ROCK STRENGTH AND ITS MEASUREMENT

Lesson 3
LESSON 3 - ROCK STRENGTH and Its MEASUREMENT

Learning Outcomes -
- Define Mohr-Coulomb Materials – Cohesion and Friction angle;
- Evaluate Shear Strength of Discontinuities;
- Evaluate Shear Strength of Rock Masses;
- Measure intact rock strength – Point Load Test;
- Measure Slake Durability of Intact Rock.
Rock Strength Categories

Intact rock

Single joint set

Two joints sets

Many joints

Jointed rock mass

Rock strength categories relate to sample dimensions
Classes of Rock Mass Strengths

- **Strong Rock with Continuous Planes Dipping Out of Face**
- **Jointed Rock Masses with Few Planes Dipping Out of Face**
- **Weathered Rock Masses Comprising Residual Soil and Weathered Rock**
- **Very Weak, Massive Rock Containing Few Discontinuities**

*Figures 3-2 to 3-4*
PLANE FAILURE ON BEDDING DIPPING OUT OF FACE
Limestone with persistent bedding planes dipping out of face
SHALLOW FAILURE IN CLOSELY JOINTED ROCK
Basalt with closely spaced, randomly oriented joints
(Oahu, HI)
CIRCULAR FAILURE IN RESIDUAL SOIL/WEATHERED ROCK
Weathered rock ranging from residual soil (upper) to core stones (lower) (AZ)
STEEP CUT IN VERY WEAK, MASSIVE ROCK
Tuff – very weak, massive rock  (I-17, Flagstaff, AZ)
Classification of rock strengths – Discontinuities

- Classes of rock strength
  - Sliding surface along discontinuity?
    - Yes
      - Joints parallel to face
        - Pair of intersecting joints
        - Use discontinuity shear strength
          Section 3.2, 3.3
    - No
      - Closely fractured rock
        - Weak, massive rock
        - Use rock mass shear strength
          Section 3.4, 3.5
  - Rock mass
Mohr-Coulomb Materials

- **Shear Strength of Rock Defined by:**
  - Cohesion \((c)\) and Friction Angle \((\phi)\)

- **Shear Strength \((\sigma)\) on Sliding Surface Given by:**

\[
\tau = c + \sigma' \tan \phi
\]

*Eq: 3-1*

*where \(\sigma\) is Effective Normal Stress on Sliding Surface*
Types of sliding surfaces

- Discontinuity with Weak Infilling
- Planar, Smooth Discontinuity with No Infilling
- Rough Discontinuity with Roughness Angle $i$
- Closely Fractured, Strong Rock
- Intact, Weak Rock

Figure 3.5
Relationship Between Shear Strength and Geological Conditions

Fig. 3.5

Friction angle

Cohesion

Effective Normal Stress, $\sigma'$

Shear Stress, $\tau$

Rough, clean fracture

Smooth, clean fracture

Infilled fracture

Discontinuities
Strength of Discontinuities

- Irregularity (Shape and Roughness)
- Wall Rock Strength
- Alteration
- Aperture
- Infilling
Rough surface formed by ripple marks
Smooth bedding planes
Effect of Surface Roughness (i) on Friction Angle

- Total Friction Angle, \( \phi_t = (\phi + i) \)

- Friction angle diminishes as asperities are ground off with increasing normal stress

Fig. 3.6
First and Second Order Asperities on Natural Rock Surfaces

a) Roughness angles for second order asperities

b) Roughness angles for first order asperities
Effect of Surface Roughness on Stability

Tensioned rock bolts prevent dilation along potential sliding surface and produce interlock along second order asperities ($i_2$).

**Displaced**

**Bolted**

$a) \quad i_1 = 13^\circ$

$b) \quad i_2 = 28^\circ \quad \psi_0 \quad 50 \text{ to } 100 \text{ mm}$
Joint Roughness Coefficient (JRC)

Roughness Angle Decreases with Increasing Normal Stress, ($\sigma'$) as Asperities are Sheared

$$\tau = \left[ \sigma' \tan(\phi + JRC \log_{10}(JCS / \sigma')) \right]$$  \hspace{1cm} Eq. 3-3

Rough Undulating \hspace{1cm} JRC 20 \hspace{1cm} e.g. Tension Joints
Smooth Undulating \hspace{1cm} JRC 10 \hspace{1cm} e.g. Foliation/Joints
Smooth Planar \hspace{1cm} JRC 5 \hspace{1cm} e.g. Bedding
Shear Strength of Filled Discontinuities

- Clay infillings
  \( \Phi < \sim 18^\circ \)

- Fault gouge (granular)
  \( \Phi \sim 22^\circ \) to \( 40^\circ \)

**Fig. 3.11**
Fault infilling
Direct Shear Tests of Discontinuities in Core to Determine Friction Angle

Fig. 3.13

True vertical displacement = gauge reading \times \frac{a}{b}.
Student Exercise - 4

Analysis of direct shear test results

Student Exercise No. 2A
Shear Strength of Fractured Rock Masses

- **Strength Determined from Back Analysis of Slope Failures:**
  - Strength of Large Scale, In Situ Rock Mass
  - **Figure 3.16 Shows Relationship Between:**
    - Cohesion ($c$) and Friction Angle ($\phi$)
    - Rock Mass Strength
    - Weathering
    - Fracturing
Plane failure in limestone quarry on bedding planes dipping at 20°
Back analysis of slope failure in limestone quarry

Relationship between cohesion and friction angle - Point 6 on Fig. 3.16

Range of strength values for slope failure
Back analysis of slope failure in limestone quarry

Factors of Safety calculated using shear strengths determined by back analysis
Shear Strength of Fractured Rock Masses by Back Analysis of Slopes

Figure 3.16

Rock descriptions on Table 3-2
Rock Durability and Compressive Strength

- Slake Durability to Estimate Rate of Weathering
- Point Load Test to Estimate Compressive Strength

Intact rock

- Single joint set
- Two joint sets
- Many joints
- Jointed rock mass
Slake Durability to Estimate Rate of Weathering
Point Load Test to Estimate Compressive Strength
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- Evaluate Shear Strength of Discontinuities;
- Evaluate Shear Strength of Rock Masses;
- Evaluate Intact Rock Strength and Slake Durability.