CE 4780 Hurricane Engineering II

Section on Flooding Protection: Earth Retaining Structures and Slope Stability

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Table of Content

- Three weeks of classes

Methods of Slope Analysis

- Two categories of analysis
  - Slope stability
  - Slope movement

Introduction

- Slope Stability Methods
  - These methods use limit equilibrium analysis
  - They require strength information of the soils
  - They do not provide information about the magnitude of movements
  - They yield a factor of safety
  - They are usually applied in the design process

Introduction

- Slope Movement Methods
  - These methods require strain-stress information about the soil.
  - The solution is usually found using finite element solutions
  - They do not provide factor of safety (direct parameter of stability)
  - They are usually applied in the prevention of landslide, and risk emergency analysis.

Limit Equilibrium Analysis

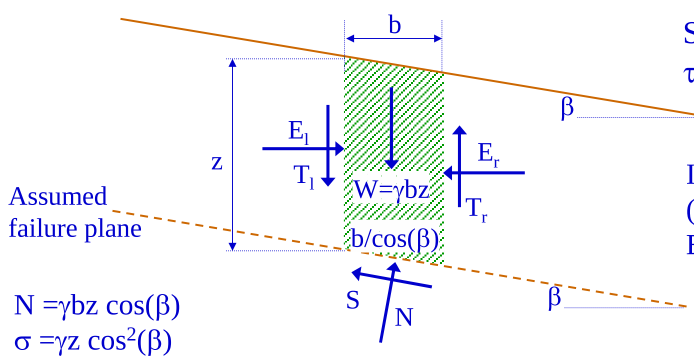
- They are based in the upper bound theorem
- Several possible failure surfaces are considered till the least favorable is found.
- For the least favorable surface, the factor of safety is determined.

Factor of Safety

- It is defined as the ratio of the shear strength over the applied shear stress (in the local sense)
- Or the resistance forces over the driving forces (in the global sense)
- The least favorable failure surface is determined in the sense of the factor of safety.

Methodology – Infinite Slopes

- Isotropic Soils and Uniform Slopes



Shear strength
$\tau = \sigma' \tan(\phi)$

Infinite slope (and small b):
$E_l=E_r$; $T_l=T_r$

$N = \gamma bz \cos(\beta)$
$\sigma = \gamma z \cos^2(\beta)$
$S = \gamma \beta z \sin(\beta)$
$\tau = \gamma z \sin(\beta) \cos(\beta)$

Methodology – Infinite Slopes

- Isotropic Soils and Uniform Slopes (cont.)
  - Dry soil at the verge of failure:

$$\sum F_{horizontal} = 0$$

$$S\cos(\beta) = N\sin(\beta) \therefore S = N\frac{\sin(\beta)}{\cos(\beta)} = N\tan(\beta)$$

  - The maximum shear resistance is:

$$\tau\Delta l = \tau\frac{b}{\cos(\beta)} = \sigma'\frac{b}{\cos(\beta)}\tan(\phi) = N\tan(\phi)$$

$$S = \tau\Delta l \therefore N\tan(\beta) = N\tan(\phi)$$

$$\boxed{FS = \frac{\tan(\phi)}{\tan(i)}}$$ Factor of safety

Methodology – Infinite Slopes

- Isotropic Soils and Uniform Slopes (cont.)
  - Saturated soil at the verge of failure (no water flow): the effective stresses and forces are reduced due to the submerged unit weight of the soil.
  - Saturated soil and flow parallel to the slope surface (helping the sliding mechanisms), max. safe slope:

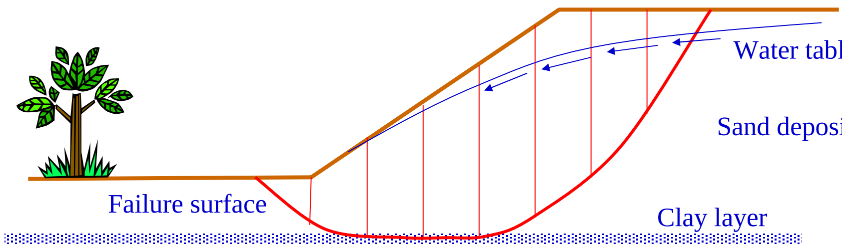
$$\tan(\beta) = \frac{\gamma - \gamma_w}{\gamma}\tan(\phi)$$

  - The maximum shear resistance is:

$$\boxed{FS = \frac{\gamma - \gamma_w}{\gamma_w}\frac{\tan(\phi)}{\tan(i)}}$$ Factor of safety

Methodology – Finite Slopes

- Failure approximate circular surfaces (mathematical convenience). Other surfaces: spirals.
- Crucial parameters: shear strength and pore pressure distribution
- Presence of weak layers and heterogeneities are important.



Methodology – Finite Slopes

- Problems
  - It is difficult to determine the weight and center of gravity of the sliding wedge.
  - The problem is statically indeterminate.
  - The normal effective stress along the failure surface is unknown.
  - The mobilized shear strength τ_m is unknown (it also varies along the failing surface).
  - The seepage forces are difficult to determine.

Methodology – Finite Slopes

- Typical Methods:
  - Basic method: circular failure surfaces in isotropic saturated soils (undrained shear strength). Simplistic analysis.
  - Fellenius method of slices: circular failure surfaces in any type of soil. Simplistic analysis.
  - Bishop method of analysis: circular failure surfaces in any type of soil. Rigorous method, solved using computer algorithms.
  - Simplified Bishop method: circular failure surfaces in any type of soil. Semi-rigorous method.

Methodology – Finite Slopes

- Typical Methods (cont.):
  - Morganstern-Price method of slices: arbitrary failure surfaces in all soil types. Rigorous method, solved using computer algorithms.
  - Spencer method of slices: arbitrary failure surfaces in all soil types. Rigorous method, solved using computer algorithms.
  - Jambu method of slices: arbitrary failure surfaces in all soil types. Rigorous method, solved using computer algorithms. Available charts simplify its use.

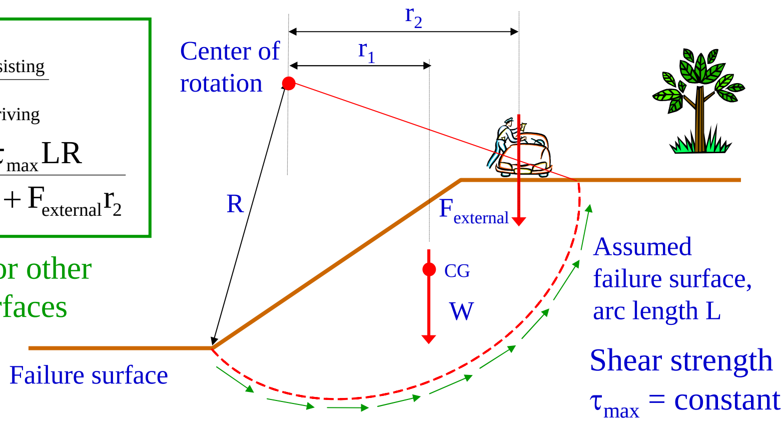
Methodology – Finite Slopes

- General Concepts – Circular Failure Surfaces

$$FS = \frac{M_{resisting}}{M_{driving}}$$

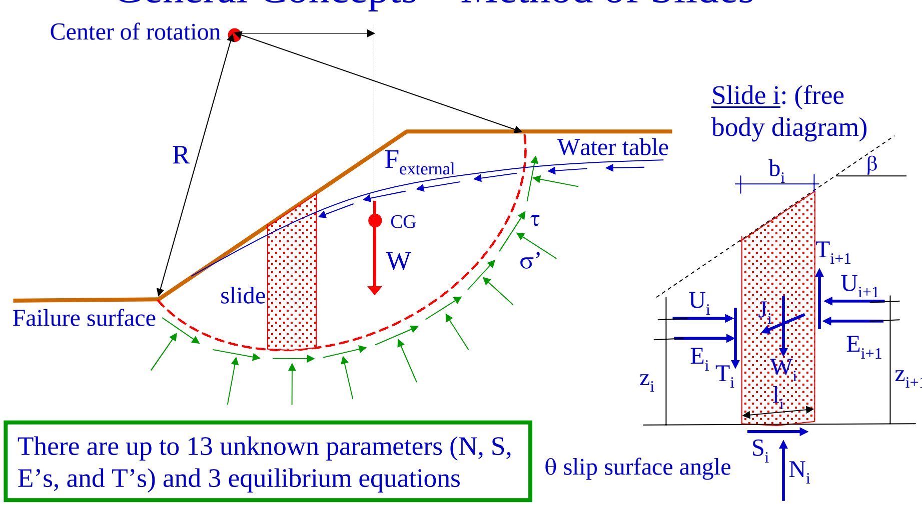
$$FS = \frac{\tau_{max} LR}{Wr_1 + F_{external} r_2}$$

Repeats for other failure surfaces



Methodology – Finite Slopes

- General Concepts – Method of Slides



There are up to 13 unknown parameters (N, S, E's, and T's) and 3 equilibrium equations

Methodology – Finite Slopes

- Method of Slides: Bishop's Method
  - Assumptions:
    - Circular slip surface
    - Colinear E_i and E_{i+1} and U_i and U_{i+1}
    - N_i acts on the center of the arc length
  - Summing of vertical forces:

$$N_i \cos(\theta_i) + S_i \sin(\theta_i) - W_i - T_i + T_{i+1} = 0$$

$$N_i' \cos(\theta_i) = -S_i \sin(\theta_i) + W_i + T_i - T_{i+1} - u_i l_i \cos(\theta_i)$$

Methodology – Finite Slopes

- Method of Slides: Bishop's Method (cont.)

$$N_i' \cos(\theta_i) = -S_i \sin(\theta_i) + W_i + T_i - T_{i+1} - u_i l_i \cos(\theta_i)$$

$$r_u = \frac{u_i b_i}{W_i}$$ Pore water pressure ratio

$$N_i' \cos(\theta_i) = W_i(1 - r_i) - S_i \sin(\theta_i) + (T_i - T_{i+1})$$

  - Bishop's method only considers moment equilibrium:

$$\sum W_i r_i - \sum S_i R = 0$$

$$\sum S_i = \sum \frac{W_i r_i}{R} = \sum W_i \sin(\theta_i)$$

Methodology – Finite Slopes

- Method of Slides: Bishop's Method (cont.)

$$FS = \frac{\tau_f}{\tau_m} = \frac{(S_f)_m}{S_i}$$ Local factor of safety

$$FS = \frac{N_i'\tan(\phi_i)}{S_i} \therefore S_i = \frac{N_i'\tan(\phi_i)}{FS}$$

$$N_i'\cos(\theta_i) = W_i(1-r_u) - \frac{N_i'\tan(\phi_i)\sin(\phi_i)}{FS} + (T_i - T_{i+1})$$

$$N_i' = \frac{W_i(1-r_u) + (T_i - T_{i+1})}{\cos(\theta_i) + \frac{\tan(\phi_i)\sin(\phi_i)}{FS}} = m_i[W_i(1-r_u) + (T_i - T_{i+1})]$$

Methodology – Finite Slopes

- Method of Slides: Bishop's Method (cont.)

$$FS = \frac{\sum[W_i(1-r_u) + (T_i - T_{i+1})]\tan(\phi_i)m_i}{\sum W_i \cdot \sin(\theta_i)}$$

Disregarding the term (T_i-T_{i+1}) the error is less than 1 %

$$FS = \frac{\sum W_i(1-r_u)\tan(\phi_i)m_i}{\sum W_i \cdot \sin(\theta_i)}$$

Water table bellow slip surface

$$FS = \frac{\sum W_i \tan(\phi_i)m_i}{\sum W_i \cdot \sin(\theta_i)}$$

References and Bibliography

- Abramson, L. W., Lee, T. S., Sharma, S., and Boyce, G. M. (2002). Slope Stability and Stabilization Methods. Second Edition. John Wiley & Sons. New York. 712 pages.
- Atkinson, J. (1993). The Mechanics of Soils and Foundations. MacGraw-Hill.
- Budhu, M. (2000). Soil Mechanics and Foundations. Wiley & Sons.
- Duncan, J. M. (1996). "Soil Slope Stability Analysis" in Landslides: Investigation and Mitigation, Ed. A. K. Turner and R. L. Schuster. Special Report 247. Transportation Research Board. Washington, DC. pp. 337-371.
- McCarthy, D. F. (2002). Essentials of Soil Mechanics and Foundations. Sixth Edition. Prentice-Hall. Upper Saddle River, NJ.