3. Rock mass structure and characterisation

3.1 Introduction

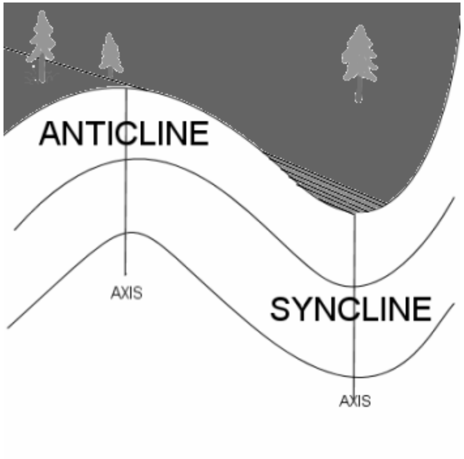
- Rock (material) and rock mass
- Rock Structure – The nature and distribution of structural features
- Structural features – bedding planes, faults, joints, folds, etc.
- Shallow depth – Block movement in jointed rock mass under low-stress environment

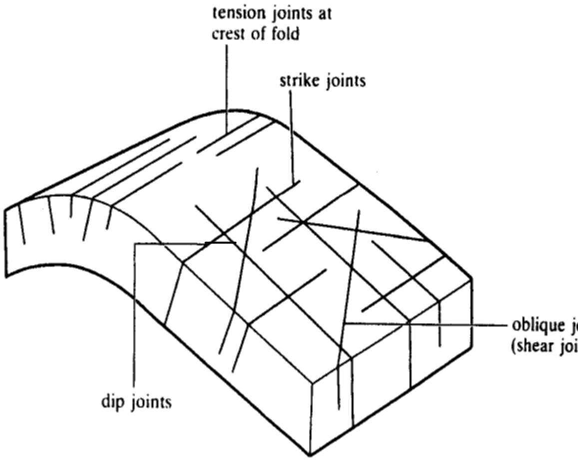
Deep mining – Stress is main concern for the mine stability. Rock mass behaves as continuum.

3.2 Major types of structural features

- Bedding planes
  - Planes between beds or strata of sedimentary rock representing interruptions in the course of deposition of the rock mass.
  - They may be cohesive or purely frictional in shear movement.

- Folds (습곡)
  - Beds bended by tectonic forces
  - Anticline (배사), Syncline (향사)

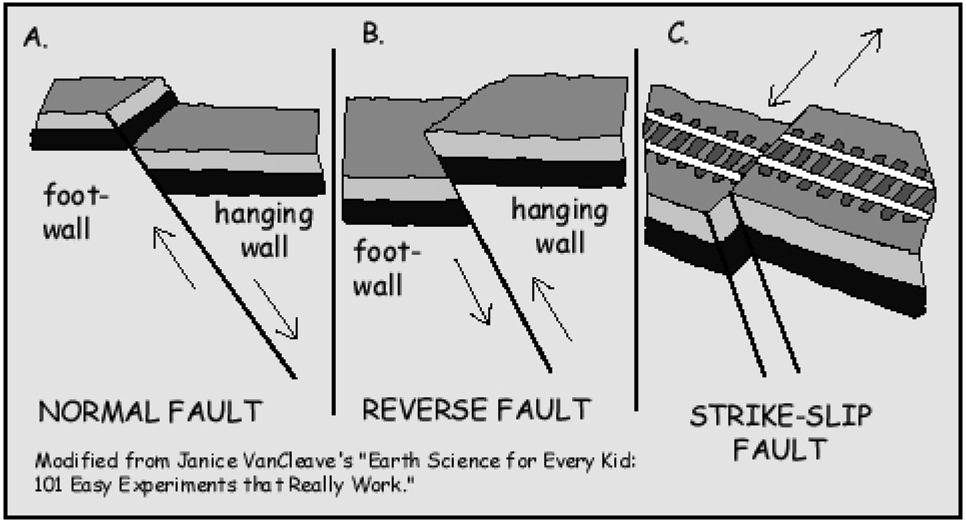




3.2 Major types of structural features

- Fault (단층)

- A shear failure plane that exhibits obvious signs of differential movement of rock mass on either side of the plane.
- It has relatively large distance between either side of the plane (mm ~ m) and shows slickensides (단층활면). It is filled with gouge (powdered rock) or fault breccia.
- Produced by tectonic stress. Larger shear displacement makes a bigger fault in terms of length and thickness.



Modified from Janice VanCleave's "Earth Science for Every Kid: 101 Easy Experiments that Really Work."

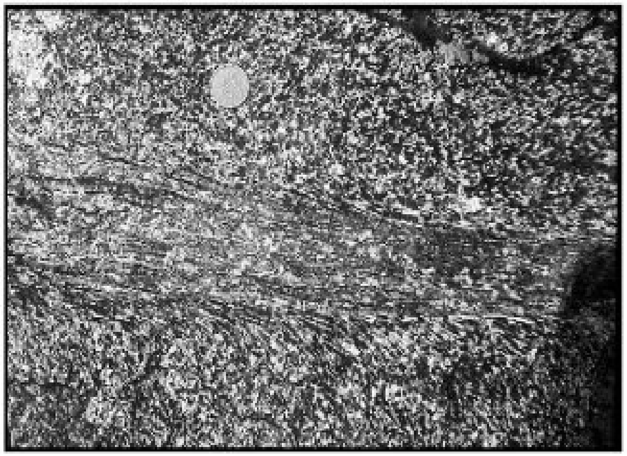
3.2 Major types of structural features

- Shear zone (전단대)

- A band of material in which local shear failure of the rock has previously taken place.

- Dyke (암맥)

- Long and narrow intrusions of generally fine-grained igneous rock with steep or vertical and approximately parallel sides.



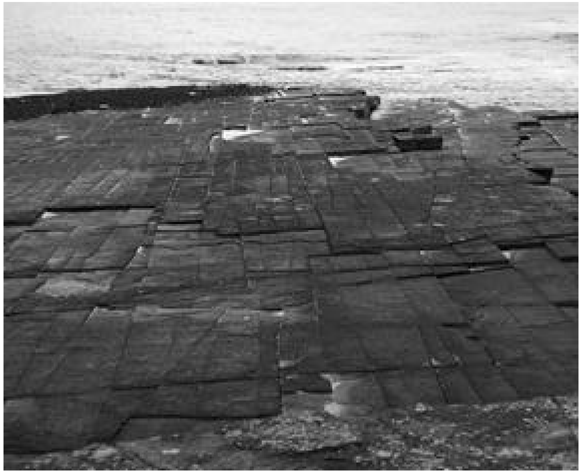
3.2 Major types of structural features

- Joints (절리)

- Breaks of geological origin along which there has been no visible displacement.
- Joint set: a group of parallel joints

- Veins

- Mineral infillings of joints or fissures which were precipitated from an hydraulic flow within the rock.



3.3 Important geomechanical properties of discontinuities

- Orientation

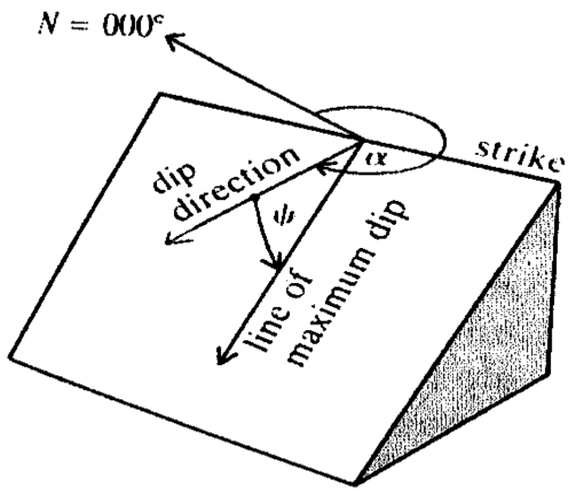
– Dip: the maximum angle between a discontinuity and horizontal plane

Dip direction: angle from north to dip line measured clockwise in horizontal plane

ex) 120/30, 045/60

– Strike line: intersection line of a discontinuity and horizontal plane

ex) N30°E/30 ° SE, N45 ° W/60 ° NE



3.3 Important geomechanical properties of discontinuities

- Spacing (간격)
  – Perpendicular distance between adjacent discontinuities.
  – Total spacing of a number of discontinuities can be approximated by a negative exponential distribution (case of a small amount of discontinuities shows a log-normal distribution):

$$f(x) = l e^{-lx} = \frac{1}{\overline{x}} e^{-x/\overline{x}}$$

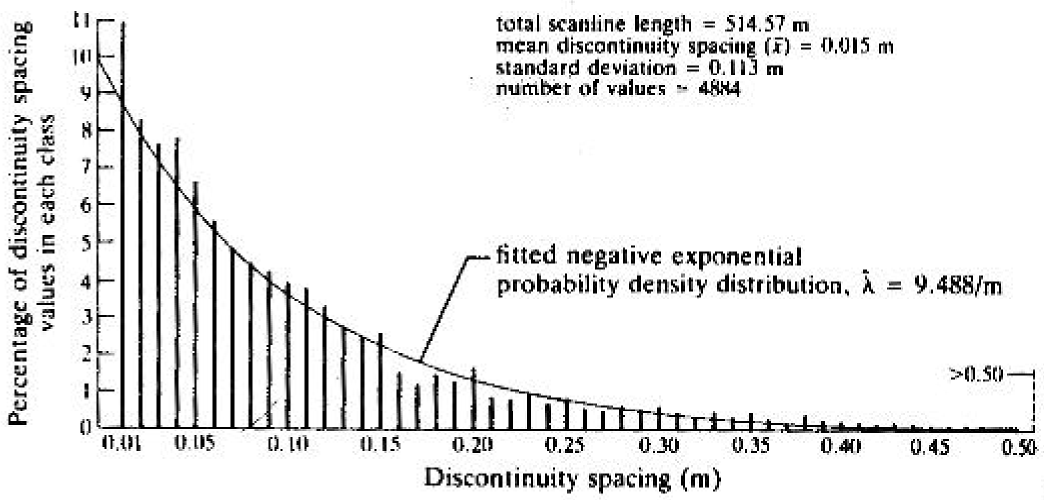


Table 3.1 Classification of discontinuity spacing.

Description	Spacing (mm)
extremely close spacing	<20
very close spacing	20–60
close spacing	60–200
moderate spacing	200–600
wide spacing	600–2000
very wide spacing	2000–6000
extremely wide spacing	>6000

3.3 Important geomechanical properties of discontinuities

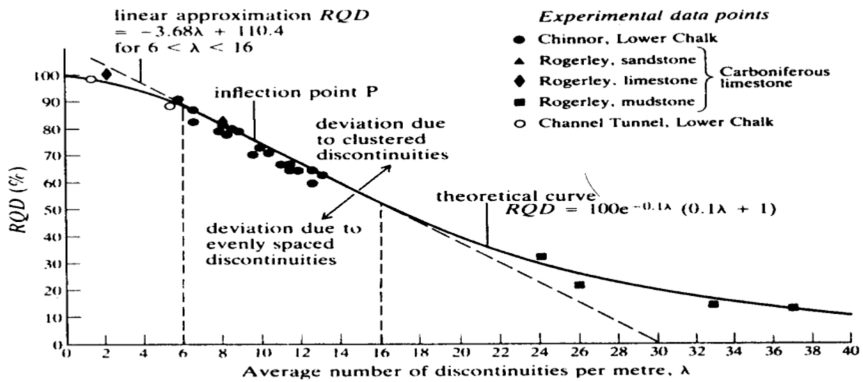
- RQD (Rock Quality Designation, 암질지수)

  - Definition: $RQD = \frac{100 \sum x_i}{L}$

  - Theoretical RQD: $TRQD = 100e^{-0.1l}\left(0.1l + 1\right)$

  - Importance: 20/100 of RMR

  - Limits: It depends on drilling orientation.
    It is not a good measure of rock mass with one joint set or widely spaced joint sets.



3.3 Important geomechanical properties of discontinuities

- Persistence

  - Importance: It has influences on shear strength, fragmentation characteristics, cavability and permeability of rock mass.

  - Limits: It is almost impossible to directly observe the discontinuities in rock mass.

    Traces are only available to estimate the joint size.

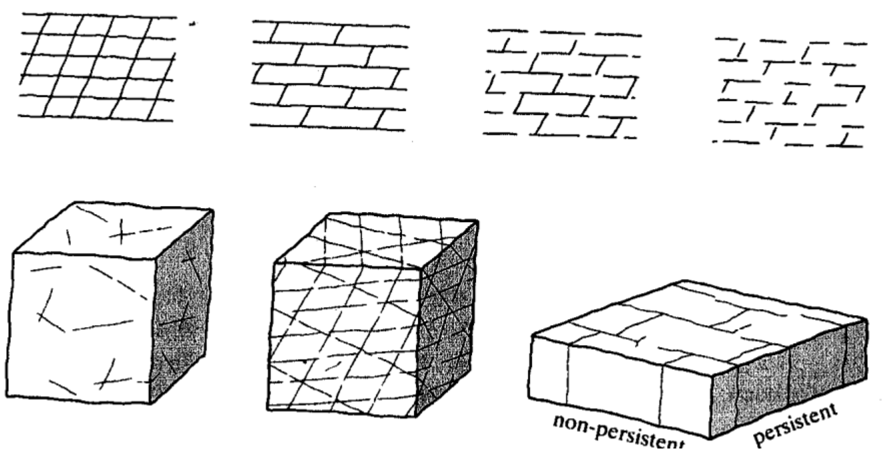


Table 3.2 Classification of discontinuity persistence.

Description	Modal trace length (m)
very low persistence	<1
low persistence	1–3
medium persistence	3–10
high persistence	10–20
very high persistence	20

3.3 Important geomechanical properties of discontinuities

- Roughness

  - A measure of the inherent surface unevenness and waviness of the discontinuity relative to its mean plane.
  - Refer to Figure 3.10~11, Table 3.3

- Aperture

  - Perpendicular distance separating the adjacent rock walls of an open discontinuity filled with air or water (Figure 3.12).
  - It has a great influence on hydraulic conductivity as follow (cubic law).

$$k = \frac{ge^3}{12u}$$

3.3 Important geomechanical properties of discontinuities

- Filling

  - Material separating the adjacent rock walls of discontinuities.

  - Important factors in filling:
    (a) mineralogy of the filling material
    (b) particle size
    (c) water content and permeability
    (d) previous shear displacement
    (e) wall roughness
    (f) width of filling
    (g) fracturing and chemical alteration of wall rock

3.4 Collecting structural data

- Mapping exposures

– Mapping methods: spot mapping, lineal mapping (scanline survey) and areal mapping (window survey)

– Recording in scanline survey (Figure 3.14): intersection distance, number of end points, discontinuity type (joint, fault…), orientation, roughness, planarity, (semi-) trace length, termination type, remarks (infilling, aperture, seepage…)

– Sampling bias of scanline

1) Orientation bias: joints parallel to the scanline cannot be sampled.

2) Size bias: larger joints have more chance to intersect the scanline.

3) Truncation bias: shorter joints than certain level are ignored in sampling

4) Censoring bias: longer joints than certain level cannot be measured.

3.4 Collecting structural data

– Correction of orientation bias:

Spacing: $x_{i0} = x_i \cos a$ (x_i: apparent spacing)

Total frequency: $l = \sum_{i=1}^{N} l_{i0} \cos a_i$

- Geotechnical drilling and core logging

– Core drilling is the most reliable tool for exploring the rock mass.

– Geotechnical drilling aims for 100% core recovery.

1) Drilling machine

– Drilled length, thrust, penetration rate, rotational speed, torque pressure, hydraulic pressure, etc. can be used to identify rock type, orebody boundary and estimate RQD.

3.4 Collecting structural data

2) Core barrel

– Competent rock or larger diameter of the core less causes mechanical breakage of the core, while drilling cost varies with the square of the core diameter.

– Double or triple tube core barrel prevents the rock core from being disturbed and damaged by rotating barrel and circulating water (Figure 3.19).

3) Drilling technique and contracts

– Special training for the geotechnical drilling and a special payment contract based on drilling time and core recovery are recommended.

4) Core orientation

– Geological markers such as bedding planes, cleavage or easily identified joint set

– Scribe reference marks on the core (acid etching and clay imprint…)

– Borehole camera (BIPS), seisviewer, borehole impression packer…

3.4 Collecting structural data

5) Core logging

– Logging items are dependent on nature of rock mass and project.

– Usually includes size, location, and orientation of the borehole, rock type, strength index, weathering index, information of discontinuities, RQD, permeability, etc.

6) Downhole logging

– Borehole camera and geophysical tools are adopted to investigate borehole walls and rock mass around the borehole.

3.5 Presentation of structural data

- Major features

– Major structural features such as dykes, faults, shear zones and persistent joints can be depicted in a variety of ways including modern computer-based systems.

- Joints and bedding planes

– Orientations are represented in distribution forms by rose diagram and stereographic projection.

– Spacing or frequency is an important item to be recorded (Figure 3.21).

3.6 The hemispherical projection

- Hemispherical projection of a plane

– Lower/upper hemisphere where planes pass through its center are used.

– Great circle is an intersection of the plane and the hemisphere (Figure 3.22).

– Lower hemisphere is preferred in rock mechanics.

– 3D shapes on the hemisphere can be converted to 2D shapes by projecting process:

Equal-angle (stereographic, Wulff, Figure 3.23) and equal-area (Lambert, Schmidt) projection.

– Stereonet is used to record the orientation of planes and measure the angle between the planes : Meridional (equatorial) / (Figure 3.24) and polar net (Figure 3.26).

– Orientation of a plane can be depicted by a great circle or a pole or the plane (Figure 3.25).

3.6 The hemispherical projection

- Plotting and analysis of discontinuity orientation data
  - Poles are plotted and counted on the projection plane (Figure 3.28).
  - Distribution of poles can be modeled by Fisher distribution (isotropic, Figure 3.29), Bingham distribution (anisotropic), etc.

3.7 Rock mass classification

- RMR (Rock Mass Rating)

  – 5 parameters: Intact rock strength, RQD, joint spacing, joint condition, groundwater condition (refer to Table 3.5)

  – Adjustment factor: joint orientation (refer to Table 3.6)

  – Information: stand-up time, cohesion and friction angle of rock mass, support type, etc.

- Q system

  – 6 parameters: RQD, joint set number, joint roughness, joint alteration, groundwater condition, stress reduction factor (0.5 for high stress but tight structure, 400 for heavy squeezing or heavy rock burst)

$$Q = \frac{RQD}{J_n} \frac{J_r}{J_a} \frac{J_w}{SRF}$$

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3.7 Rock mass classification

- GSI (Geological strength index)
  - Evaluation from observation: structure (blockiness and interlocking) and discontinuity surface condition (refer to Figure 3.30)
  - It does not explicitly include uniaxial strength, groundwater or stress condition and avoids double allowance for discontinuity spacing as in RMR.
  - Information: stand-up time, cohesion and friction angle of rock mass, support type, etc.