3. Description of Discontinuities

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Instructional Objectives

1. List the ISRM Suggested Methods characteristics of joints, explain what they are and how they are measured, and determine how they fit into the Size strength classification of rock masses.
2. Explain how we present this data so that is readily understood.
3. Propose ways to use the data for our ultimate purpose of engineering design.
4. Evaluation which data is biased in some way and how it can be rectified.
5. Measure or estimate these parameters.
Description of Joints (ISRM)

- Orientation
- Spacing
- Persistence
- Roughness
- Wall Strength
- Aperture
- Filling
- Seepage
- Number of Sets
- Block Size

Joint Parameters

- Definition (conceptual and practical)
- Measurement (how it is done)
- Rectification if necessary for sampling bias
- Display of the information
- Ultimate use of the information
Why Characterize?

- Classification of ground, into good, bad, moderate, etc., i.e. Rock Mass Classification.
- As input to modeling programs - need specific geometric data and property data.
- For specific design criteria.

Sampling

- We will get to this later, but bear in mind that we cannot see every discontinuity, so we have sample and measure.
- Sampling biases will occur, and they must be dealt with whenever possible.
- Two biases 1) representative sampling, 2) “hidden” aspects.
1. DEF: Orientation

- Defined in its simplest form as attitude in space.
- Inherent assumption that joint is generally planar, and can be described by the equation of a plane in 3-D Space. An often reasonable assumption, but always necessary, as we can’t deal with anything more complicated.

Orientation: Measurement

![Image of discontinuity plane with orientation angles labeled]

*Figure 6.5 Measurement of the orientation of discontinuities.*

Gonzales de Vallejo and Ferrer
Measuring Strike, Small Dip

Measuring Strike, Large Dip
Measuring Dip, Low Angle

Measuring Dip, High Angle
From Borehole Cores

![Image of borehole cores with discontinuities and solid rock labeled]

From Borehole Camera

![Image of borehole camera view]

From Stereoscopic Photos

From 2D Images
Orientation: Rectification

• No systematic measurement errors to be rectified.
• 1) Errors tend to be as a result of the non-planar nature of a discontinuity (undulating or roughness).
• 2) Orientation sampling bias

Terzaghi Bias

• Bias due to linear sampling
  – The sampling line will tend to intersect preferentially the larger, or more persistent, discontinuities.
  – The sampling line will tend to intersect preferentially those discontinuities whose normals make a small angle to the sampling line.
Sampling Bias

• An infinite linear sampling line will always intersect an infinite plane perpendicular to that line and never intersect an infinite plane parallel to that line.
• Probability of intersection is a function of the cosine of the angle between the discontinuity normal and the sampling line \( \cos \delta \).
• Consequently one could use weighting factors of \( 1/\cos \delta \) to amplify the number of joints that have a low probability of being sampled.

Orientation: Display

• 2-D easy - rosettes
Orientation: Display

- 3-D need visualization and calculation model
- Example a 3-D model

Steronet

- 3-D visualization
- Standard method = stereonet
- In engineering we always use a lower hemisphere, and we show individual joints as poles to the plane
Orientation: Analysis

- Organization of data by contouring or clustering data into measures of central tendency and perhaps variability and input into models, e.g. limiting equilibrium slope stability or numerical methods.
- Organization of data into categories, such as classes of dip, or dip direction favorable or unfavorable with respect to orientation of excavation, as an input into a classification scheme.

Steronet Contouring

- Method to better see trends - measures densities.
- Filters out orientations with sparse representation.
- Towards idea of clusters
Steronet Clustering

- Method to better see trends even better—measures clustering.
- Minimizes orientations with sparse representation.

Geological Map

- Symbols of traditional geological maps
- Discontinuity with dip of 45 degrees, horizontal and vertical discontinuity

\[45^\circ\] joints bedding foliation
Orientation: Ultimate Use

- Numerical modelling 2-D, 3-D
- Limiting equilibrium analysis
- Jointing models
- Rock mass classification
- Conceptual models

2. DEF: Spacing

- Defined as the average distance between adjacent joints.
- Characterizes the “brokenness” of the rock; the smaller the spacing, the less “intact” the rock.
- Two conventions - 1) between any joints in a particular direction and 2) between sub-parallel joints only, in perpendicular direction.
Spacing: Measurement

Descriptive, Modal Spacing

- Extremely close spacing  <20 mm
- Very close spacing  20-60 mm
- Close spacing  60-200 mm
- Moderate spacing  200-600 mm
- Wide spacing  600-2000 mm
- Very wide spacing  2000-6000 mm
- Extremely wide spacing  >6000 mm
Spacing: Rectification

- 1) Orientation sampling bias. With modal spacing, need to calculate the perpendicular distance (multiple by sin of the angle between scan line and discontinuity plane)
- 2) Size of exposure sampling bias (modal spacing)

Spacing: Display (non-modal)

- Spacing a function of direction of sampling
- In this case sampling done in a 2-D plane.
Non-modal spacing and RQD

- RQD is a way of measuring directional spacing.
- Defined as the percent of core run recovered in pieces 10 cm (4”) or longer.
- Relationship to fracture frequency

\[ RQD = 100e^{-0.1 \lambda} (0.1 \lambda + 1) \]

Spacing: Ultimate Use

- Numerical modeling 2-D, 3-D
- Jointing models
- Rock mass classification
- Conceptual models
3. DEF: Persistence

- Defined as the measure of a joint’s continuity or areal extent in space.
- Concept is quite fuzzy, three D problem, shape or boundary conditions of joints are largely unknown.
- In practice it is even fuzzier, since the joints of consequence are usually bigger than exposure they are seen on.

“persistence”

Figure 6.9 Diagrams showing different models of persistence in various sets of discontinuities (ISRM, 1981).
"step persistence"

Persistence: Measurement

- Simply measured with a tape measure on an exposure.
- Not possible to measure in borehole or borehole core
Descriptive, Persistence

- Very low persistence <1 m
- Low persistence 1-3 m
- Medium persistence 3-10 m
- High persistence 10-20 m
- Very high persistence >20 m

Persistence: Rectification

- Statistical reconstruction of trace length distribution as a consequence of censuring bias.
Persistent joints

Figure 7. Composite Jointing Pattern, Gaspé Mine.

Discontinuities (Hudson)

- Analytical techniques for modeling the effects of discontinuities are still in their infancy; it is usually necessary to treat the discontinuity pattern as though each discontinuity is planar and through-going, and as consisting of regular sets of parallel discontinuities.
Persistence: Ultimate Use

- Jointing models
- Rock mass classification
- Conceptual models
- Limiting Equilibrium

4. DEF: Roughness

- Defined as the deviation of the joint surface from the idealized plane of the joint.
- Interest is on the friction resistance to shearing, or the shear strength of the joint.
- WAVINESS = large scale roughness.
Roughness/Waviness

Roughness: Measurement

- Visual estimation.
- Compass and disc-clinometer
- Estimating roughness inclination angle
- Linear profiling
• VISUAL ESTIMATION - DESCRIPTIVE TERMS
  • Typical roughness profiles and suggested nomenclature
  • Small Scale (cm)
  • Large Scale (m)

• VISUAL ESTIMATION - COMPARISON TO PE PROFILES
  • Typical roughness profiles and classification
  • Link to shear strength (important)
Compass and disc-clinometer

- Measures i-angle (inclination angle)

Direct Measurement of Angles

- Best for stepped failure path
Linear Profilometry

- Mechanical Profilometry
- Shadow Profilometry

• MECHANICAL PROFILOMETRY
Shadow Profilometry

- Roughness Profile with $Z_2$ (root mean square of the first derivative), $i$ (average micro inclination angle), $R_p$ (roughness profile index)
Roughness: Rectification
Scale effect only

Roughness: Presentation

- Actual Profile.
- Spread of orientation data.
- Parameters measured on the profile.
Roughness: Ultimate Use

- Rock mass classification
- Conceptual models
- Limiting Equilibrium
- SHEAR STRENGTH MODELS EVERYWHERE

5. DEF: Wall Strength

- Defined as the compressive strength of the rock comprising the walls of the discontinuity.
- This parameter is important to measure when the rock adjacent to the joint has been weakened by alteration or weathering.
Wall Strength: Measurement

- Descriptive Classification
- Index Testing - Correlation to Uniaxial Compressive Strength
- Schmidt Hammer Tests (from concrete testing)

## Weathering Index

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>No visible sign of rock material weathering; perhaps slight discolouration on major discontinuity surfaces.</td>
<td>I</td>
</tr>
<tr>
<td>Slightly Weathered</td>
<td>Discolouration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering and may be somewhat weaker externally than in its fresh condition.</td>
<td>II</td>
</tr>
<tr>
<td>Moderately Weathered</td>
<td>Less than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones.</td>
<td>III</td>
</tr>
<tr>
<td>Highly Weathered</td>
<td>More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock it present either at a discontinuous framework or at corestones.</td>
<td>IV</td>
</tr>
<tr>
<td>Completely Weathered</td>
<td>All rock material it decomposed and/or disintegrated to soil. The original mass structure is still largely intact.</td>
<td>V</td>
</tr>
<tr>
<td>Residual</td>
<td>All rock material is converted to soil. The mass structure and material fabric are destroyed. There it a large change in volume but the toil has not been significantly transported.</td>
<td>VI</td>
</tr>
</tbody>
</table>
Weathering Grade

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>No visible sign of weathering of the rock material.</td>
</tr>
<tr>
<td>Discoloured</td>
<td>The colour of the original fresh rock material is changed. The degree of change from the original colour should be indicated. If the colour change is confined to particular mineral constituents this should be mentioned.</td>
</tr>
<tr>
<td>Decomposed</td>
<td>The rock is weathered to the condition of a soil in which the original material fabric is still intact but some or all of the mineral grains are decomposed.</td>
</tr>
<tr>
<td>Disintegrated</td>
<td>The rock is weathered to the condition of a soil in which the original fabric is still intact. The rock is friable but the mineral grains are not decomposed.</td>
</tr>
</tbody>
</table>

Soil Rating Index

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Field Identification</th>
<th>Approx. range of uniaxial compressive strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Very soft clay</td>
<td>Easily penetrated several inches by fist</td>
<td>&lt;0.025</td>
</tr>
<tr>
<td>S2</td>
<td>Soft clay</td>
<td>Easily penetrated several inches by thumb</td>
<td>0.025-0.05</td>
</tr>
<tr>
<td>S3</td>
<td>Firm clay</td>
<td>Can be penetrated several inches by thumb with moderate effort</td>
<td>0.5-0.10</td>
</tr>
<tr>
<td>S4</td>
<td>Stiff clay</td>
<td>Readily indented by thumb but penetrated only with great effort</td>
<td>0.1-0.25</td>
</tr>
<tr>
<td>S5</td>
<td>Very stiff clay</td>
<td>Readily indented by thumbnail</td>
<td>0.25-0.5</td>
</tr>
<tr>
<td>S6</td>
<td>Hard clay</td>
<td>Indented with difficulty by thumbnail</td>
<td>&gt;0.5</td>
</tr>
</tbody>
</table>
Rock Rating Index

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Field Identification</th>
<th>Approx. range of uniaxial compressive strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0</td>
<td>Extremely weak rock</td>
<td>Indented by thumbnail</td>
<td>0.25-1.0</td>
</tr>
<tr>
<td>R1</td>
<td>Very weak rock</td>
<td>Crumbles under firm blows with point or geological hammer, can be peeled by a pocket knife</td>
<td>1.0-5.0</td>
</tr>
<tr>
<td>R2</td>
<td>Weak rock</td>
<td>Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with point of geological hammer</td>
<td>5.0-25</td>
</tr>
<tr>
<td>R3</td>
<td>Medium strong rock</td>
<td>Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer</td>
<td>25-50</td>
</tr>
<tr>
<td>R4</td>
<td>Strong rock</td>
<td>Specimen requires more than one blow of geological hammer to fracture it</td>
<td>50-100</td>
</tr>
<tr>
<td>R5</td>
<td>Very strong rock</td>
<td>Specimen requires many blows of geological hammer to fracture it</td>
<td>200-250</td>
</tr>
<tr>
<td>R6</td>
<td>Extremely strong rock</td>
<td>Specimen can only be chipped with geological hammer</td>
<td>&gt;250</td>
</tr>
</tbody>
</table>

Schmidt Hammer Hardness

- Instrument well suited for fieldwork
- Often mistakenly used for rock strength
- High variability requires many replicates
Wall Strength: Ultimate Use

- Rock mass classification
- Conceptual models
- Limiting Equilibrium (base friction)
- SHEAR STRENGTH MODELS EVERYWHERE (friction angle)

Chart to get joint wall compressive strength from Schmidt hardness number as a function of rock density.
6. DEF: Joint Aperture

- Defined as the perpendicular distance between two walls of an open joint.
- This parameter is critical for fluid flow studies.
- Problem: Apertures are small and highly variable. In effect they cannot be “measured”.

![Image of a person in a grassy field]
Aperture: Measurement

- Large apertures are typically measured with a measuring tape (very open joints, rare)
- Smaller apertures are measured by means of a feeler gauge (inaccurate, high variability)
- For very small apertures, the average aperture can be calculated if the permeability of the fracture is known.

Aperture: Ultimate Use

- FRACTURE FLOW HYDROLOGY
7. DEF: Joint Filling or Infilling

- Defined as the material inside the joint, whose composition, strength or properties are different from that of the rock.
- Typically an weathering residual, although could also be an “infilling” of material from another source.
Joint Filling: Measurement

• Qualitative: Joint filling is characterized by geological standards such as mineralogy, thickness, particle size, hardness, etc.
• Quantitative: Joint filling is characterized by its effect on shear strength, which is base friction angle, and by width of filling.
• Water content important.

Water content and permeability

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>The filling materials are heavily consolidated and dry, significant flow appears unlikely due to very low permeability.</td>
</tr>
<tr>
<td>W2</td>
<td>The filling materials are damp, but no free water is present.</td>
</tr>
<tr>
<td>W3</td>
<td>The filling materials are wet, occasional drops of water.</td>
</tr>
<tr>
<td>W4</td>
<td>The filling materials show signs of outwash, continuous flow of water (estimate litres/minute).</td>
</tr>
<tr>
<td>W5</td>
<td>The filling materials are washed out locally, considerable water flow along outwash channels (estimate litres/minute and describe pressure i.e. low, medium, high).</td>
</tr>
</tbody>
</table>
Joint Filling: Ultimate Use

- Rock mass classification
- Conceptual models
- Limiting Equilibrium (base friction)
- SHEAR STRENGTH MODELS EVERYWHERE (friction angle)

7. DEF: Seepage

- Defined as the amount of moisture, water, or water flow that is occurring in or from the joint.
- Rather than a parameter, it is a condition, that depends on the joint interconnectivity, hydraulic conductivity (joint aperture) and pressure gradient.
### Seepage: Measurement

<table>
<thead>
<tr>
<th>Seepage Rating</th>
<th>Description Unfilled Discontinuities</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>The discontinuity is very tight and dry, water flow along it does not appear possible.</td>
</tr>
<tr>
<td>II</td>
<td>The discontinuity is dry with no evidence of water flow.</td>
</tr>
<tr>
<td>III</td>
<td>The discontinuity is dry but shows evidence of water flow, i.e. rust staining, etc.</td>
</tr>
<tr>
<td>IV</td>
<td>The discontinuity is damp but no free water is present.</td>
</tr>
<tr>
<td>V</td>
<td>The discontinuity shows seepage, occasional drops of water, but no continuous flow.</td>
</tr>
<tr>
<td>VI</td>
<td>The discontinuity shows a continuous flow of water. (Estimate 1/min and describe pressure i.e. low, medium, high).</td>
</tr>
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<th>Seepage Rating</th>
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<td>I</td>
<td>The filling materials are heavily consolidated and dry, significant flow appears unlikely due to very low permeability.</td>
</tr>
<tr>
<td>II</td>
<td>The filling materials are damp, but no free water is present.</td>
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<td>III</td>
<td>The filling materials are wet, occasional drops of water.</td>
</tr>
<tr>
<td>IV</td>
<td>The filling materials show signs of outwash, continuous flow of water (estimate 1/mm).</td>
</tr>
<tr>
<td>V</td>
<td>The filling materials are washed out locally, considerable water flow along out-wash channels (estimate 1/mm and describe pressure i.e. low, medium, high).</td>
</tr>
<tr>
<td>VI</td>
<td>The filling materials are washed out completely, very high water pressures experienced, especially on first exposure (estimate 1/mm and describe pressure).</td>
</tr>
</tbody>
</table>

### Seepage: Ultimate Use

- **FRACTURE FLOW HYDROLOGY**
- Rock mass classifications
9. DEF: Number of Sets

- Traditional: A joint set is defined as a collection of joints with a parallel or sub-parallel attitude.
- Newer: A collection of joints with similar attributes of all kinds.

1/2/3 Joint Sets

Figure 6.17 Block diagrams showing sets of discontinuities.

Gonzales de Vallejo and Ferrer
Sets: Measurement

- Same as orientation parameter

Consider: A lower hemisphere stereonet with four joint normals (poles) each pole from a different depth along an imaginary vertical bore hole.

Each pole is plotted on an individual stereonet, and the stereonets are stacked with spacing proportional to the spacing between the discontinuities along the borehole.

http://web.mst.edu/~norbert/pdf/Maerz_Alaska.pdf
Classification of Sets

- I massive, occasional random joints
- II one joint set
- III one joint set plus random
- IV two joint sets
- V two joint sets plus random
- VI three joint sets
- VII three joint sets plus random
- VIII four or more joint sets
- IX crushed rock, earth-like
Sets: Ultimate Use

- CONCEPTUAL MODELS
- Numerical modelling 2-D, 3-D
- Jointing models
- Rock mass classification

10. DEF: Block Size

- Size of the blocks bounded by the joints or discontinuities.
- Either volume or average length, or by some type of index.
- Block shape?
Blocky, Irregular, Tabular, Columnar Shape

Block Size: Measurement

1. RQD from drilling
2. RQD from spacing measurements
3. Block Size Index
4. Volumetric Joint Count
5. Block Models
RQD from drilling

- RQD is a modified core recovery percentage in which all the pieces of sound core over 10 cm long are counted as recovered.
- Rudimentary form of block size (bounded at both ends).
- Very useful, because usually available in an engineering project.

RQD from spacing measurements

\[ RQD = 100e^{-0.1\lambda} (0.1\lambda + 1) \]

- Lamda = 1/spacing (non-modal)
- just like RQD if is a function of sampling direction
- reflect different processes:
  - Real RQD = mechanical,
  - spacing-derived-RQD = geometric
Block size index

\[ I_b = \frac{S_1 + S_2 + S_3}{3} \]

- Size index which is the average spacing (modal) of three joint sets (if 3 present)

Volumetric Joint Count

\[ J_v = \frac{N_1}{l_1} + \frac{N_2}{l_2} + \ldots + \frac{N_n}{l_n} \]

- = sum of the number of joints per m for each joint set
- where \( N = \) the number of joint \( l = \) measurement length (for each set)
Volumetric Joint Count

\[ RQD = 115 - 3.3J_v \]

- Empirical relationship to RQD

Block Models
Block Models

- Correlation
Block Size: Ultimate Use

- Jointing models
- Rock mass classification (Size/Strength)
- Conceptual models

HOW IT ALL FITS TOGETHER

**SIZE**
- Orientation
- Spacing
- Persistence
- Block Size
- Number of Sets

**STRENGTH**
- Roughness
- Wall Strength
- Filling
- Aperture
- Seepage