1 – INTRODUCTION

Geotechnical Problems Review of Soil Mechanics (Chapter 3):
Design Philosophy (21-1) Effective stresses,
Design Loads (2.1) Shear strength: drained and undrained,
Mohr circle

“The most important thing is to keep the most important thing the most important thing”

“A structure is not stronger than its connections”

Foundations transmit all the structural loads to the underlain soils. The foundation engineer must be multi-disciplinary and have knowledge of Geotechnical Engineering, Structural Engineering and Construction Engineering.

…and we can save 1000 Lira by not conducting soil studies!
1.1 Geotechnical problems

- Principal aspects of the project
  - Expected performance: strength and deformation
    - Factor of safety: $P_{\text{failure}}$ by Code (cost, uncertainties, tolerances, compounding the cost)
    - e.g. Earth dams 1.3 – 1.5, Retaining walls 1.5 – 2.0, Foundations 2.0 – 3.0
  - Site investigation
  - Predicted strength and time effects: settlement
    (data from adjacent facilities, consolidation test)
  - Performance and safety check
  - Construction and design recommendations
  - Contingency Plan
    - Monitoring program during construction

- Redesign
  - Site-improvement
1.2 Design philosophy

Since the behaviour of soils is quite complex, most of our analysis and design methods include a mixture of rational and empirical techniques. The *success* of a geotechnical engineer relays on his solutions to practical design problems based on his *understanding* of the strengths and limitations of this mix of rationalism and empiricism (CE 353). A successful structure will fulfill the following performance requirements:

- Strength
- Serviceability
- Constructibility
- Economy.

Settlement

- Connection with existing structures
- Utility lines
- Surface drainage
- Access
- Aesthetics.

In spite of uncertainties in analysis and design, the society expects engineers to develop economical, timely, and reliable designs. The factor of safety (F.S.) is based on required reliability (i.e. the acceptable probability of failure), consequences of failure, uncertainties in soil properties and applied loads, construction tolerances (design and as-built dimensions), ignorance of true behaviour, cost-benefit ratio of additional conservatism in the design. Therefore, the factor of safety is used to compensate for uncertainties.

We use the factor of safety:

\[ \text{F.S.} = \frac{\text{Strength}}{\text{Load}} \text{ (deterministic method)} \]

In Geotechnical Engineering there are two main approaches for design:

- Working stress design or allowable stress design (WSD, ASD): forces from working conditions
- Limit state design or load and resistance factor design (ULS, LRFD): forces from maximum loads

\[ P_u = \gamma_1 P_d + \gamma_2 P_d + \ldots \]

\[ P_u \leq \phi P_n \]
\[ P[\text{failure}] = P[L > S] = \sum P[S = S_o] P[L > S_o] \]

### 1.3 Design loads

\[ D \]

\[ D + L + F + H + T + (L \text{ or } S \text{ or } R) \]

\[ 0.75[D + L + (L \text{ or } S \text{ or } R) + (W \text{ or } E)] \]

\[ 0.75[D + (W \text{ or } E)] \]

where:

- **D**: dead loads;
- **L**: live loads;
- **S**: snow loads;
- **R**: rain loads;
- **H**: earth pressure loads;
- **F**: fluid loads;
- **E**: earthquake loads;
- **W**: wind loads;
- **T**: self-straining loads;
- **I**: impact loads;
- **SF**: stream flow loads;
- **ICE**: ice loads;
- **CF**: centrifugal loads; and,
- **BF**: braking loads.
1.4 Review of soil mechanics

1.4.1 Total and effective stresses

\[ \sigma' = \sigma_t - u \]

Example 1.1

Soil 1: \( H = 5 \text{m}, \gamma_T = 16 \text{ kN/m}^3, \phi' = 30^\circ, c' = 15 \text{ kPa} \)

Soil 2: \( H = 7 \text{m}, \gamma_T = 19 \text{ kN/m}^3 \) and \( \phi' = 35^\circ \)

Compute the total and effective stresses at the soil 2 – bedrock interface.

What is the water content of soil 2 if the in-situ void ratio is 0.60?

1.4.2 Drained (\( \tau_f \)) and undrained shear strength (\( \tau_t \))

Drained shear strength:

\[ \tau_f = c' + \sigma' \tan(\phi') \]

Example 1.2:

Compute the maximum shear stresses that can be applied on a vertical or horizontal plane at depth H.
Undrained shear strength: \( \tau_f = C_u \)

Example 1.3:
Compute the maximum load “q” for a strip footing on clay for fast loading. \( C_u = 80 \text{ kPa} \).
1.4.3 Mohr Circle: Graphical representation of the state of stress at any direction, at a given point

Characteristics of Mohr circle:

1- A change of an angle θ in the element represents an angle 2θ in the circle

2- Principal stresses $\sigma_1$ and $\sigma_3 \rightarrow$ Null shear stress

3- Radius and centre of the circle:

   From principal stresses $\quad R = \frac{\sigma_1 - \sigma_2}{2} \quad C = \frac{\sigma_1 + \sigma_2}{2}$

   From non-principal stresses $\quad R = \sqrt{\left(\frac{\sigma_y - \sigma_x}{2}\right)^2 + \tau_{yx}^2} \quad C = \frac{\sigma_x + \sigma_y}{2}$

4- The resultant stress at any plane is given by

$$\sigma_R = \sqrt{(\sigma_N)^2 + (\tau_N)^2} =$$
5- The maximum shear stress is equal to the radius of the circle. Maximum shear stress acts on planes at 45° with respect to principal stresses.

1- Stresses at any given orientation → Pole or origin of planes. Locate any given state of stresses (σ, τ) on the Mohr circle (Point A). Draw a line parallel to the plane on which the stresses (σ, τ) are acting at Point A and extend this plane until it intersects again the circle (Point P). The intersection of this plane with the Mohr circle (Point P) defines the pole. This procedure can be used with any known state of stresses and the same pole should be obtained.

Sign convention:
**Example 1.4:**

For a triaxial test, $\sigma_1 = 10$ kPa and $\sigma_2 = 5$ kPa. Find the normal and shear stresses in a plane inclined +30° with respect to the horizontal.

**Example 1.5:**

Find the maximum height $H$ for an open-cut excavation on Soil 1.
Soil 1: $\gamma_T = 16$ kN/m$^3$, $\phi^\prime = 30^\circ$, $c^\prime = 15$ kPa
Review Formula Sheet

\[ G_s = \frac{\rho_s}{\rho_w} \quad e = \frac{V_v}{V_s} \quad n = \frac{V_v}{V} \quad \omega = \frac{W_w}{W_s} \quad S = \frac{V_w}{V_v} \quad S = \frac{\omega G_s}{e} \quad A = \frac{V}{V_v} \]

\[ \gamma_w = 9.81 \text{kN/m}^3 \]

\[ \rho_T = (1 + \omega) \rho_d \quad \rho_T = \frac{(1 + \omega)}{(1 + e)} G_s \rho_w \quad \rho_d = \frac{G_s (1 - A)}{(1 + \omega G_s)} \rho_w \quad \text{dd} \propto \left[ \frac{D T}{v^2 n} \right]^{1/2} \]

\[ Cu = \frac{D_{60}}{D_{10}} \quad Cc = \frac{(D_{30})^2}{(D_{10} D_{60})} \quad q = k \ i \ A \quad i = \frac{\Delta h_r}{\Delta s} \quad q = k \ h_{T(last)} \ (N_t/N_d) \]

\[ Cu \geq 6 \quad 1 \leq Cc \leq 3 \ (SW) \quad Cu \geq 4 \quad 1 \leq Cc \leq 3 \ (GW) \]

\[ i_c = \frac{\gamma_T - \gamma_w}{\gamma_w} \]

\[ FS = \frac{\text{Strength}}{\text{Load}} \quad C_v = \frac{0.196d^2}{t_{50}} \quad S_o = \text{Surface/Mass} \]

\[ u = \sum_{m=0}^{\infty} \frac{2 u_0}{M} \sin \left( \frac{Mz}{d} \right) e^{-M^2 r} \quad S_\infty = \frac{\Delta e}{1 + e_o} H \quad S_t = \frac{q B}{E} \mu_p \mu_i \quad I_z = \frac{E}{q} \]

\[ M = \frac{\pi}{2} (2m + 1) \quad C \log \left( \frac{\sigma_2}{\sigma_1} \right) \quad S_\infty = \frac{H}{1 + e_o} \]

\[ K_A = \tan^2 (25 - \frac{\phi'}{2}) \quad T_v = \frac{\pi U^2}{4} \quad \bar{U} < 0.6 \]

\[ K_P = \tan^2 (25 + \frac{\phi'}{2}) \quad \sigma' = \frac{q}{\pi} \left[ \alpha + \sin \alpha \cos (\alpha + 2 \beta) \right] \]

\[ \sigma_H = K_A \sigma_v - 2c' \sqrt{K_A} \quad \sigma' = \frac{q}{\pi} \left[ \alpha - \sin \alpha \cos (\alpha + 2 \beta) \right] \]

\[ \sigma_H' = K_P \sigma_v + 2c' \sqrt{K_P} \quad \bar{U} > 0.6 \quad \tau_{xy} = \frac{q}{\pi} \left[ \sin \alpha \sin (\alpha + 2 \beta) \right] \]

\[ K_o = 1 - \sin(\phi') \quad C = \frac{\sigma_1 + \sigma_2}{2} \quad R = \frac{\sigma_1 - \sigma_2}{2} \quad \alpha' = c' \cos \phi' \]

\[ K_{oc} = K_{oc}^{OCR} \quad OCR \sin \phi' \quad C = \frac{\sigma_x + \sigma_y}{2} \quad R = \sqrt{\left( \frac{\sigma_y - \sigma_x}{2} \right)^2 + \tau_{xy}^2} \quad \tan \alpha' = \sin \phi' \]