDFILLS

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Recap of previous lecture…..

- Slope Stability of Side Liner
- Design Of Landfill Liners
  - Stability Of Cover Soil For Infinite Slope:
  - Veneer Slope Stability For Uniform Thickness
    Unreinforced Cover Soil
  - Veneer Slope Stability For Uniform Thickness
    Reinforced Cover Soil:
  - Seismic Analysis In Veneer Slope Stability For
    Uniform Thick Cover Soil (Without Reinforcement)
5. Seismic analysis in veneer slope stability for uniform thickness cover soil with reinforcement

Seismic forces in reinforced uniform thickness cover soil
(Modified after Qian et al., 2002)

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Geosynthetics Engineering: In Theory and Practice

\[ FS = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

\[ a = (C_s \cdot W_A + N_A \cdot \sin \beta) \cdot \cos \beta + C_s \cdot W_p \cdot \cos \beta - T \cdot \cos^2 \beta \]
\[ b = -[(C_s \cdot W_A + N_A \cdot \sin \beta) \cdot \sin \beta \cdot \tan \phi + (N_A \cdot \tan \delta + C_a) \cdot \cos^2 \beta + (C + W_p \cdot \tan \phi) \cdot \cos \beta - T \cdot \sin \beta \cdot \cos \beta \cdot \tan \phi] \]
\[ c = (N_A \cdot \tan \delta + C_a) \cdot \sin \beta \cdot \cos \beta \cdot \tan \phi \]

[Note: The validation of these equations can be made by putting average seismic coefficient \( C_s = 0 \).
- It will yield the same results and equations proposed by Koerner and Soong (1998) for static case.]
Design Example (Inclusion of seismic force in veneer slope stability analysis for reinforced case):

Cover soil slope ($\beta$) = 15°, Length of slope ($L$) = 35 m,
Thickness of the cover soil ($h$) = 0.35 m,
Unit weight of the cover soil ($\gamma$) = 18 kN/m$^3$,
Cohesion of the cover soil ($c$) = 0,
Adhesion between cover soil and GCLs ($C_a$) = 0,
Internal friction angle of cover soil ($\phi$) = 32°,
Interface friction angle between GCLs and cover soil ($\delta$) = 18°,
Average seismic coefficient ($C_S$) = 0.1,
$T_{ult}$ = 100 kN/m, and R.F. = 4.0

Determine the factor of safety against cover soil sliding.

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## Input data format in LSS Model:

### Slope Characteristics
- Length of the slope measured along the GCL (m): \( L = 35.0 \)
- Slope angle (in degree): \( \beta = 15.0 \)
- Thickness of the cover soil (m): \( h = 0.35 \)

### Cover Soil Properties
- Unit weight of the cover soil (kN/m³): \( \gamma = 18.0 \)
- Cohesion of the cover soil (kN/m²): \( c = 0 \)
- Friction angle of cover soil (in degree): \( \Phi = 32 \)

### GCLs/GM Properties
- Interface friction angle between GCLs/GM and cover soil (in degree): \( \delta = 18 \)
- Adhesion between GCLs/GM and cover soil (kN/m²): \( c_a = 0 \)

### Seismic Characteristic
- Average seismic coefficient: \( C_S = 0.10 \)

### Reinforcement Detail
- Ultimate tensile strength of the Reinforcing geotextile/geogrid (kN): \( T_{ult} = 100 \)
- Reduction factor for installation damage: \( RF(id) = 1.25 \)
- Reduction factor for creep: \( RF(cr) = 1.28 \)
- Reduction factor for chemical/biological degradation: \( RF(cbd) = 2.00 \)
- Reduction factor for seams: \( RF(sm) = 1.25 \)
Output data format in LSS Model:

Seismic Analysis for Veneer Slope Stability
(With Reinforcement)

OUTPUT

Weight of the active wedge (kN) \( W_A = 211.681 \)
Weight of the passive wedge (kN) \( W_P = 4.412 \)
Interwedge force acting on the active wedge from the passive wedge (kN) \( E_A = 1.921 \)
Interwedge force acting on the passive wedge from the active wedge (kN) \( E_P = 1.921 \)
Factor of safety \( F_S = 1.335 \)

Comments
Since the \( F_S \)-value (in seismic conditions) is more than the 75\% of \( F_S \)-value (in static conditions) so the design is safe and stable.
Design curve for seismic analysis with varying average seismic coefficients for reinforced and unreinforced case

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**Comparison of LSS-Model with Help-Model**

<table>
<thead>
<tr>
<th>Case</th>
<th>HELP-Model</th>
<th>LSS-Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced case ((T_{ult} = 100) kN/m &amp; RF = 4.0)</td>
<td>No such option is available in HELP-Model</td>
<td>FS = 1.335</td>
</tr>
</tbody>
</table>
6. Run out and anchor trench design (After Qian et al., 2002 and Koerner, 2005)

There may be three different arrangements possible:

i) Only run out length

ii) Run out length followed by a rectangular anchor trench

iii) Run out length followed by a V-shaped anchor trench
(i) Run out length calculation (After Qian et al., 2002 and Koerner, 2005)

\[
L_{RO} = \frac{T_{allow} (\cos \beta - \sin \beta \tan \delta_L)}{\sigma_n (\tan \delta_U + \tan \delta_L)}
\]

\(T_{allow}\) = allowable force in GCLs
stress = \(\sigma_{allow} \times t\),
\(\sigma_{allow}\) = allowable stress in GCLs,
\(t\) = thickness of GCLs,
\(\beta\) = side slope angle,
\(\sigma_n\) = applied normal stress from cover soil,
\(L_{RO}\) = length of GCLs run out;
\(d_{AT}\) = depth of the anchor trench
\(P_A\) = active each pressure against the backfill side of the anchor trench,
\(P_P\) = passive earth pressure against the in-situ side of the anchor trench,
\(F_{U\sigma}\) = shear force above GCLs due to cover soil,
\(F_{L\sigma}\) = shear force below GCLs due to caver soil, and
\(F_{LT}\) = shear force below GCLs due to vertical component of \(T_{allow}\)

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(ii) Run out length followed by a rectangular anchor trench (After Qian et al., 2002 and Koerner, 2005)

(a) Cross-section of GCLs run out with anchor trench

From Figure (a),

\[ \sum F_x = 0 \]
\[ T_{\text{allow}} \cos \beta = F_{U\sigma} + F_{L\sigma} + F_{LT} - P_A + P_P \]
(b) Development of active and passive forces and frictional resistance

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From Figure (b),

\[ F_{u\sigma} = \sigma_n \tan \delta_u \cdot L_{RO} \]
\[ F_{l\sigma} = \sigma_n \tan \delta_l \cdot L_{RO} \]
\[ F_{LT} = T_{allow} \sin \beta \tan \delta_l \]
\[ P_A = (0.5 \gamma_{AT} \cdot d_{AT} + \sigma_n) K_A \cdot d_{AT} \]
\[ P_P = (0.5 \gamma_{AT} \cdot d_{AT} + \sigma_n) K_P \cdot d_{AT} \]

From Figure (a),

\[ \sum F_X = 0 \]
\[ T_{allow} \cos \beta = F_{u\sigma} + F_{l\sigma} + F_{LT} - P_A + P_P \]

Here,
- \( K_A \) = coefficient of active earth pressure
- \( K_P \) = coefficient of passive earth pressure
- \( \gamma_{AT} \) = unit weight of the anchor trench

Using the above values, we can find out the required depth of anchor trench for a given geosynthetic material or vice-versa.

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Design Example (Design of run-out length and rectangular anchor trench):

The following properties of side slope and materials were used in LSS-Model to design the rectangular anchor trench. The results were compared with literatures.

\[
\begin{align*}
\beta &= 18.4^\circ, \quad T_{\text{all}} = 24.5 \text{ kN/m}, \quad h = 0.35 \text{ m}, \\
\gamma &= \gamma_{\text{AT}} = 18 \text{ kN/m}^3, \quad c = 0, \quad C_a = 0, \quad \phi = 30^\circ, \\
\text{Interface friction angle between GCLs (or GM) and cover soil} (\delta_L) &= 20^\circ, \quad \text{and} \quad \delta_U = 0
\end{align*}
\]
**Input data format in LSS Model:**

**Problem Statement:** This slope stability program determines the depth of anchor trench required.

**INPUT DATA**

**Slope Characteristics**
- Slope angle (in degree) $\beta = 19.4$
- Thickness of the cover soil (m) $h = 0.35$

**Cover Soil Properties**
- Unit weight of the cover soil (kN/m$^3$) $\gamma = 18$
- Friction angle of cover soil (in degree) $\Phi = 30$

**GCLs/GM Properties**
- Allowable stress of GCL (kN/m$^2$) $\sigma_{all} = 2450$
- Thickness of the GCL (mm) $t = 10$
- The friction angle of the GCL to the soil (below the GCL) $\delta_L = 20$
- The friction angle of the GCL to the soil (above the GCL) $\delta_U = 0$

**Runout Length**
- $LRO = 1.0$

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Output data format in LSS Model:

**OUTPUT**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of the anchor trench (m)</td>
<td>$d_{AT} = 0.58$</td>
</tr>
<tr>
<td>Runout length (m)</td>
<td>$L_{ro} = 1$</td>
</tr>
<tr>
<td>Active earth pressure on anchor trench (kN/m²)</td>
<td>$P_{A} = 2.271$</td>
</tr>
<tr>
<td>Passive earth pressure on anchor trench (kN/m²)</td>
<td>$P_{P} = 20.416$</td>
</tr>
</tbody>
</table>

**Comments**

1. Depth of anchor trench can be increased or decreased by decreasing or increasing the runout length.
2. If the user is using the Textured HDPE Geomembrane, then he may face problem to bend and bury it in narrow rectangular anchor trench. So for these cases V-Shaped anchor trenches are recommended.
3. Do you want to redesign this problem with V-Shaped anchor trench? [Yes]
Relationship between various run-out lengths ($d_{AT}$) and interface friction angle ($\delta_L$) for rectangular anchor trench

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7. Application of GCLs or GM as a liquid containment liner (After Koerner, 2005)

GCLs are successfully being used in water reservoirs, canals and in landfills as a containment liner.

Two main criteria for the selection of GCLs as liner are:
(i) Geometric consideration, and
(ii) Thickness consideration

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(i) Geometric liner consideration (After Koerner, 2005)

Before selecting the GCLs type, the desired liquid volume to be contained in the available land area must be considered.

For a square and rectangular section with uniform side slopes, the general equation for the volume is,

\[ V = H L W - S H^2 L - S H^2 W + 2 S^2 H^3 \]

\( V \) = Volume of reservoir \((m^3)\),
\( H \) = Depth of the reservoir at the centre \((m)\),
\( L \) = Length at ground surface \((m)\),
\( W \) = Width at ground surface \((m)\), and
\( S \) = Slope ratio (horizontal to vertical)
With the help of LSS-Model, one can determine the depth of landfill/reservoir required for a particular storage volume. This option is not available in HELP-Model.

**Design Example (Geometric Consideration):**

The following properties are used in LSS-Model to find out the depth of landfill required.

- Length of the landfill (L) = 100 m,
- Width of the landfill (W) = 100 m,
- Side slope (S) = 4(H) to 1(V), and
- Storage volume of landfill (V) = 30000 m³ (3.0×10⁷ liters)
Input data format in LSS Model:

**Problem Statement:** This programme determines the depth of liquid containment system for a particular storage area. (Rectangular area only)

**INPUT DATA**
- Storage volume required (in litres)
- Width at ground surface (m)
- Length at the ground surface (m)
- Slope ratio (Horizontal/Vertical)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>30000000</td>
</tr>
<tr>
<td>W</td>
<td>100</td>
</tr>
<tr>
<td>L</td>
<td>100</td>
</tr>
<tr>
<td>S</td>
<td>4.0</td>
</tr>
</tbody>
</table>
Output data format in LSS Model:

OUTPUT

Required height of the liquid containment system (m)  

\[ H = 4.16 \text{ m} \]

Comments

This calculated height is on the basis of theoretical analysis, however, the lined impoundment must be somewhat deeper to allow for free board against overfilling, wave action, and so on.
Area versus Volume design chart for landfills (or liquid containment ponds) with side slope of 4(H) to 1(V)

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(ii) Thickness consideration (After Koerner, 2005)

According to the depth of contained liquid/waste, thickness of the GCL (or geomembrane) is calculated.

The basic model for this purpose requires the occurrence of deformation-mobilized tensile force.
Design model and related forces used to calculate the geomembrane thickness (After Koerner, 2005)

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At equilibrium,

\[ \sum F_x = 0 \quad \text{and} \quad T \cos \beta = F_{U\sigma} + F_{L\sigma} + F_{LT} \]

\[ T \cos \beta = \sigma_n \tan \delta_U(x) + \sigma_n \tan \delta_L(x) + 0.5 \left( \frac{2T \sin \beta}{x} \right) (x) \tan \delta_L \]

\[ T = \frac{\sigma_n x (\tan \delta_U + \tan \delta_L)}{(\cos \beta - \sin \beta \tan \delta_L)} \]

Since, \[ T = \sigma_{allow} t \]

\[ t = \frac{\sigma_n x (\tan \delta_U + \tan \delta_L)}{\sigma_{allow} (\cos \beta - \sin \beta \tan \delta_L)} \]

➢ LSS-Model can determine the thickness of Geomembrane (or GCLs) required for a particular reservoir/landfill. This option is not available in HELP-Model.
Design Example (Thickness Consideration):

The following properties are used in LSS-Model to find out the thickness of Geomembrane (or GCLs) required.

Depth of the reservoir \((H) = 8.0\) m,
Settlement angle mobilizing the geomembrane tension \((\beta_s) = 30^\circ\),
Allowable stress of geomembrane \((\sigma_{\text{allow}}) = 20,000\) kPa,
Interface friction angle above geomembrane \((\delta_U) = 0^\circ\),
Interface friction angle below geomembrane \((\delta_L) = 30^\circ\),
Estimated mobilized distance for liner deformation \((X) = 100\) mm, and
Unit weight of reservoir fill = 9.81 kN/m\(^3\) (here, water is considered)
Problem Statement: This programme determines the required thickness of GCLs or GM in a liquid containment system.

INPUT DATA

- Allowable GM stress (kN/m²) $\sigma_{\text{allow}} = 20000$
- Mobilization distance of GM (mm) $x = 100$
- Settlement angle mobilizing the GM tension (degree) $\beta = 45$
- Angle of shearing resistance between GM and upper soil/GT (degree) $\delta_U = 0$
- Angle of shearing resistance between GM and lower soil/GT (degree) $\delta_L = 30$
- Water reservoir height (m) $H = 8$
Output data format in LSS Model:

**OUTPUT**

Required Thickness of the GCL or Geomembrane (in mm)  

\[ H = 0.756 \]

**Comments**

Note that adequate Geomembrane thickness cannot be addressed solely on the basis of above result. Other factors, such as construction equipment movement and their weight can impose severe stresses on the liner. So this thickness can be considered as the minimum thickness required. But in situ thickness must be slightly higher than this value.
Design chart for geomembrane thickness based on unit height of water for various allowable stresses

Prof. J. N. Mandal, Department of Civil Engineering, IIT Bombay
Please let us hear from you

Any question?

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