Eurocode 7 and Slope Design

Engineering Sustainable Slopes
10th June 2008
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Outline of presentation

- Principles of EC7 for slope engineering
- Implications of partial factor system for slopes
- Use of existing charts and software
- Conclusion
Principles of EC7 for slope engineering

Scope of sections 11 and 12 of EN 1992-1

Scope

- Section 11 covers overall stability of the ground and movements in the ground related to foundations, retaining structures, natural slopes, embankments, and excavations
- Section 12 covers embankments for small dams and infrastructure
Application of partial factors and tolerances

Actions

\[ F_d = \gamma_F F_{rep} \]

Effects of actions

\[ E_d = \gamma_E E \left\{ F_d, X_d, a_d \right\} \]

Material properties

\[ X_d = \frac{X_k}{\gamma_M} \]

Resistances

\[ R_d = \frac{R \left\{ F_d, X_d, a_d \right\}}{\gamma_R} \]

Geometrical parameters

\[ a_d = a_{nom} \pm \Delta a \]

Verification of strength

Verification of strength is expressed in Eurocode 7 by:

\[ E_d \leq R_d \]

\( E_d \) = design effect of actions
\( R_d \) = design resistance corresponding to that effect
Limits states for slopes and embankments

Limit states for slopes in general

- Limit states for slopes include:
- Loss of overall stability of the ground and associated structures
- Excessive movement
- Loss of serviceability
Design Approaches for STR/GEO

- §2.4.7.3.4.1(1)P The manner in which equations are applied shall be determined using one of three Design Approaches
  - Design Approaches apply ONLY to STR and GEO limit states
  - Each nation can choose which one (or more) to allow
  - only Design Approach 1 is to be used in the UK
  - In simplest terms, the design approaches apply factors to the following…
### Design Approaches

#### Design Approach

<table>
<thead>
<tr>
<th>Combination 1</th>
<th>Combination 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actions</td>
<td>Material properties</td>
</tr>
</tbody>
</table>

#### Partial factors for limit states GEO/STR (DA1) Slopes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Combination 1</th>
<th>Combination 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent action (G)</td>
<td>γ&lt;sub&gt;G&lt;/sub&gt;</td>
<td>1.35</td>
<td>1.0</td>
</tr>
<tr>
<td>Variable action (Q)</td>
<td>γ&lt;sub&gt;Q&lt;/sub&gt;</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Shearing resistance (tan φ)</td>
<td>γ&lt;sub&gt;θ&lt;/sub&gt;</td>
<td>1.0</td>
<td>1.25</td>
</tr>
<tr>
<td>Effective cohesion (c&lt;sub&gt;e&lt;/sub&gt;)</td>
<td>γ&lt;sub&gt;c&lt;/sub&gt;</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Undrained shear strength (c&lt;sub&gt;u&lt;/sub&gt;)</td>
<td>γ&lt;sub&gt;cu&lt;/sub&gt;</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Unconfined compressive strength (q&lt;sub&gt;u&lt;/sub&gt;)</td>
<td>γ&lt;sub&gt;qu&lt;/sub&gt;</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Weight density (γ)</td>
<td>-</td>
<td>(0)</td>
<td>(0)</td>
</tr>
<tr>
<td>Bearing resistance (R&lt;sub&gt;b&lt;/sub&gt;)</td>
<td>γ&lt;sub&gt;b&lt;/sub&gt;</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Sliding resistance (R&lt;sub&gt;s&lt;/sub&gt;)</td>
<td>γ&lt;sub&gt;s&lt;/sub&gt;</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Earth resistance (R&lt;sub&gt;e&lt;/sub&gt;)</td>
<td>γ&lt;sub&gt;e&lt;/sub&gt;</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Design Approach 1 for slopes and embankments

Implications of partial factor system for slopes
Stability of infinitely long slope

Implications of partial factor system for slopes

Infinitely long slope overlying permeable and impermeable rock
Equations for infinite slope

- Traditional definition of factors of safety

\[ F = \frac{c' + (1 - r_u) \gamma H \cos^2 \beta \tan \varphi}{\gamma H \sin \beta \cos \beta} \]

\[ r_u = \frac{\gamma_w h_w}{\gamma H} \]

Applying partial factors

- The design effect of actions may be taken as:

\[ E_d = \sigma_{vd} \sin \beta \cos \beta = \gamma_G \gamma_k H \sin \beta \cos \beta \]

- The design resistance may be taken as:

\[ R_d = \frac{c'd + (1 - r_u) \sigma_{vd} \cos^2 \beta \tan \phi_d}{\gamma_{Re}} \]

\[ = \frac{c_k' + (1 - r_u) \gamma_G \gamma_k H \cos^2 \beta \tan \phi_k}{\gamma_{Re}} \]
Applying partial factors

The design resistance may be taken as:

\[ R_d = c'k + (1 - r_u) \frac{\gamma_{G; fav} \gamma_k H \cos^2 \beta \tan \phi_k}{\gamma_{Re}} \]

- As long as \( R_d \) is at least as great as \( E_d \) the requirements of EN 1997-1 are satisfied.

Effect of favourable or unfavourable

EN 1997-1 applies different partial factors to favourable and unfavourable actions.

<table>
<thead>
<tr>
<th>Individual partial factor</th>
<th>Design Approach 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combination 1</td>
</tr>
<tr>
<td>( \gamma_G )</td>
<td>1.35</td>
</tr>
<tr>
<td>( \gamma_{G; fav} )</td>
<td>1.0</td>
</tr>
<tr>
<td>( \gamma_{cu} )</td>
<td>1.0</td>
</tr>
<tr>
<td>( \gamma_{Re} )</td>
<td>1.0</td>
</tr>
<tr>
<td>( \gamma_\phi = \gamma_c )</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>
Unfavourable/favourable

- In the $E_d$ term the action due to the self-weight of the soil is unfavourable and should be multiplied by $\gamma_G = 1.35$
- In the $R_u$ term the self-weight is favourable and may be multiplied by $\gamma_{G,fav} = 1.0$
- If this is assumed then Combination 1 always governs for effective stress analysis with an equivalent overall factor of safety of 1.35
- However, is it logical to multiply the same action by different partial factors?

Single source principle

EN 1997-1 Clause 2.4.2 Note

- Unfavourable (or destabilising) and favourable (or stabilising) permanent actions may in some situations be considered as coming from a single source. If they are considered so, a single partial factor may be applied to the sum of these actions or to the sum of their effects.
Unfavourable/unfavourable

- If self weight is considered unfavourable when assessing both the design effect of the actions and the design resistance, Combination 2 governs for all effective stress cases.
- In this case the equivalent factor of safety for the slope is 1.25 except for very low angles of friction and provided there are no variable actions.
- Is this large enough?

Unfavourable/favourable?

(1:3 slope, \( r_u = 0.5 \))
Stability of a finite slope

Implications of partial factor system for slopes

Key features of circular slip analysis
Bishop’s ‘Routine’ (aka ‘Simplified’) Method

\[
F = \sum_i \left[ c' b_i + (W_i + Q - u b_i) \tan \phi \right] \sec \alpha_i \left( \frac{\tan \phi}{F} \right) \\
\sum_i (W_i + Q) \sin \alpha_i
\]

Applying partial factors to Bishop’s Method

- In principle the same approach may be adopted as for infinite slopes
- It is complicated by the iterative nature of circular slip analysis (or non-circular)
- It is less clear what parts of the equation are favourable or unfavourable
  - e.g. when \( \alpha \) is negative the self-weight of the slip reduces the overturning moment
- There is therefore no fully logical way of applying \( \gamma_G \) and \( \gamma_{G,\text{fav}} \)
Use of existing charts and software

Traditional stability chart for infinite slope (1:3 slope, $r_u = 0.5$)
Design Approaches compared
(1:3 slope, $r_u = 0.5$)

Infinite slope - design chart for
Design Approach 1
($r_u = 0.5$) from Bond & Harris (2008)
Slope stability software

- Standard slope stability software does not allow different factors to be applied to different parts of the relevant equations
- Combination 1 may be approximated by multiplying the weight density of the soil by 1.35 and any applied variable action by 1.5/1.35 = 1.11
  - This applies the unfavourable partial factor to both the favourable and unfavourable elements of the equations

Software (cont)

- Combination 2 is relatively easy to accommodate as the strength parameters may be factored on input. Any variable action may be multiplied by 1.3
- Provided the critical surface has a “factor of safety” greater or equal to 1.0 then the requirements of EN 1997-1 are satisfied
- In principle the results of a DA1-1 and DA1-2 analysis should be compared to identify which is most critical, but it is clear that DA1-2 will govern
Conclusion

Eurocode 7 and Slope Design

Summary of key points 1

• Unless the ‘Single Source Principle’ is invoked, Eurocode 7 requires different partial factors to be applied to unfavourable and favourable actions, which is not possible with typical limit equilibrium slope stability calculations.
• For Design Approach 1, Combination 2 governs the design of slopes and embankments for practical values of soil shearing resistance.
Summary of key points 2

- As Combination 2 governs is the equivalent factor of safety = 1.25 adequate?
- The logical approach to limit equilibrium slope stability problems is to factor strength, thus EC7 makes little change
- EC7 defines the minimum required levels of safety, it may be necessary to use higher partial factors

Decoding Eurocode 7

- Book published Autumn 2008 by Spon in hardback with colour section
- Authors Andrew Bond (Geocentrix) and Andy Harris (Geomantix)
- Web: www.decodingeurocode7.com
- Key features
  - Covers EN 1997-1 and -2, plus relevant parts of other Eurocodes
  - Also covers associated execution and testing standards
  - Explains key principles and application rules with real-life case studies
  - Material extensively tested on training courses over 5 years
- ISBN 9780415409483
‘Decoding the Eurocodes’ blog

- Web log (blog) started May 2006
- Website: www.eurocode7.com
- Aim to post articles at least once a month
- Categories include:
  - BGA
  - Books
  - BSI
  - Eurocode 3
  - Eurocode 7
  - ICE
  - IStructE
  - Seminars
  - Singapore
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