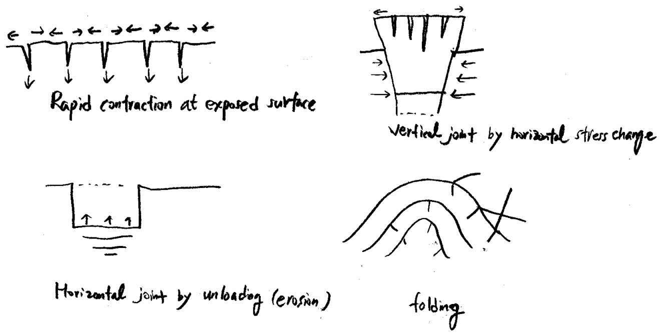
1. Introduction to discontinuities

● Definition of discontinuities: any significant mechanical break or fracture of negligible tensile strength in a rock
- No referring to any geological origin or mode of formation of the discontinuities. (such as 'made by shear movement', 'rapid cooling' or 'erosion of upper rock mass')

● Classification of discontinuities

1) Natural discontinuities: include fault (단층), joint (절리), bedding (층리), cleavage (벽개) which show relatively large, smooth, weathered and infilled (gouge, 充塡) surfaces compared to artificial ones.
  ① Fault: 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 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.
    - Strike-slip fault (주향이동단층), oblique-slip fault (사교단층), dip-slip fault (경사단층: normal/reverse/thrust fault belongs to this), normal fault (정단층, tensile), reverse fault (역단층, compressive, >45°), thrust fault (<45°).
  ② Joint: Cracks and fractures in rock along with which there has been extremely little or no movement
    - Different from fault in term of shear displacement, generally having smaller size but higher frequency than those of fault.
      Refer to the shear joint in Fig. 1.3 which shows a very small shear displacement.
    - Systematic/non-systematic joints: systematic joints corresponds to joint sets which have sub-parallel joints.
    - Formation: Due to differential cooling of rock (columnar joint), compressive/tensile stress, change in stress environment (uplifting of rock block or erosion of upper layer) or folding



③ Bedding: A surface created by a change in such factors as grain size, grain orientation, mineralogy or chemistry during the deposition of a sedimentary rock.

- Might be non-discontinuous even with different colors and/or composition.
- When they are discontinuous they are parallel to each other and very extensive as sedimentary layers are. It should be taken care of at statistical modelling of discontinuities (should be treated as an independent set of discontinuities).

④ Cleavage: Property of a mineral/rock that allows it to break smoothly along specific internal planes (parallel to crystal faces)

- More closely spaced and with higher tensile strength than other discontinuities
- Flow cleavage (continuous): formed by parallel alignment of platy minerals
- Fracture cleavage (false cleavage, spaced = discontinuous): formed by a loss of material resulting from pressure solution or by stress environment (independent of any parallel alignment of minerals)
- Development of cleavage:
  mudstone(이암)→slate(점판암)→phyllite(천매암)→schist(편암)→gneiss(편마암)
  (left → regional metamorphism(광역 변성작용)/larger crystal size → right)

⑤ Fracture(단구): A discrete break in a rock which is not parallel with a visible fabric

- It indicates a discontinuity that dose not show any definite pattern in orientation.
- In rock engineering field it frequently means a discontinuity or crack.
- In many cases it indicates an artificial discontinuity

※ Fissure has been defined differently by various scholars, and therefore it is not recommended to use the term without defining it in advance.

2) Artificial discontinuities: Generated by drilling, blasting or rock specimen test.

- Its surface is relatively small, rough and fresh.
- No definite pattern for orientation

● Properties of discontinuity (Piteau, 1973)

1) Orientation

-Major factor for rock slope stability analysis: Plane/Wedge/Toppling/Circular failure

-Major parameter for block theory analysis

-Adjustment factor in RMR: Due to relationship between tunnel axis and joint orientation

C.EFFECT OF DISCONTINUITY ORIENTATIONS IN TUNNELLING

Strike perpendicular to tunnel axis			
Drive with dip		Drive against dip	
Dip 45 - 90	Dip 20 - 45	Dip 45 - 90	Dip 20 - 45
Very favourable	Favourable	Fair	Unfavourable

Strike parallel to tunnel axis		Irrespective of strike
Dip 20 - 45	Dip 45 - 90	Dip 0 - 20
Fair	Very unfavourable	Fair

D. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS

Orientations of Discontinuities		Very Favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

2) Size

-Many slope stability analysis and block theory assume the discontinuity size to be large enough or infinite.

-RMR/Q-system don't consider joint size.

-Borehole, the most convenient and versatile surveying tool, cannot give the information of joint size.

-Only joint trace, not the whole stereographic shape or size of a joint, is observable in rock exposure.

-Mean joint trace length is frequently referred to as an indirect indicator of joint size. The joint size has a form of probability distribution function.

3) Frequency (빈도)

-RQD (20) and joint spacing (20) in RMR reflect the frequency repeatedly and indirectly.

-Q-system also considers it in RQD and joint set number.

-Block theory usually does not consider it.

4) Surface geometry

- Effective roughness angle by Patton (1966), :

- JRC by Barton (1973):

- Quantification of roughness: Roughness profile index, ave. inclination angle, root

mean square of i-angle, fractal dimension etc.
-Expression in RMR: Very rough+no separation (30)...
-Expression in Q-system: Rough or irregular, undulating (3)...

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter			Ranges of values						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4 - 10	2 - 4	1 - 2	For this low range, uniaxial compressive test is preferred		
		Uniaxial compressive strength (MPa)	>250	100 - 250	50 - 100	25 - 50	5 - 25	1 - 5	<1
		Rating	15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90 - 100	75 - 90	50 - 75	25 - 50	<25		
		Rating	20	17	13	8	3		
3	Spacing of discontinuities		>2m	0.6 - 2m	200 - 600mm	60 - 200mm	<60mm		
		Rating	20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1mm Slightly weathered wall rock	Slightly rough surfaces Separation <1mm Highly weathered wall rock	Slickensided surfaces or Gouge <5mm thick or Separation 1 - 5mm Continuous	Soft gouge >5mm thick or Separation >5mm Continuous		
		Rating	30	25	20	10	0		
5	Groundwater	Inflow per 10m tunnel length (l/min)	None	<10	10 - 25	25 - 125	>125		
		ratio (joint water pressure)/(major principal stress)	0	<0.1	0.1 - 0.2	0.2 - 0.5	>0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
		Rating	15	10	7	4	0		

5) Genetic type (성인)
- Refer to Classification of discontinuities

6) Infill material (충전물)
-RMR: Considered in condition of discontinuities (gouge)
-Q-system: Considered it partly in joint roughness number and mainly in joint alteration number.

● Representation of joint orientation

1) Trend/Plunge(선주향/선경사)

Trend: An angle in the horizontal plane measured in clockwise from the north to the vertical plane containing the given line.

Plunge: An acute angle measured in a vertical plane between the given line and the horizontal plane

Ex.) 320/23, 012/56

2) Dip direction/Dip(경사방향/경사)

Dip direction: Trend of the maximum dip line (dip vector) of the given plane

Dip: Plunge of the maximum dip line of the given plane

Ex.) 268/31, 029/45

3) Strike/Dip (주향/경사)

Strike: An angle measured in the horizontal plane from the north to the given plane

예) N15°E/30°SE, N25°W/56SW

※N15°E/30°SE → N15°/30°SE, N15°E/30°E, 15°/30°(right-hand rule)

※ Sometimes, -90° ≤ Strike and Dip ≤ 90° is possible with right-hand rule.

-30°/20° = 330°/20°, 40°/-30° = 220°/30°, -20°/-40° = 160°/40°

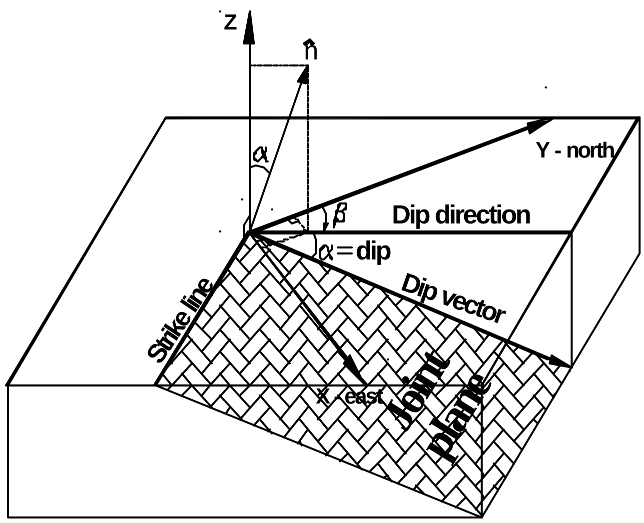


Fig. Dip direction, dip, strike and normal vector of a joint plane.

4) Pole to a plane

Pole: An intersection point of the normal vector of a given plane and a hollow sphere of which center is contained in the given plane. It is located in either hemisphere: upper or lower hemisphere.

※ 3D Cartesian coordinates of normal vector of a joint whose dip direction(β) and dip(α) are given (when +Z axis points vertical up):

● Measuring joint orientation by Clinocompass

1) Dip

① Make the clinocompass contact with the joint by its either side so that the contact side is roughly directed into the joint dip vector

② Adjust the clinocompass direction until its hand is not in contact with a reading plate.

③ Get the dip angle by multiplying 10 by the inner reading.

2) Strike

① Make the clinocompass contact with the joint keeping it horizontal so that N-S or E-W on reading plate becomes the strike line of the joint.

② Read the acute angle from the north pointing magnetic hand to the strike line.

③ Assume that you are at the center of the plate. If the strike line is in right (left) side of the north pointing hand, E (W) follows the strike angle.

3) Dip direction

① Make the clinocompass contact with the joint keeping it horizontal so that N-S or E-W on reading plate becomes the dip direction (dip direction is normal to the contact line of the clinocompass).

② Read the angle from the north pointing hand to the dip direction.