II. Evaluation of Engineering Geological Data

Rock mass = rock material + natural discontinuities

Mapping of geological structure is an essential component of the design of underground excavations

1. Engineering geological data collection

(1) Proposed by the Geological Society of London (Anon, 1977)

the International Society for Rock Mechanics (ISRM, 1978)

(2) Character of the rock mass = geological + geometric parameters

(3) Goal: To describe the rock mass as accurately as possible

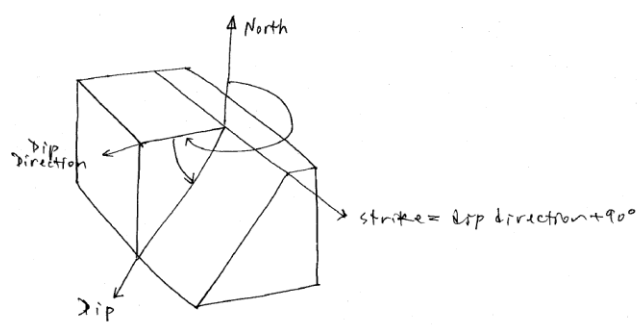
2. Structural geological terms

(1) Dip: the vertical angle of the line of maximum inclination, measured from a horizontal plane

(2) Dip direction: the orientation of the horizontal projection of the line of maximum inclination, measured from clockwise from north

i.e. 35/120

30/35SE or 030/35 (right hand rule; thumb – strike, fingers – dip)



3. Structural geological data collection

(1) With compasses and clinorules

(2) Scanline or windows (scanline orientation)

(3) At least 100 measurements of dip and dip direction in each structural domain

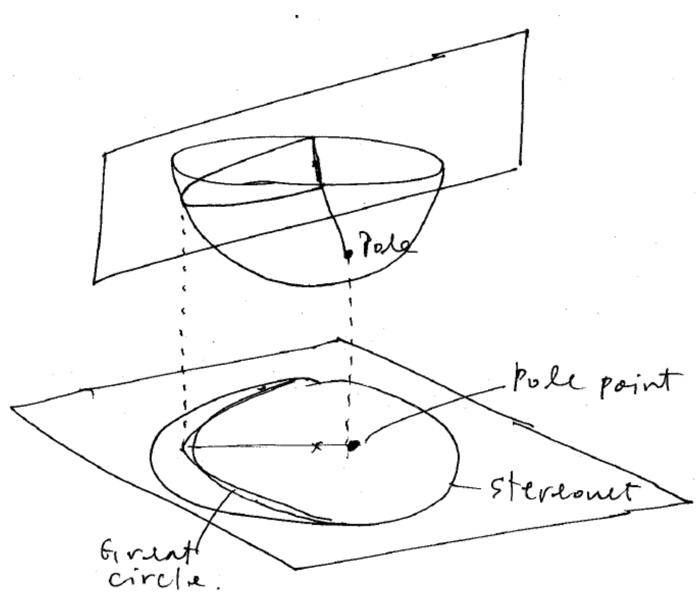
4. Structural geological data presentation

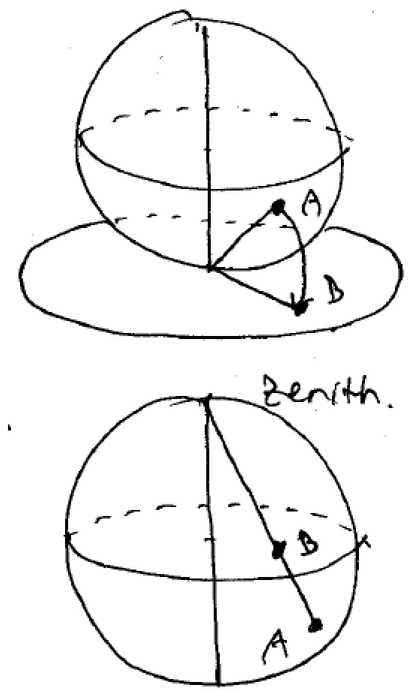
(1) Spherical projection technique (3D → 2D)

(2) Ubiquitous planes – planes all pass through the center of the reference sphere

(3) Equal area projection

(4) Equal angle projection





5. Geological data analysis

(1) Poles on a stereonet

(2) Identify families of significant discontnuities

(3) Different symbol for a fault or major shear zone

III. Investigation

- Important points

  (1) Quality of design $\propto$ quality of input parameters
  (2) Procedures or methods to get input data should be justified and planned.
  (3) Quantitative rather than qualitative information

- Initial site characterization (mainly geological data)

  (1) Rock (soil) types
  (2) Depth and character of overburden
  (3) Macroscopic discontinuities (i.e. major faults)
  (4) Groundwater conditions
  (5) Weak ground / swelling rock

- Methods of initial site characterization

  (1) Existing geological maps
  (2) Published literature
  (3) Local information
  (4) Areal photographs
  (5) Others

  Limited field and laboratory tests, i.e. geophysical methods, remote sensing
  Preliminary geological maps (section)

- Final site investigation (최종부지조사)

  Includes detailed exploratory drilling, geological mapping, geophysical surveys, rock mechanics testing

1. Drilling investigations (시추조사)

(1) Purpose
- Confirm geologic interpretations
- Determine the characteristics of the rock mass and/or soil profile
- Study groundwater conditions
- Provide cores for rock mechanics testing

(2) Required considerations

- High cost (Nevada, USA, 1995)

Typical cost		
Rotary	$3~8/ft	~$5/ft (avg.)
Diamond drill	$20~30/ft	~$22/ft (avg.)

  - Softer – cheaper, harder – more expensive
  - Cost includes labor, but not mobilization
  - Water tank (~$50/day)
  - Driver $215/10 hrs., $1.25/mile
  - Mobilization $1500/drill
  - Hole abandonment $210/crew/hr + cost + 15% (overhead)

- Diamond drill
  - Most expensive
  - Bit with industrial diamonds
  - Reaming shell with dismonds
  - Core barrel ~10 ft

- Rotary drill
  - Prime advantage is cost.
  - Very fast in soft rock (100 ~ 200 ft/hr)
  - Bigger hole / larger sample 4” ~ 7”
  - Need good site access (for trucks)
  - Can drill several 1000 ft
  - May get contamination
- Diamond drill

Size	Core Dia. (mm)	Hole Dia. (mm)
XR	18.3	30
EX	21.4	36
EXT	23.8	36
AX	29.4	47
AXT	32.5	47
BX	42.1	59
NX	54.8	75

First letter – hole size

Second letter – core barrel series

Third letter – thin-walled

- Borehole examination (i.e. borehole camera)
- Core orientation should be marked.
- Inclined drilling for vertical discontinuities
- Core recovery is important.
- Good care required for the recovered core;

2. Geophysical investigations

(1) Types Seismic, electrical resistivity, gravimetric, magnetic

(2) Should be accompanied with diamond drilling investigations

(3) Seismic refraction – most popular

Seismic refraction techniques

- Measure time delay (source → detector / geophone)
- P- and S-wave
- $(V_F/V_L)^2$ Index of rock quality

  V_F – P-wave velocity measured in the field

  V_L – P-wave velocity measured in the laboratory

  (very poor) $0 < (V_F/V_L)^2 < 1$ (very good) (Due to structural discontinuities)
- Dynamic modulus of deformation (E_d) and Poisson's ratio

$$v_p = \left[\frac{E}{\rho}\frac{1-\nu}{(1+\nu)(1-2\nu)}\right]^{\frac{1}{2}}$$

$$v_s = \left[\frac{E}{\rho}\frac{1}{2(1+\nu)}\right]^{\frac{1}{2}}$$

$$\left[\frac{v_p}{v_s}\right]^2 = \frac{2(1-\nu)}{1-2\nu}$$

$$\therefore E_d = \rho v_p^{\,2}\frac{(1-2\nu)(1+\nu)}{1-\nu} = 2v_s^{\,2}\rho(1+\nu)$$

$$\nu = \frac{\left(\frac{v_p}{v_s}\right)^2 - 2}{2\left[\left(\frac{v_p}{v_s}\right)^2 - 1\right]}$$

v_p: P-wave velocity (m/s)

v_s: S-wave veocity (m/s)

ρ: density of rock (mass) material (kg/m^3)

Petite Seismique

- New geophysical technique (1967, Schneider)
- Involves seismic parameters of shear wave

  i.e. frequency, velocity, attenuation, $\lambda/2$, rather than seismic wave velocities
- Major findings

  Shear wave velocity & attenuation trends → indentification

  Wave-length (S-wave) $\propto$ (E_{seis} / E_m)

  E_{seis}: seismic modulus

  E_m: static in-situ modulus

  Shear wave freq. $\propto$ static modulus of deformation

Table 5.2 Typical longitudinal wave velocities through different materials

Rock type	Velocity (m/s)
Sandstone	1400–4500
Shale	1200–3500
Slate	4500–5000
Limestone: Soft	1700–4200
Hard	2800–6400
Dolomite	3500–6900
Granite	4600–7000
Diabase	5800–6000
Gabbro	6400–6700
Basalt	3600–6400
Schist	4200–4900
Gneiss	3500–7500
Coal	800–1300
Clay	900–2500
Sand	200–2000
Water	1450
Air	335

Table 5.3. Velocity index and rock mass quality

Velocity index $(V_F/V_L)^2$	Rock mass quality
$<$ 0.2	Very poor
0.2 to 0.4	Poor
0.4 to 0.6	Fair
0.6 to 0.8	Good
0.8 to 1.0	Very good

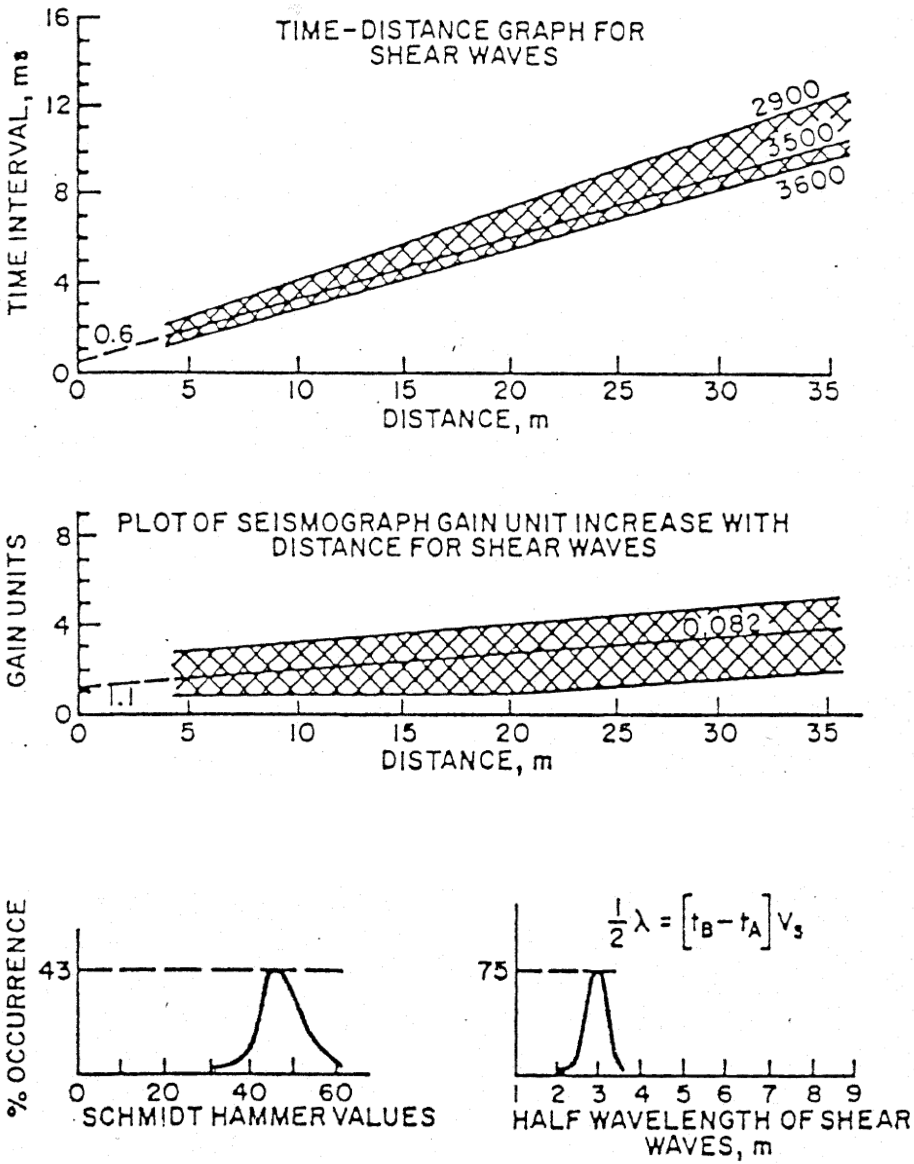


Figure 5.3. Rock mass identification by 'petite sismique' (after Schneider, 1967).

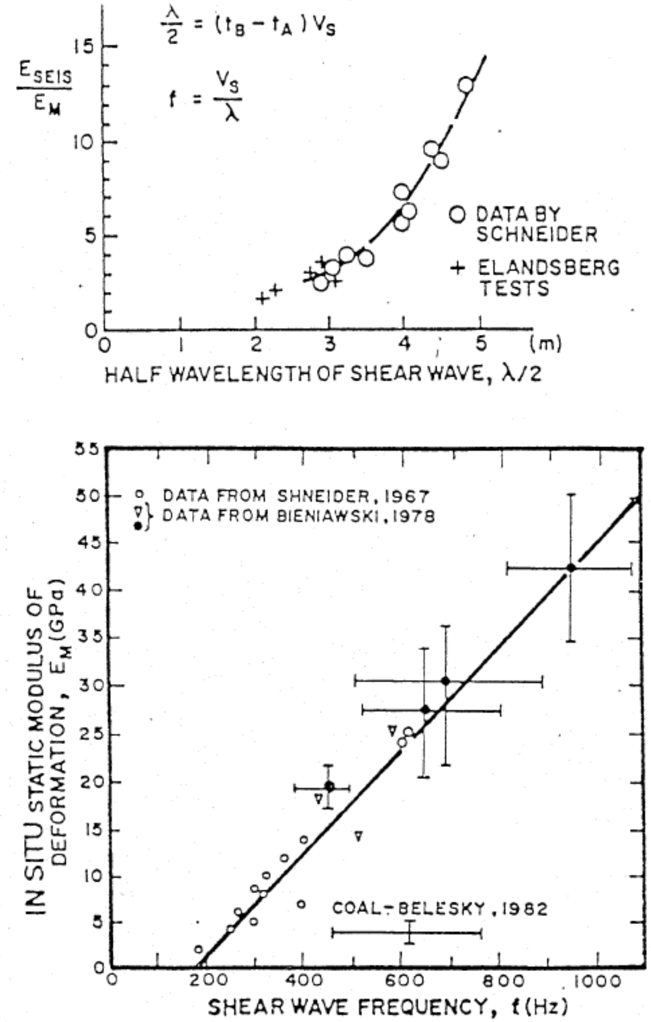


Figure 5.4. Petite sismique correlations: a) Ratio of seismic modulus to in situ modulus of deformation versus shear-wave half-wave length, b) Static modulus of deformation from plate-bearing tests versus shear-wave frequency.

3. Hazard analysis

(1) Orientation of discontinuities in the rock mass

(2) Spacing of discontinuities in the rock mass

(3) Condition of discontinuities

(i.e. roughness, separation, continuity, weathering, infilling gouge)

(4) Groundwater conditions

(5) Major faults

(6) Properties of intact rock material

4. Ground stress

(1) Virgin stress + induced stress → Field stress

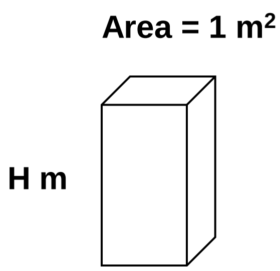
i.e. gravitational, tectonic, residual (thermal, swelling, etc.)

(2) Measuring techniques

overcoring methods (stress relief), flat jack techniques (stress compensation), hydrofracturing

(3) Vertical stress

Simple calculation based on the weight



Volume = H m^3

Density = 2.5 g/cm^3 = 2500 kg/m^3

Mass = 2500H kg

Weight = 25000H Newton (g = 10 m/s^2)

Stress = force/area = (25000H N)/(1 m^2) = 25000H Pa = 0.025H Mpa

(H in meter)

(4) Horizontal stress

From the Modified Hooke's Law

$$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \nu\left(\sigma_y + \sigma_z\right)\right]$$

$$\varepsilon_y = \frac{1}{E}\left[\sigma_y - \nu\left(\sigma_z + \sigma_x\right)\right]$$

$$\varepsilon_z = \frac{1}{E}\left[\sigma_z - \nu\left(\sigma_y + \sigma_x\right)\right]$$

$$\varepsilon_v = \frac{1}{E}\left[\sigma_v - \nu\left(\sigma_H + \sigma_H\right)\right]$$

$$\varepsilon_H = \frac{1}{E}\left[\sigma_H - \nu\left(\sigma_H + \sigma_v\right)\right] = 0$$

$$\therefore \sigma_H = \nu\left(\sigma_H + \sigma_v\right)$$

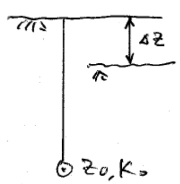
$$\sigma_H = \frac{\nu}{1-\nu}\sigma_v$$

(5) K = ratio of horizontal stress to vertical stress

= σ_H / σ_v

= $\nu/(1-\nu)$ (= 1/3 @ ν = 0.25)

(6) Change in K due to removal of material



	σ_V	σ_H
Before	$\rho g z_0$	$K_0 \rho g z_0$
Change	$-\rho g \Delta z$	$-\frac{\nu}{1-\nu}\rho g \Delta z$
New stress	$\rho g (z_0 - \Delta z)$	$\rho g (K_0 z_0 - \frac{\nu}{1-\nu}\Delta z)$

$$\text{New } K = \frac{\rho g \left(K_0 z_0 - \frac{\nu}{1-\nu}\Delta z\right)}{\rho g (z_0 - \Delta z)}$$

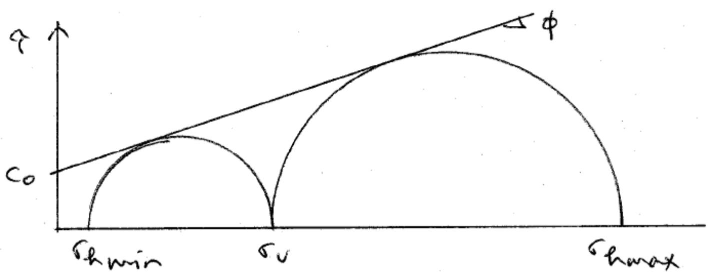
$$= \frac{\left(K_0 - \frac{\nu}{1-\nu}\frac{\Delta z}{z_0}\right) + K_0\frac{\Delta z}{z_0} - K_0\frac{\Delta z}{z_0}}{\left(1 - \frac{\Delta z}{z_0}\right)}$$

$$= K_0 + \frac{\frac{\Delta z}{z_0}\left(K_0 - \frac{\nu}{1-\nu}\right)}{1 - \frac{\Delta z}{z_0}}$$

(7) Summary

- $\sigma_v = \rho gh \approx 0.025$ Mpa/m ≈ 1.08 psi/ft
- Vertical stress assumes a principal stress
- $K = \sigma_h / \sigma_v$
- $K \approx 1$ in some area
- $K = \nu/(1-\nu)$ (= 1/3 @ $\nu = 0.25$)

(8) Bounds on K for intact



$K_{min} = \frac{\sigma_{hmin}}{\sigma_v}$, $K_{max} = \frac{\sigma_{hmax}}{\sigma_v}$

Mohr-Coulomb criterion

$$\sigma_1 = B_u + \sigma_3 \tan^2(45 + \frac{\phi}{2})$$

$K_{min} \Rightarrow \begin{cases} \sigma_v = \text{max. principal stress} & \sigma_1 = \rho g z \\ \sigma_h = \text{min.} \quad '' & \sigma_3 = K_{min} \rho g \end{cases}$

$$\sigma_v = B_u + \sigma_h \tan^2(45 + \frac{\phi}{2})$$

$$\rho g z = B_u + K_{min} \rho g z \tan^2(45 + \frac{\phi}{2})$$

$$\therefore K_{min} = \frac{\rho g z - B_u}{\rho g z \tan^2(45 + \frac{\phi}{2})}$$

$$\Rightarrow K_{min} = \frac{1}{\tan^2(45 + \frac{\phi}{2})} - \frac{B_u}{\rho g z \tan^2(45 + \frac{\phi}{2})}$$

$K_{max} \Rightarrow \begin{cases} \sigma_v = \text{min. principal stress} & \sigma_3 = \rho g z \\ \sigma_h = \text{max.} \quad '' & \sigma_1 = K_{max} \rho g z \end{cases}$

$$K_{max} \rho g z = B_u + \rho g z \tan^2(45 + \frac{\phi}{2})$$

$$\therefore K_{max} = \frac{B_u + \rho g z \tan^2(45 + \frac{\phi}{2})}{\rho g z}$$

$$\Rightarrow K_{max} = \frac{B_u}{\rho g z} + \tan^2(45 + \frac{\phi}{2})$$

Both have the form of $K = \frac{A}{z} + B$

※ Brown & Hoek (1978)

$$0.3 + \frac{100}{z} \le \bar{K} \le 0.5 + \frac{1500}{z}.$$