109.01

Engineering Geology
工程地質

CH3 岩石、岩體與工程(PART 2)
岩體分類法

授課教師：邱雅筑

2020/10/12

大綱

- 岩體分類法
- 岩體評分法(Rock Mass Rating, RMR)
- Q法 (Q-system)
- 台灣岩體分類法

如何量化岩體力學特性？

1

數學模式：

Jaeger's single plane of weakness theory, Bray's superposition theory…

2

室內實驗

3

現地實驗

4

數值模擬

5

經驗統計法：

岩體分類法

Gonzales de Vallejo and Ferrer (2011)

Cretaceous dolomite. Very good quality. Two main sets of discontinuities. 白堊紀白雲岩，品質極佳，兩組主要不連續面

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Ordovician quartzite. Poor quality. Weathered and heavily jointed rock mass. 奧陶紀石英岩，品質差，已風化且節理發達

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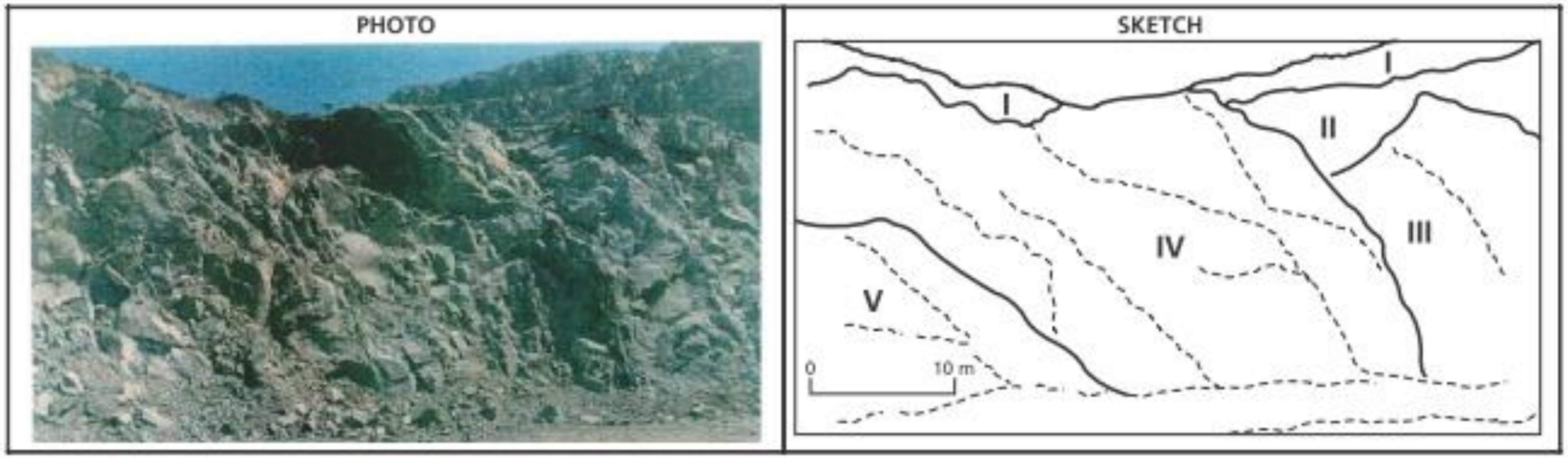
岩體分類之用意 Goel and Singh (2011)

岩體之工程分類在澳洲、南非、美國、歐洲、印度等地應用廣泛，主因為：

1. 提供業主、地質師、設計者、包商與工程師較好的溝通媒介。
2. 工程量化分類系統可有效連結工程師的觀察、經驗與判斷。
3. 工程師偏好量化數據而非觀察描述，因此量化的岩體分類較易推廣。
4. 分類法有助於全盤地理解岩體類型。
5. 岩體的工程分類能完美應用於水力發電廠、隧道開挖、地底洞室建造、橋梁、筒倉、複合式建築、山區道路、鐵路隧道…等計畫。

岩體分類法

- **Rock mass classifications**岩體分類法：Obtaining geomechanical parameters to use when designing engineering projects.
- The most frequently used geomechanical classifications nowadays are the RMR and the Q classifications.



岩體評分法 Rock Mass Rating (RMR)

- Developed by Z.T. Bieniawski in 1973 at the South African Council of Scientific and Industrial Research (**CSIR**), and updated in 1979 and 1989. Also called the **Geomechanics Classification** (地質力學評分法).
- 評分項目包含：
  1. Uniaxial compressive strength (UCS) of intact rock material
  2. Rock quality designation (RQD)
  3. Joint or discontinuity spacing
  4. Joint condition
  5. Groundwater condition
  6. Joint orientation

岩體評分法(RMR)

RMR = 以下六項之**加總**

- Uniaxial compressive strength of intact rock. 單壓強度 (15%)
- Degree of fracturing (RQD). 破裂程度(RQD) (20%)
- Spacing of discontinuities. 不連續面間距 (20%)
- Condition of discontinuities. 不連續面狀態 (20%)
- Groundwater conditions. 地下水狀態 (30%)
- Orientation of discontinuities. 不連續面位態 (-60~0%)

RMR CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter			Range of values						
1	Strength of intact rock material (MPa)	ISRM description	chipped with hammer	Fractured > n blow of hammer	Fractured > 1 blow of hammer	Fractured 1 blow of hammer	Peeled by knife hard	Peeled by knife	Indented by thumbnail
		Point-load	> 10	10 - 4	4 - 2	2 - 1	NA	NA	NA
		UCS	> 250	250 - 100	100 - 50	50 - 25	25 - 5	5 – 1	< 1 MPa
	Rating		15	12	7	4	2	1	0

2	RQD(%)	100 - 90	90 - 75	75 - 50	50 - 25	< 25
	Rating	20	17	13	8	3
3	Spacing of joints	> 200 cm	200 – 60 cm	60 – 20 cm	20 – 6 cm	< 6 cm
	Rating	20	15	10	8	5

4	Condition of joints	Persistence	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m
		Rating	6	4	2	1	0
		Aperture	None	< 0.1 mm	0.1 - 1 mm	1 - 5 mm	> 5 mm
		Rating	6	5	4	1	0
		Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
		Rating	6	5	3	1	0
		Infilling	None	Hard filling< 5mm	Hard filling> 5mm	Soft filling< 5mm	Soft filling> 5mm
		Rating	6	4	2	2	0
		Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
		Rating	6	5	3	1	0

5	Ground water	Completely dry	Damp	Wet	Dripping	Flowing
	Rating	15	10	7	4	0

RMR = ( ) + ( ) + ( ) + ( ) + ( ) = ( )

Made by Rocklab, IMRE, NTUT

Goel and Singh (2011)

1.Uniaxial compressive strength (UCS) of intact rock

- 岩石材料的單軸壓縮強度
- 分7級，1, 5, 25, 50, 100, 250 MPa

TABLE 6.1 Strength of Intact Rock Material (強度越強，分數越高)

Qualitative description	Compressive strength (MPa)	Point load strength (MPa)	Rating
Extremely strong*	>250	8	15
Very strong	100–250	4–8	12
Strong	50–100	2–4	7
Medium strong*	25–50	1–2	4
Weak	5–25	Use of UCS is preferred	2
Very weak	1–5	-do-	1
Extremely weak	<1	-do-	0

At compressive strength of rock material less than 1.0 MPa, many rock materials would be regarded as soil.
**Terms redefined according to ISO 14689.*

Sources: Bieniawski, 1979, 1984; ISO14689-1, 2003.

2. Rock quality designation (RQD)

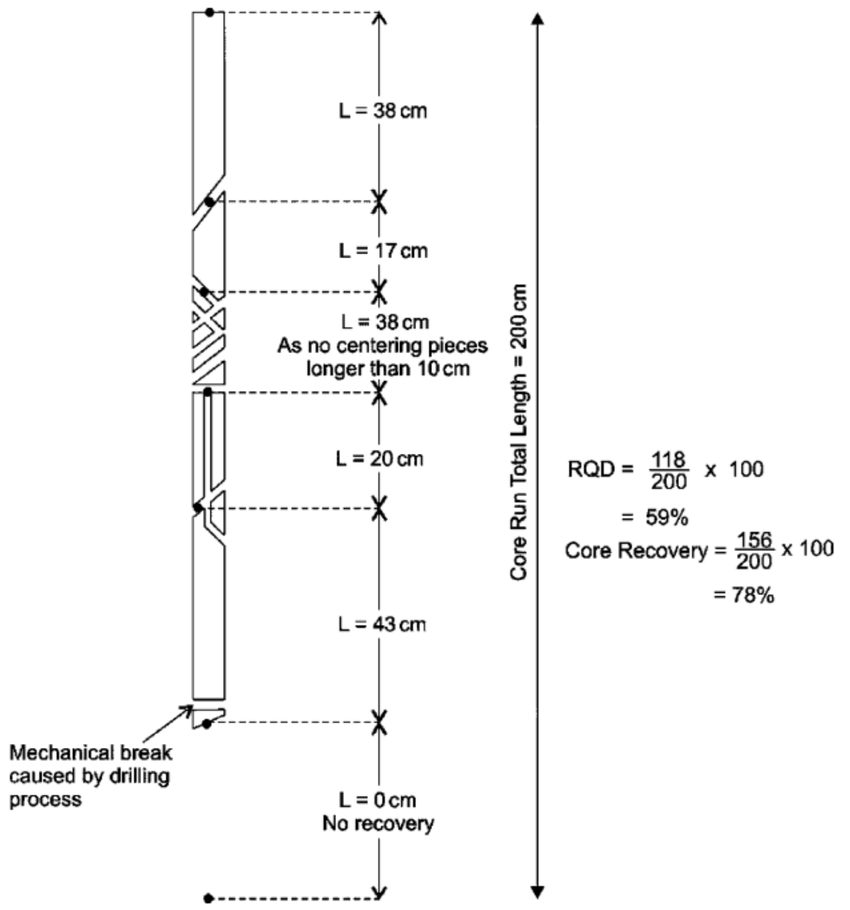


FIGURE 4.1 Procedure for measurement and calculation of rock quality designation (RQD). *(From Deere, 1989)*

$$\mathrm{RQD} = \frac{\text{sum of core pieces} \geq 10\ \text{cm}}{\text{total drill run}}\ .\ 100,\ \%$$

- 大於10 cm的部分之長度總和占岩心全長比例。
- 分5級，25, 50, 75, 90 (RQD越大，分數越高)

TABLE 6.2 Rock Quality Designation

Qualitative description	RQD (%)	Rating
Excellent	90–100	20
Good	75–90	17
Fair	50–75	13
Poor	25–50	8
Very poor	<25	3

Source: Bieniawski, 1979.

RQD之應用 (關聯完整岩石與岩體力學特性)

- 波速

$$RQD = (V_F/V_L)^2 \cdot 100$$

V_F is in situ compressional wave velocity
V_L is compressional wave velocity in intact rock core

- Deformation modulus of the rock mass
  - Zhang and Einstein (2004)

E_d and E_r are the deformation moduli of the rock mass and the intact rock

$$\frac{E_d}{E_r} = 10^{0.0186\ RQD - 1.91}$$

RQD之應用

數字越大，代表岩體越破碎

- Volumetric Joint Count (J_v): the number of joints within a unit volume of rock mass

$$J_v = \sum_{i=1}^{J} \left(\frac{1}{S_i} \right)$$

S_i is the average joint spacing in meters for the i^{th} joint set

J is the total number of joint sets except the random joint set.

  - clay-free rock masses, long or flat blocks (Palmstrom, 1982)

$$RQD = 115 - 3.3\ J_v$$

  - for blocks of a cubical (bar) shape (Palmstrom, 2005).

$$RQD = 110 - 2.5\ J_v$$

加權節理密度

Weighted joint density (Palmstrom, 1996)

- Based on the measurement of the angle between each joint and the surface or the drill hole.
- Weighted joint density (wJd) (只有J大寫)

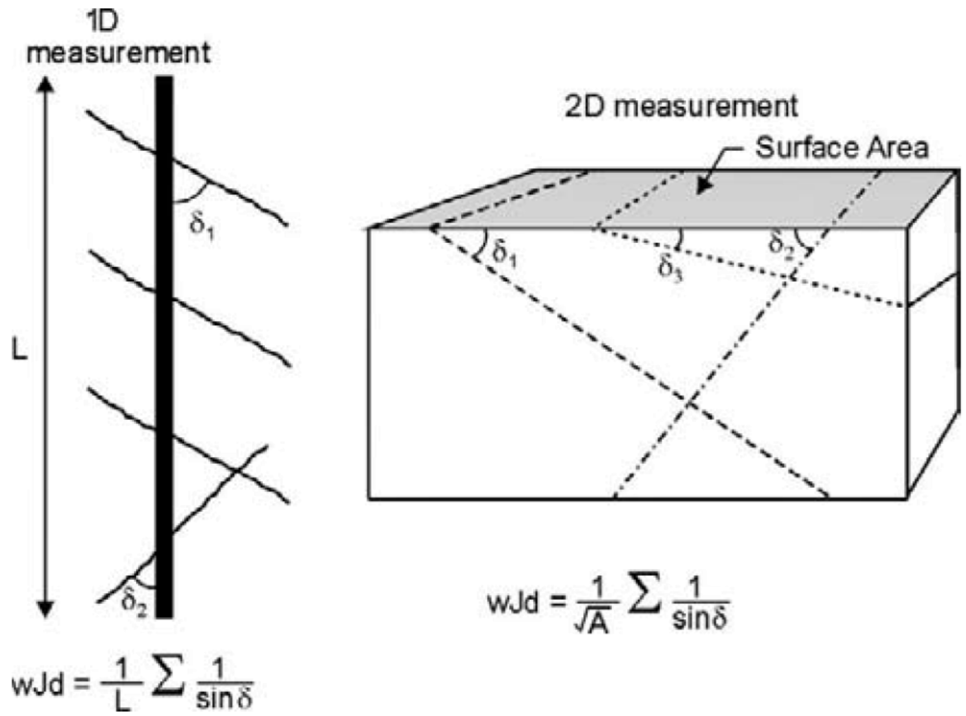


FIGURE 4.2 The intersection between joints and a drill core hole (left) and between joints and a surface (right). *(From Palmstrom, 1996)*

for measurements in rock surface: $\mathrm{wJd} = \frac{1}{\sqrt{A}} \sum f_i$

for measurements along a drill core or scan line: $\mathrm{wJd} = \frac{1}{L} \sum f_i$

δ is the intersection angle

A is the size of the observed area in m^2

L is the length of the measured section along the core or scan line

f_i is a rating factor

To solve the problem of small intersection angles and to simplify the observations, the angles have been divided into intervals

- Intervals fo

for measurements in rock surface: $wJd = \frac{1}{\sqrt{A}} \sum f_i$

for measurements along a drill core or scan line: $wJd = \frac{1}{L} \sum f_i$

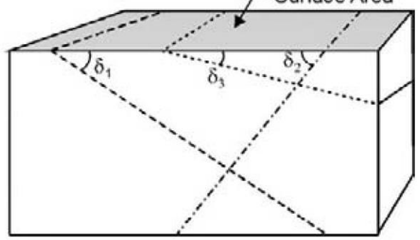


TABLE 4.3 Angle Intervals and Rating of the Factor f_i (交角越小，加權越重)

Angle interval (between joint and borehole or surface)	$1/\sin\delta$	Chosen rating of the factor f_i
$\delta > 60°$	<1.16	1
$\delta = 31–60°$	1.16–1.99	1.5
$\delta = 16–30°$	2–3.86	3.5
$\delta < 16°$	>3.86	6

Source: Palmstrom, 2005.

Surface Measurement of wJd

- the weighted joint density measurement produces values that are somewhat higher than the known value for the volumetric joint count (Palmstrom, 1996)

TABLE 4.3 Angle Intervals and Rating of the Factor f_i

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$\delta = 16–30°$	2–3.86	3.5
$\delta < 16°$	>3.86	6

Source: Palmstrom, 2005.

TABLE 4.4 Calculation of Weighted Joint Density from Analysis of Jointing Shown for the Surfaces in Figure 4.3

Location	Area (A) m^2	Number of joints (n) within each interval >60°	31–60°	16–30°	<16°	Total number of joints	Number of weighted joints $N_w = \sum n \times f_i$	wJd = (1/√A) N_w	Jv
Example 1	25	12	4	3	1	20	34.5	6.9	
Example 2	25	6	4	2	0	12	19	3.8	3.05
Rating of f_i =		1	1.5	3.5	6				

Source: Palmstrom, 1996.

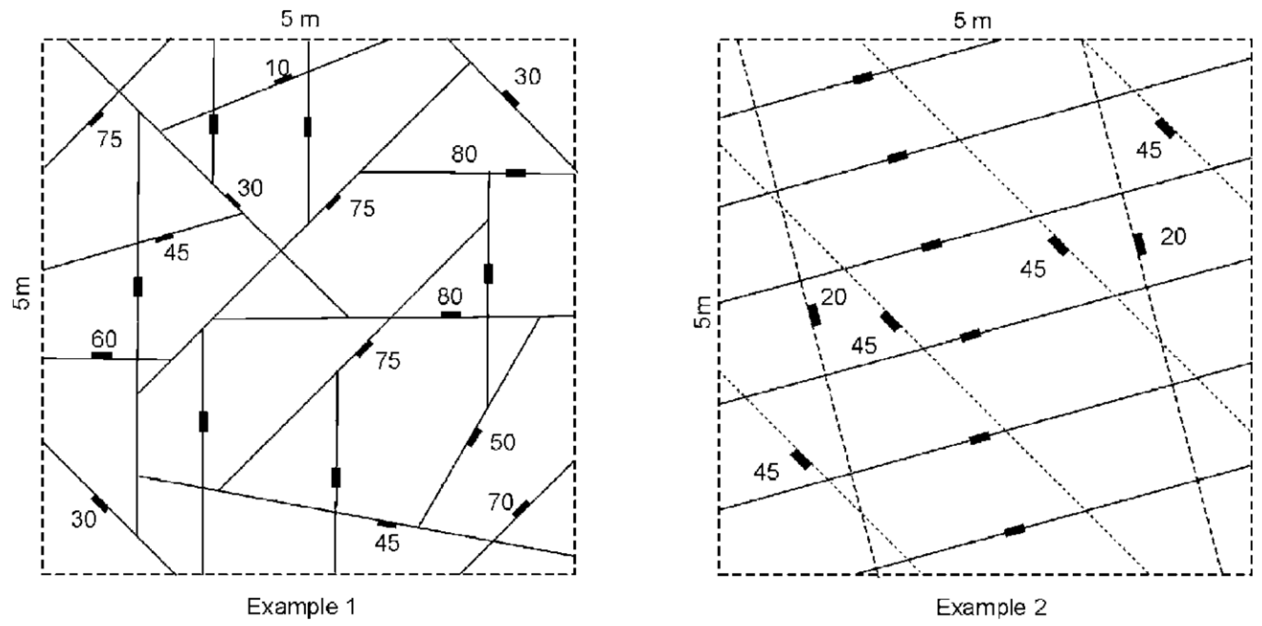


FIGURE 4.3 Two examples of jointing on a surface. *(From Palmstrom, 1996)*

Drill Hole Measurements of wJd

- By Palmstrom(1996)
- The 5 m long part of the core has been divided into the following three sections with similar density of joints.

求這些做什麼？

更好地量化岩體破碎程度

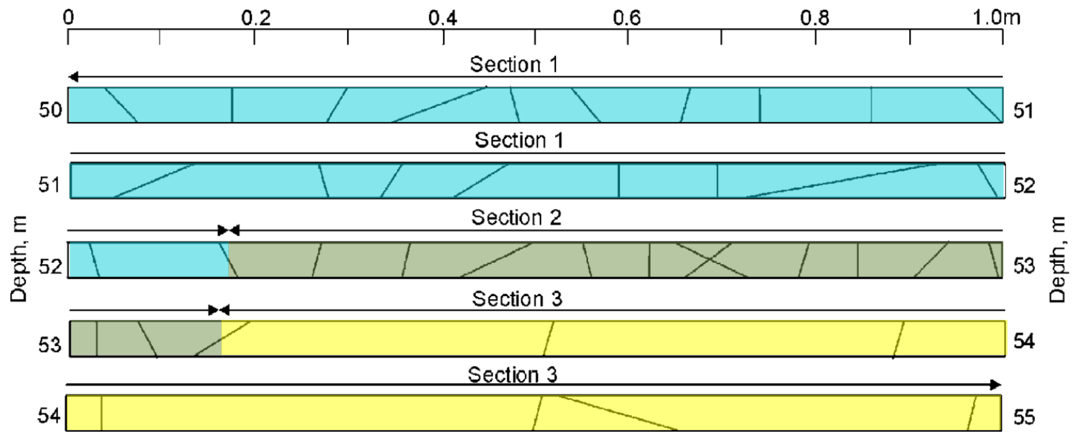


FIGURE 4.4 Example of jointing along part of a borehole. *(From Palmstrom, 1996)*

TABLE 4.6 Calculation of the Weighted Joint Density from Registration of Jointing in the Borehole in Figure 4.4

Depth	(分段)全長 Length (L)	Number of joints (n) within each interval				Total number of joints	Number of weighted joints	wJd =
m	*m*	*>60°*	*31–60°*	*16–30°*	*<16°*		$N_w = \sum n \times f_i$	(1/L) N_w
50–52.17	2.17	11	6	2	1	20	33	15
52.17–53.15	0.98	9	3	2	0	14	20.5	20.9
53.15–55.0	1.85	5	0	1	0	6	8.5	4.6
Rating of f_i =		1	1.5	3.5	6			

Source: Palmstrom, 1996.

3. Joint or discontinuity spacing

- The linear distance between two adjacent discontinuities should be measured for all sets of discontinuities. 每組間距都要量。
- 分5級，0.06, 0.2, 0.6, 2 m

(間距越大，分數越高)

TABLE 6.3 Spacing of Discontinuities

Description	Spacing (m)	Rating
Very wide	>2	20
Wide	0.6–2	15
Moderate	0.2–0.6	10
Close	0.06–0.2	8
Very close	<0.06	5

If more than one discontinuity set is present and the spacing of discontinuities of each set varies, consider the unfavorably oriented set with lowest rating. ISO 14689 uses the term "extremely close" for joint spacing less than 0.02 m.

Sources: Bieniawski, 1979; ISO 14689-1, 2003.

4. Joint condition

- Includes roughness of discontinuity surfaces, their separation, length of continuity, weathering of the wall rock or the planes of weakness, and infilling (gouge) material

TABLE 6.4 Condition of Discontinuities

Description	Joint separation (mm)	Rating
Very rough and unweathered, wall rock tight and discontinuous, no separation	0	30
Rough and slightly weathered, wall rock surface separation <1 mm	<1	25
Slightly rough and moderately to highly weathered, wall rock surface separation <1 mm	<1	20
Slickensided wall rock surface, or 1–5 mm thick gouge, or 1–5 mm wide continuous discontinuity	1–5	10
5 mm thick soft gouge, 5 mm wide continuous discontinuity	>5	0

Source: Bieniawski, 1979.

4. Joint condition

- roughness of discontinuity surfaces, separation, length of continuity, weathering of the wall rock or the planes of weakness, and infilling (gouge) material各項的評分標準。

TABLE 6.5 The RMR System: Guidelines for Classification of Discontinuity Conditions (節理越粗糙、新鮮、緊密 分數越高)

Parameter*	Ratings				
Discontinuity length (persistence/ continuity)	<1 m	1–3 m	3–10 m	10–20 m	>20 m
	6	4	2	1	0
Separation (aperture)	None	<0.1 mm	0.1–1.0 mm	1–5 mm	>5 mm
	6	5	4	1	0
Roughness of discontinuity surface	Very rough	Rough	Slightly rough	Smooth	Slickensided
	6	5	3	1	0
Infillings (gouge)		Hard filling		Soft filling	
	None	<5 mm	>5 mm	<5 mm	>5 mm
	6	4	2	2	0
Weathering discontinuity surface	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
	6	5	3	1	0

**Some conditions are mutually exclusive. For example, if infilling is present, it is irrelevant what the roughness may be, since its effect will be overshadowed by the influence of the gouge. In such cases use Table 6.4 directly.*

Source: Bieniawski, 1993.

5. Groundwater condition

- **Completely dry**, **damp**, **wet**, **dripping**, or **flowing**
- If actual water pressure data are available, these should be stated and expressed in terms of the ratio of the seepage water pressure to the major principal stress.

TABLE 6.6 Groundwater Condition (節理內水的影響越小，分數越高)

Inflow per 10 m tunnel length (L/min)	None	<10	10–25	25–125	>125
Ratio of joint water pressure to major principal stress	0	0–0.1	0.1–0.2	0.2–0.5	>0.5
General description	Completely dry	Damp	Wet	Dripping	Flowing
Rating	15	10	7	4	0

Source: Bieniawski, 1979.

6. Joint orientation (節理位態對預定工程的影響)

- The influence of the strike and dip of discontinuities is considered with respect to the direction of tunnel drivage, slope face orientation, or foundation alignment.
- 分5級。

TABLE 6.10 Adjustment for Joint Orientation

Joint orientation assessment for	Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
Tunnels	0	−2	−5	−10	−12
Raft foundation	0	−2	−7	−15	−25
Slopes*	0	−5	−25	−50	−60

**It is recommended to use slope mass rating (SMR; Chapter 18).*

Source: Bieniawski, 1979.

6. Joint orientation

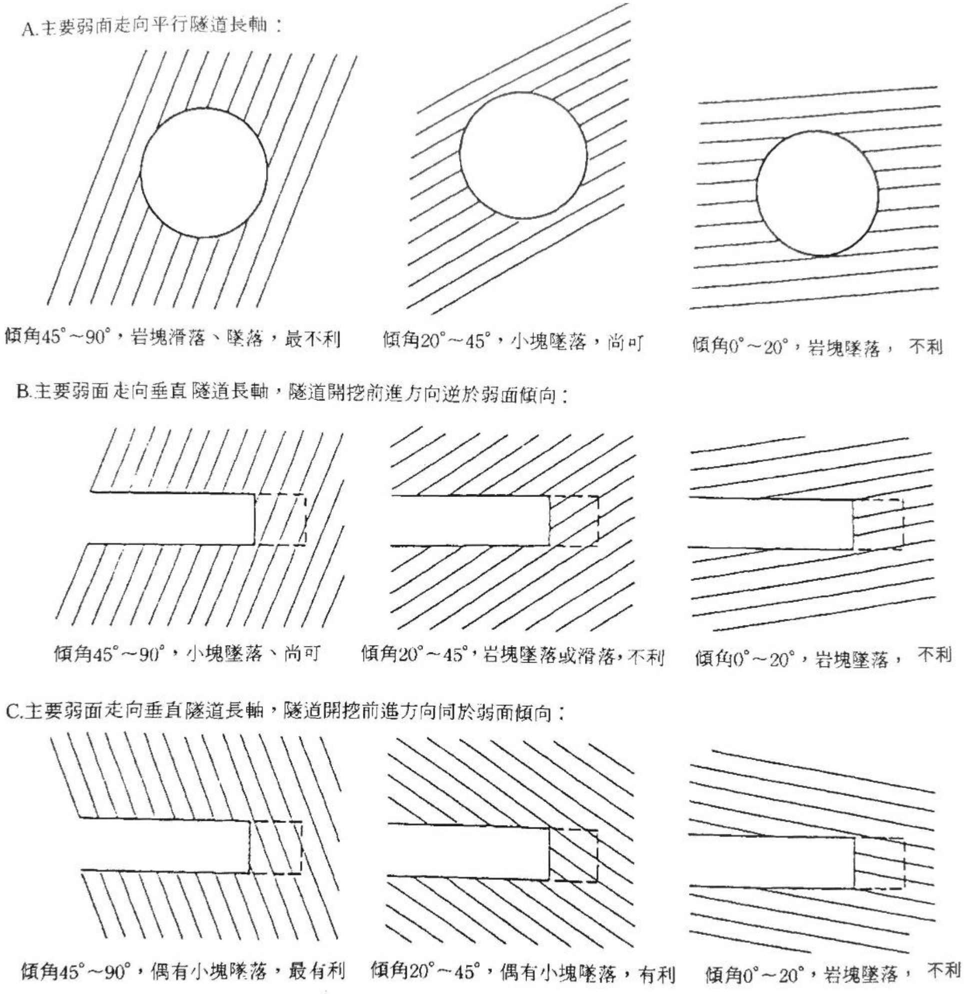


圖 12.9 主要弱面方位對隧道開挖穩定性之關係

TABLE 6.8 Assessment of Joint Orientation Effect on Tunnels

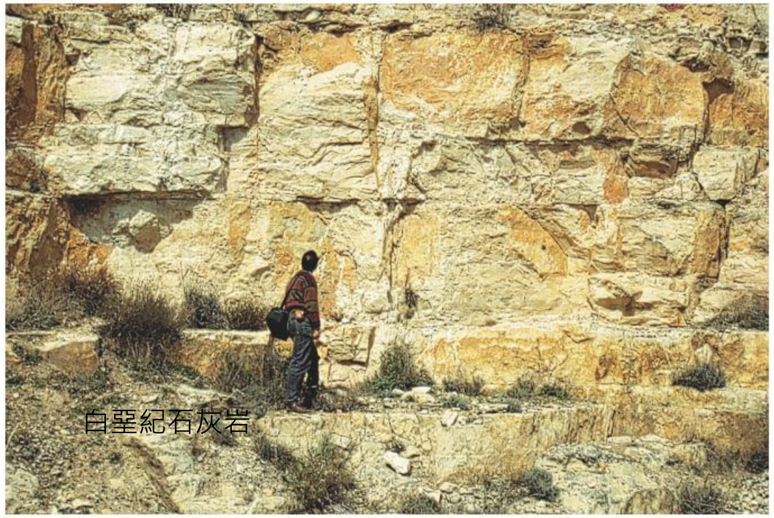
Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Irrespective of strike
Drive with dip		*Drive against dip*				
Dip 45°–90°	Dip 20°–45°	Dip 45°–90°	Dip 20°–45°	Dip 20°–45°	Dip 45°–90°	Dip 0°–20°
Very favorable	Favorable	Fair	Unfavorable	Fair	Very unfavorable	Fair

Source: Bieniawski, 1984.

RMR Class 1, 2

Table 3.27	ROCK MASS QUALITY ACCORDING TO THE RMR INDEX			
Class	**Quality**	**RMR rating**	**Cohesion (MPa)**	**Friction angle**
I	Very good	100–81	>0.4	>45°
II	Good	80–61	0.3–0.4	35°–45°
III	Fair	60–41	0.2–0.3	25°–35°
IV	Poor	40–21	0.1–0.2	15°–25°
V	Very poor	<20	<0.1	<15°

Class I (RMR = 81-100) and Class II (RMR= 61-80) rock masses



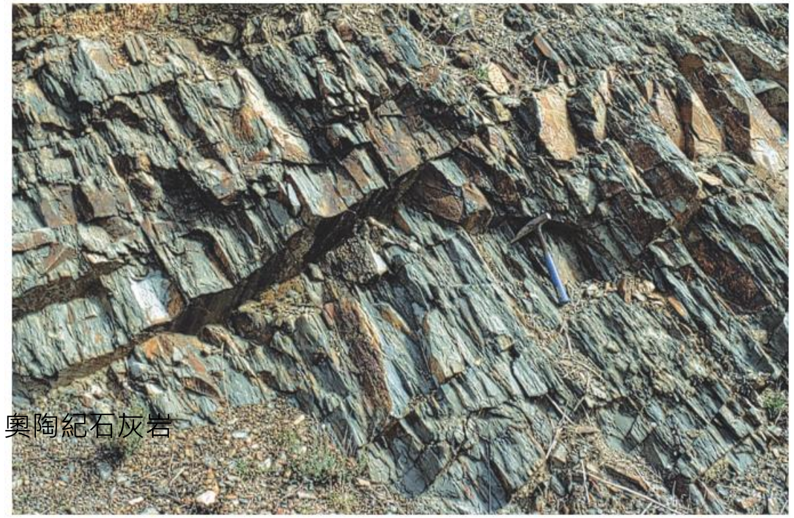
Cretaceous dolomite. Very good quality. Two main sets of discontinuities.

Granite. Good quality. Several sets of weathered discontinuities.

RMR Class 3

Table 3.27 ROCK MASS QUALITY ACCORDING TO THE RMR INDEX				
Class	**Quality**	**RMR rating**	**Cohesion (MPa)**	**Friction angle**
I	Very good	100–81	>0.4	>45°
II	Good	80–61	0.3–0.4	35°–45°
III	Fair	60–41	0.2–0.3	25°–35°
IV	Poor	40–21	0.1–0.2	15°–25°
V	Very poor	<20	<0.1	<15°

Class III rock masses (RMR= 41-60)



Ordovician slate. Fair quality. High fracturing degree. Weathering degree: III.

Ordovician quartzite. Fair quality. High fracturing degree. Very hard intact rock.

RMR Class 4, 5

Table 3.27 ROCK MASS QUALITY ACCORDING TO THE RMR INDEX				
Class	**Quality**	**RMR rating**	**Cohesion (MPa)**	**Friction angle**
I	Very good	100–81	>0.4	>45°
II	Good	80–61	0.3–0.4	35°–45°
III	Fair	60–41	0.2–0.3	25°–35°
IV	Poor	40–21	0.1–0.2	15°–25°
V	Very poor	<20	<0.1	<15°

Class IV (RMR= 21-40) and Class V (RMR ≤20) rock masses

Ordovician quartzite. Poor quality. Weathered and heavily jointed rock mass.

Palaeozoic slate. Very poor quality. Heavily jointed. Degree of weathering: V.

岩體評分法 Rock Mass Rating (總表)

Table 3.26 ROCK MASS RATING SYSTEM

A. Classification parameters

	Parameter		Range of values				
1	Strength of intact rock material (MPa)	Point-load strength index	>10	10–4	4–2	2–1	Uniaxial compressive strength (MPa)
		Uniaxial compressive strength	>250	250–100	100–50	50–25	25–5 / 5–1 / <1
	Rating		15	12	7	4	2 / 1 / 0
2	RQD		90%–100%	75%–90%	50%–75%	25%–50%	<25%
	Rating		20	17	13	8	3
3	Spacing of discontinuities		>2 m	0.6–2 m	0.2–0.6 m	60–20 mm	<60 mm
	Rating		20	15	10	8	5
4	Conditions of discontinuities (see E)		Very rough surfaces. Not continuous. No separation. Unweathered wall rock.	Slightly rough surfaces. Separation <1 mm. Slightly weathered walls.	Slightly rough surfaces. Separation <1 mm. Highly weathered walls.	Slickensided surfaces. or Gouge <5 mm thick or Separation 1–5 mm. Continuous.	Soft gouge >5 mm thick. Separation >5 mm. Continuous.
	Rating		30	25	20	10	0
5	Ground water	Inflow per 10 m tunnel length	None	<10 litres/min	10–25 litres/min	25–125 litres/min	>125 litres/min
		(Joint water press)/(Mayor principal stress)	0	0.0–0.1	0.1–0.2	0.2–0.5	>0.5
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
	Rating		15	10	7	4	0

B. Rating adjustment for discontinuity orientations (*see F*)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Rating	Tunnels and mines	0	–2	–5	–10	–12
	Foundations	0	–2	–7	–15	–25
	Slopes	0	–5	–25	–50	–60

C. Rock mass classes

Class	I	II	III	IV	V
Description	Very good	Good	Fair	Poor	Very poor
Rating	100–81	80 – 61	60 – 41	40 – 21	<20

Table 3.26 ROCK MASS RATING SYSTEM (CONT.)

D. Meaning of rock classes

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 yr for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass	>400 kPa	300–400 kPa	200–300 kPa	100–200 kPa	<100 kPa
Friction angle of rock mass	>45°	35°–45°	25°–35°	15°–25°	<15°

E. Guidelines for classification of discontinuity conditions

Length (persistence)	<1 m	1–3 m	3–10 m	10–20 m	>20 m
Rating	6	4	2	1	0
Separation (aperture)	None	<0.1 mm	0.1–1.0 mm	1–5 mm	>5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling	Hard filling >5 mm	Soft filling <5 mm	Soft filling >5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moder. weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

F. Effect of discontinuity strike and dip orientation in tunnelling

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0°–20° Irrespective of strike
Drive with dip		Drive against dip				
Dip 45–90°	Dip 20–45°	Dip 45–90°	Dip 20–45°	Dip 45–90°	Dip 20–45°	
Very favourable	Favourable	Fair	Unfavourable	Very unfavourable	Fair	Fair

(Bieniawski, 1989).

Table 3.27 ROCK MASS QUALITY ACCORDING TO THE RMR INDEX

Class	Quality	RMR rating	Cohesion (MPa)	Friction angle
I	Very good	100–81	>0.4	>45°
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III	Fair	60–41	0.2–0.3	25°–35°
IV	Poor	40–21	0.1–0.2	15°–25°
V	Very poor	<20	<0.1	<15°

RMR法的應用

隧道的平均自立時間(不加支撐可以持續的時間)

- Average Stand-up Time for an Arched Roof
  - The stand-up time depends upon an effective (unsupported) span of the opening, which is defined as the width of the opening or the distance between the tunnel face and the last support (whichever is smaller)

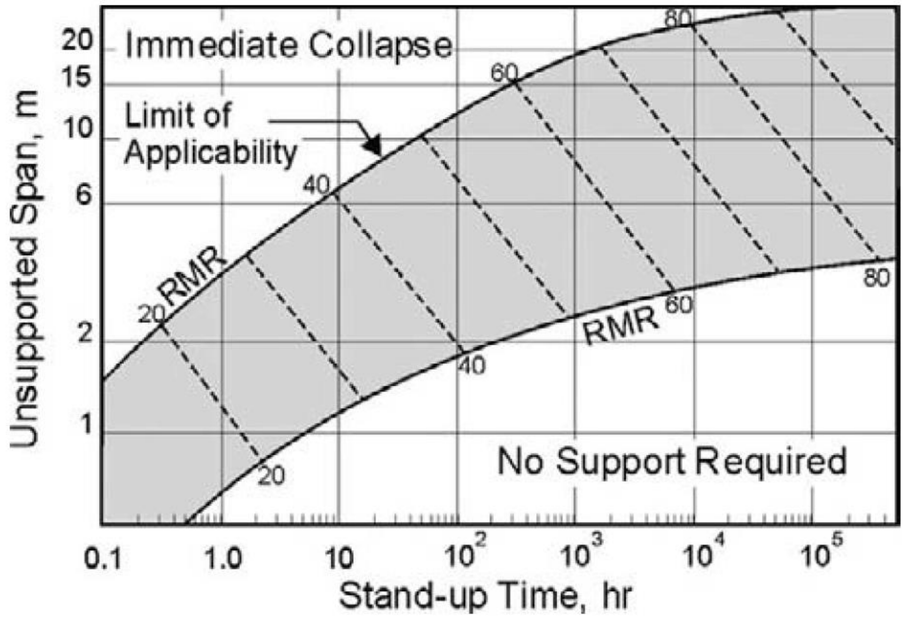


FIGURE 6.1 Stand-up time versus unsupported span for various rock mass classes according to RMR. *(From Bieniawski, 1984)*

RMR法的應用 岩體凝聚力與摩擦角

- Cohesion and Angle of Internal Friction

TABLE 6.11 **Design Parameters and Engineering Properties of Rock Mass**

S. No.	Parameter/ properties of rock mass	RMR (rock class)				
		100–81 (I)	*80–61 (II)*	*60–41 (III)*	*40–21 (IV)*	*<20 (V)*
1	Classification of rock mass	Very good	Good	Fair	Poor	Very poor
2	Average stand-up time	20 years for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 1 m span
3	Cohesion of rock mass (MPa)*	>0.4	0.3–0.4	0.2–0.3	0.1–0.2	<0.1
4	Angle of internal friction of rock mass	>45°	35–45°	25–35°	15–25°	<15°
5	Allowable bearing pressure (T/m^2)	600–440	440–280	280–135	135–45	45–30
6	Safe cut slope (°) (Waltham, 2002)	>70	65	55	45	<40

During earthquake loading, the above values of allowable bearing pressure may be increased by 50% in view of rheological behavior of rock masses (see Chapter 20).
**These values are applicable to slopes only in saturated and weathered rock mass.*

Source: Bieniawski, 1993.

RMR法的應用 岩體變形模數

- Modulus of Deformation of rock mass.
- MRF, which is defined as a ratio of the modulus of deformation of a **rock mass** to the elastic modulus of the **rock material** obtained from the core.

• Singh (1979)

$$E_d = E_r \cdot \ MRF$$

• Bieniawski (1978) for hard rock masses (q_c > 100 MPa).

$$E_d = 2\ RMR - 100, GPa \quad (\text{applicable for } RMR > 50)$$

• Serafim and Pereira (1983)

$$E_d = 10^{(RMR-10)/40}, GPa$$

$$(\text{applicable for } RMR < 50 \text{ also})$$

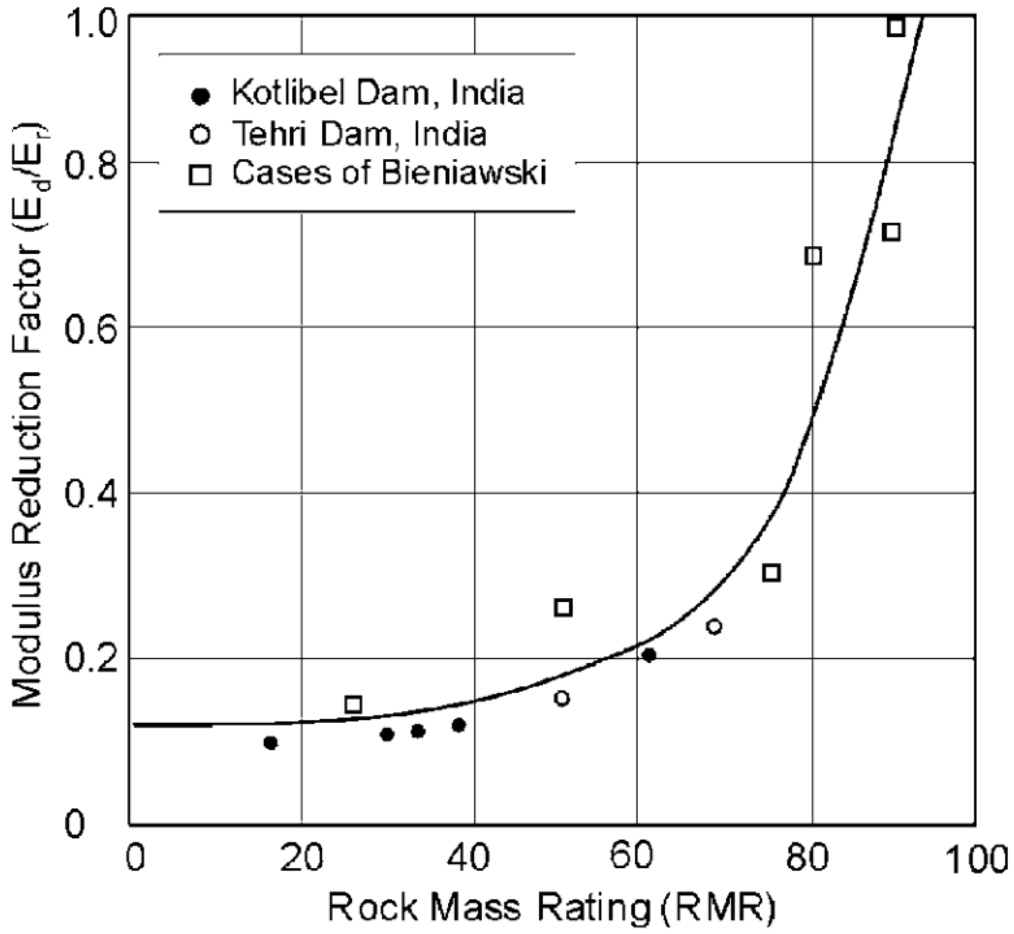


FIGURE 6.2 Relationship between rock mass rating (RMR) and modulus reduction factor. *(From Singh, 1979)*

RMR法的應用

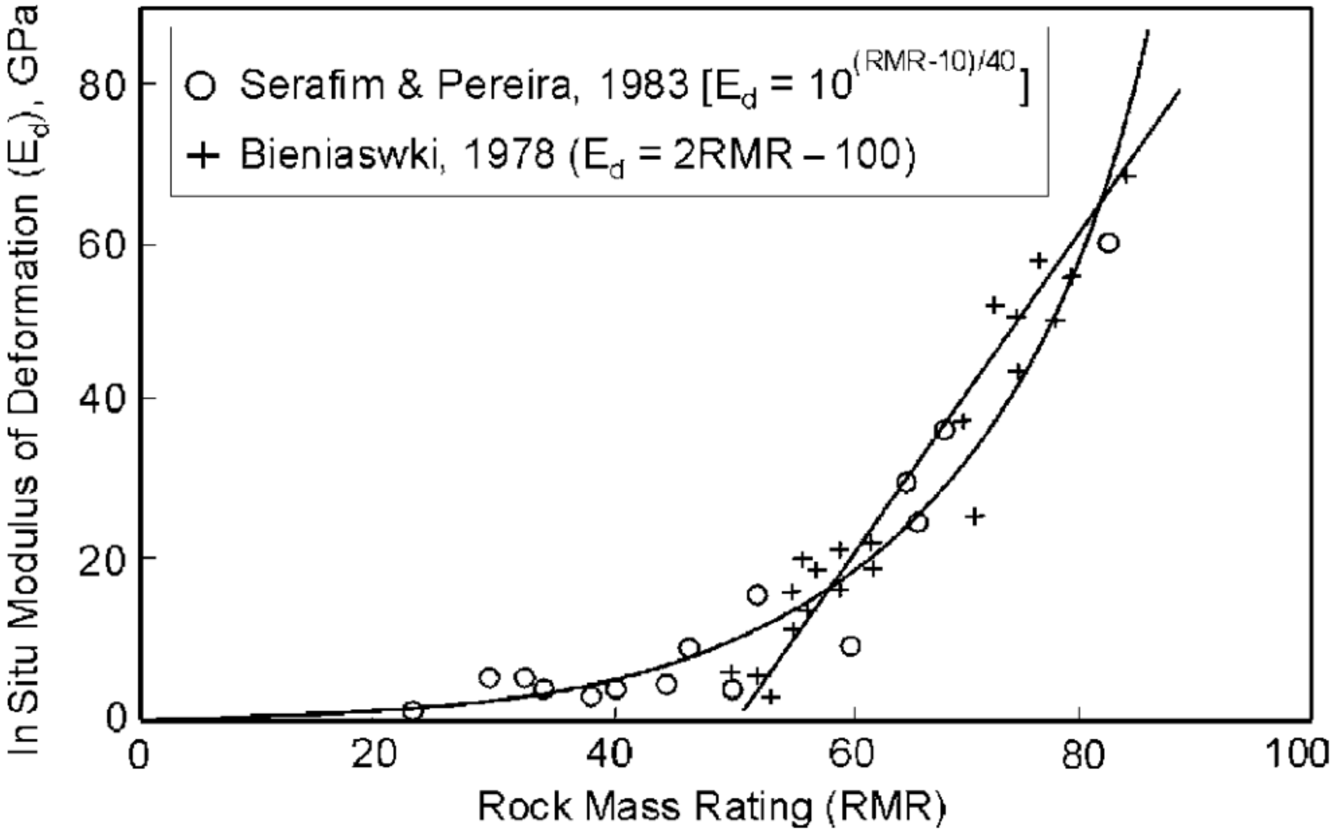


FIGURE 6.3 Correlation between modulus of deformation of rock masses and RMR. *(From Bieniawski, 1984)*

RMR法的應用

- The modulus of deformation of a dry and weak rock mass (q_c < 100 MPa) around underground openings located at depths exceeding 50 m is dependent upon confining pressure due to overburden and may be determined by the following correlation (Verman, 1993)

$$E_d = 0.3\,H^{\alpha} \cdot 10^{(RMR-20)/38}, \text{GPa}$$

α = 0.16 to 0.30 (higher for poor rocks)

H = depth of location under consideration below ground surface in meters $\geq$ 50 m

- Read, Richards, and Perrin (1999)

$$E_d = 0.1(RMR/10)^{0.3}, \text{GPa}$$

TABLE 8.14 Empirical Correlations for Overall Modulus of Deformation of Rock Mass in the Non-Squeezing Ground Condition (GSI & RMR << 100) 岩體變形模數

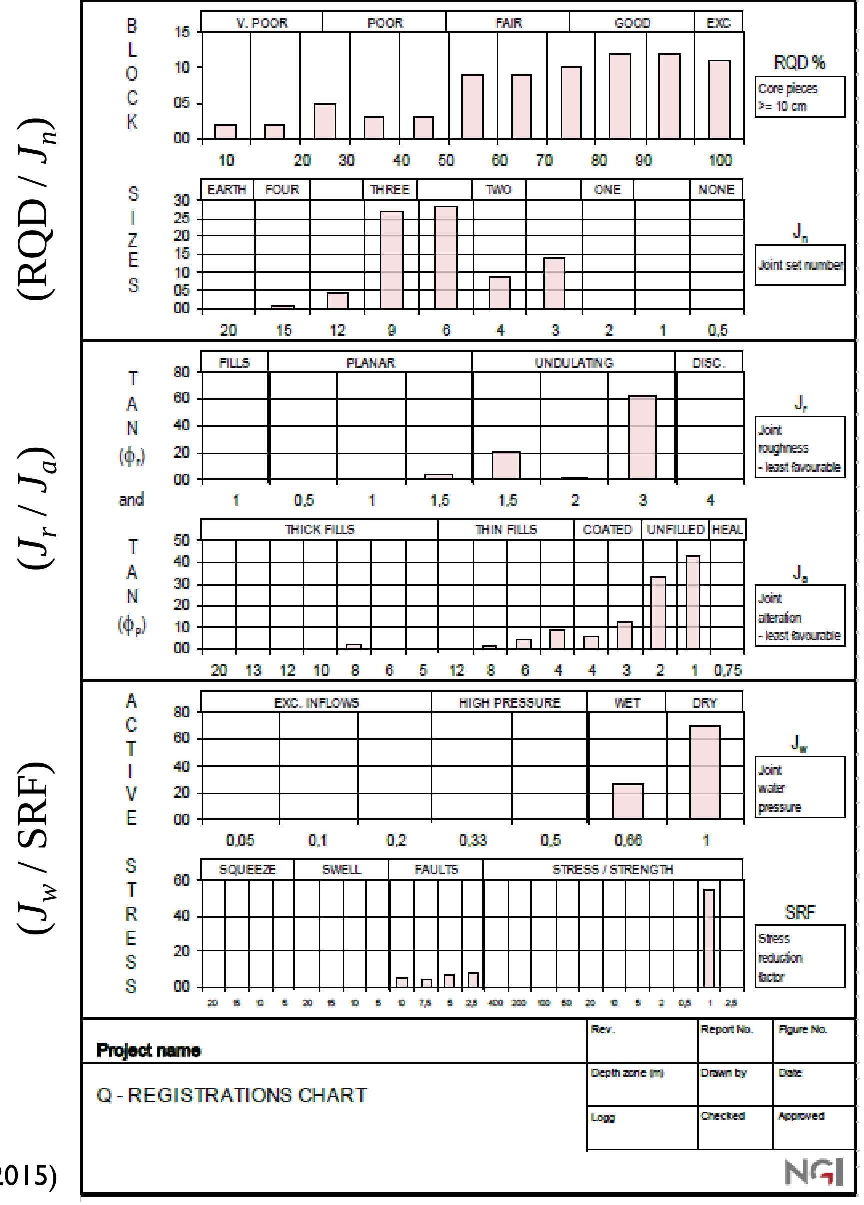
Authors	Expression for E_d (GPa)	Conditions	Recommended for
Bieniawski (1978)	$E_d = 2\ RMR - 100$	$q_c > 100$ MPa and RMR > 50	Dams
Serafim & Pereira (1983)	$E_d = 10^{(RMR-10)/40}$	$q_c \geq 100$MPa	Dams
Nicholson & Bieniawski (1990)	$E_d/E_r = 0.0028\ RMR^2 + 0.9\ e^{(RMR/22.82)}$	—	
Verman (1993)	$E_d = 0.3\ H\alpha.\ 10^{(RMR-20)/38}$	$\alpha = 0.16$ to 0.30 (higher for poor rocks) $q_c \leq 100$ MPa; $H \geq 50$ m; $J_w = 1$ Coeff. of correlation = 0.91	Tunnels
Mitri et al. (1994)	$E_d/E_r = 0.5[1\text{-}\cos(\pi\ RMR/100)]$	—	
Singh (1997)	$E_d = Q^{0.36}\ H^{0.2}$ $E_e = 1.5Q^{0.6}\ E_r^{0.14}$	$Q < 10$; $J_w = 1$ Coeff. of correlation for $E_e = 0.96$; $J_w \leq 1$	Dams and slopes Dams
Hoek et al. (2002)	$E_d = \left(1 - \frac{D}{2}\right)\sqrt{\frac{q_c}{100}} \cdot 10^{((GSI-10)/40)}$ $E_d = \left(1 - \frac{D}{2}\right) \cdot 10^{((GSI-10)/40)}$	$q_c \leq 100$ MPa D = disturbance factor (Table 26.4) $q_c \geq 100$ MPa	
Adachi & Yoshida (2002)	$E_d = 10^{(0.0431R-0.8853)}$	For weak rocks, R = In situ average Schmidt hammer rebound number	
Barton (2008)	$E_d = 10[Q \cdot q_c/100]^{1/3} < E_r$	$Q = 0.1 - 100$ $q_c = 10 - 200$ MPa	Tunnels
Zhang & Einstein (2004)	$\frac{E_d}{E_r} = 10^{0.0186\ RQD-1.91}$	For $0 \leq RQD \leq 100$	Preliminary analysis
Hoek & Diederichs (2006)	$E_d = \left[0.02 + \frac{1 - D/2}{1 + \exp((60 + 15\ D - GSI)/11)}\right]$		Tunnels, caverns, and dam foundations

The above correlations are expected to provide a mean value of modulus of deformation.

Q法 (Q-system)

- $$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$
- The Q-value varies between 0.001 and 1000.
- (RQD / J_n): Degree of jointing, a relative measure of the **block size**. 也可以直接使用岩塊實際尺寸。
- (J_r / J_a): Joint friction, an indicator of the inter-block **shear strength**.
- (J_w / SRF): **active stresses**.

Q - VALUES:	(RQD	/	J_n)	*	(J_r	/	J_a)	*	(J_w	/	SRF)	=	Q
Q (typical min) =	10	/	15.0	*	1.5	/	8.0	*	0.66	/	10.0	=	0.008
Q (typical max) =	100	/	3.0	*	3.0	/	1.0	*	1.00	/	1.0	=	100.0
Q (mean value) =	71	/	6.7	*	2.6	/	2.3	*	0.91	/	2.4	=	4.44
Q (most frequent) =	70	/	9.0	*	3.0	/	1.0	*	1.00	/	1.0	=	23.33



NGI (2015)

1.Rock Quality Designation (RQD)

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

- *"RQD is the sum of the length (between natural joints) of all core pieces more than 10 cm long (or core diameter x 2) as a percentage of the total core length"* (Deere, 1963)
- 注意：僅考慮自然節理，人為損傷(如：開炸)造成之節理不計
- 變質岩的面狀構造如片麻岩、板岩之葉理不計入(RQD值高)
- 軟岩RQD值可能很高，片麻岩等葉理發達的岩石風化後RQD可能為零

1	RQD (Rock Quality Designation)		RQD
A	Very poor	(> 27 joints per m^3)	0-25
B	Poor	(20-27 joints per m^3)	25-50
C	Fair	(13-19 joints per m^3)	50-75
D	Good	(8-12 joints per m^3)	75-90
E	Excellent	(0-7 joints per m^3)	90-100
Note: i) Where RQD is reported or measured as ≤ 10 (including 0) the value 10 is used to evaluate the Q-value ii) RQD-intervals of 5, i.e. 100, 95, 90, etc., are sufficiently accurate			

NGI (2015)

2. Joint Set Number (J_n)

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

- 節理組數(joint set)之判定：同一組節理有超過一條以上(至少兩條)出現於評估範圍內即視為一組。換言之，僅出現一道的節理不算視節理組，而是隨機節理(random joint)。

2	Joint set number	J_n
A	Massive, no or few joints	0.5-1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random heavily jointed "sugar cube", etc	15
J	Crushed rock, earth like	20

Note: i) For tunnel intersections, use 3 x J_n 隧道交叉段 $J_n \times 3$

ii) For portals, use 2 x J_n 隧道洞口段 $J_n \times 2$

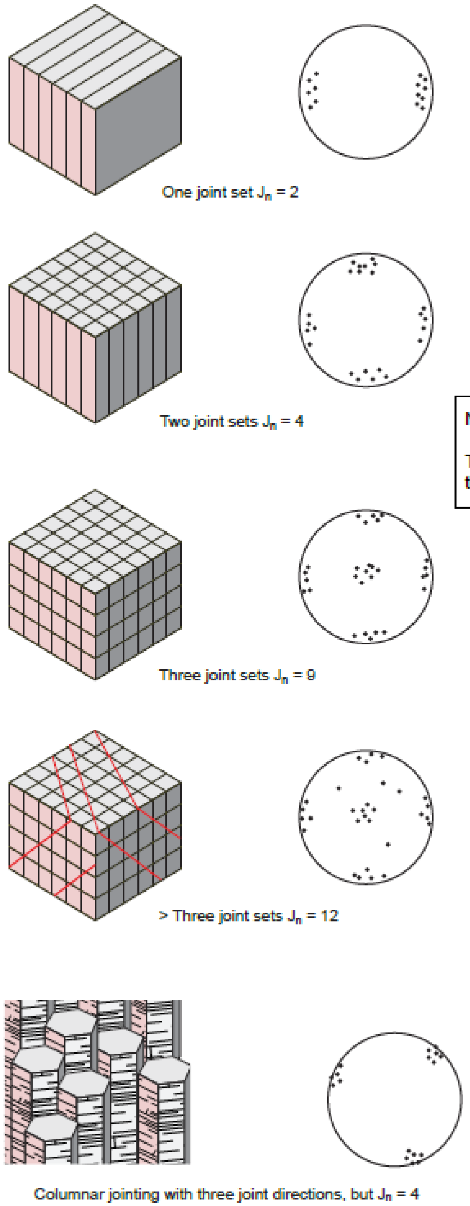
NGI (2015)

2. Joint Set Number (J_n)

- 長節理通常影響較大，短節理(short joint)很多時候可以當作裂隙(crack)而不予考慮，除非短節理為構成潛在危險岩塊的其中一個或數個面。
- 部分情況不能僅考慮節理方向，也要考慮節理所構成之岩塊是否有可能掉落，例如柱狀節理發生岩塊掉落可能性極低，J_n應取**兩組節理**所對應的數值**4**，而非三組節理所對應的數值9。

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

NGI (2015)



Note:

The number of joint directions is not always the same as the number of joint sets

3. Joint Roughness Number (J_r)

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

- 針對**最不利**的那組節理進行判斷，例如可能發生剪力破壞的該組節理

NGI (2015)

3	Joint Roughness Number	J_r
	a) Rock-wall contact, and *b) Rock-wall contact before 10 cm of shear movement*	
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough, irregular, planar	1.5
F	Smooth, planar	1
G	Slickensided, planar	0.5
	Note: i) Description refers to small scale features and intermediate scale features, in that order	
	c) No rock-wall contact when sheared	
H	Zone containing clay minerals thick enough to prevent rock-wall contact when sheared	1
	Note: ii) Add 1 if the mean spacing of the relevant joint set is greater than 3 m (dependent on the size of the underground opening) iii) J_r = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented in the estimated sliding direction	

3. Joint Roughness Number (J_r)

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

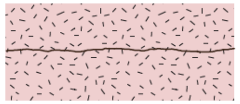
- 大尺度變化：Stepped階梯狀, Undulating波浪狀, Planar平面狀。在節理面上放置1 m長的尺，對照右圖進行評估。
- 小尺度變化(rough粗糙, Smooth平滑, Slickensided具擦痕)：數公厘至數公分的起伏，用手指沿著節理面感覺。
- 評估**方向**考慮1.岩塊尺寸2.可能滑動方向
- 軟岩無顯著節理(行為接近土壤)：J_r =1

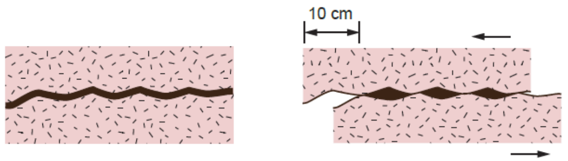
NGI (2015)

Figure 3 Examples of joint wall surfaces with different J_r - values. The length of each profile is in the range: 1 - 10 m. The vertical and horisontal scales are equal. (Modified from ISRM 1978)

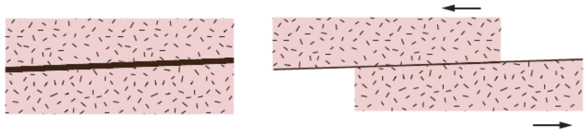
4. Joint Alteration Number (J_a)

- 除了節理面粗糙度之外，節理填充物也對摩擦力影響很大，其影響來自於**填充物**的**厚度**與**強度**。
- J_a 之判定基於**填充物厚度**和**沿節理面剪動時岩壁的接觸程度**分為三類：“a”,“b” 和 “c”。


Rock-wall contact



Rock-wall contact before 10 cm shear


No rock-wall contact when sheared

NGI (2015)

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

NGI (2015)

4	Joint Alteration Number	Φ_r approx.	J_a
a)	*Rock-wall contact (no mineral fillings, only coatings)* 岩壁互相接觸，無填充物		
A	Tightly healed, hard, non-softening, impermeable filling, i.e., quartz or epidote.		0.75
B	Unaltered joint walls, surface staining only.	25-35°	1
C	Slightly altered joint walls. Non-softening mineral coatings; sandy particles, clay-free disintegrated rock, etc.	25-30°	2
D	Silty or sandy clay coatings, small clay fraction (non-softening).	20-25°	3
E	Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc gypsum, graphite, etc., and small quantities of swelling clays.	8-16°	4
b)	*Rock-wall contact before 10 cm shear (thin mineral fillings)* 剪動10 cm以內距離時岩壁互相接觸，填充物薄		
F	Sandy particles, clay-free disintegrated rock, etc.	25-30°	4
G	Strongly over-consolidated, non-softening, clay mineral fillings (continuous, but <5 mm thickness).	16-24°	6
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5 mm thickness).	12-16°	8
J	Swelling-clay fillings, i.e., montmorillonite (continuous, but <5 mm thickness). Value of J_a depends on percent of swelling clay-size particles.	6-12°	8-12
c)	*No rock-wall contact when sheared (thick mineral fillings)* 剪動時岩壁不接觸，填充物厚		
K	Zones or bands of disintegrated or crushed rock. Strongly over-consolidated.	16-24°	6
L	Zones or bands of clay, disintegrated or crushed rock. Medium or low over-consolidation or softening fillings.	12-16°	8
M	Zones or bands of clay, disintegrated or crushed rock. Swelling clay. J_a depends on percent of swelling clay-size particles.	6-12°	8-12
N	Thick continuous zones or bands of clay. Strongly over-consolidated.	12-16°	10
O	Thick, continuous zones or bands of clay. Medium to low over-consolidation.	12-16°	13
P	Thick, continuous zones or bands with clay. Swelling clay. J_a depends on percent of swelling clay-size particles.	6-12°	13-20

5. Joint Water Reduction Factor (J_w)

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

- 節理面上的水可能弱化或帶走填充物質，進而降低節理面之摩擦力。水壓力亦可降低正向應力，使岩塊更易滑動。
- J_w之判定根據**水流狀態**及**水壓大小**。

5	Joint Water Reduction Factor	J_w
A	Dry excavations or minor inflow (humid or a few drips)	1.0
B	Medium inflow, occasional outwash of joint fillings (many drips/"rain")	0.66
C	Jet inflow or high pressure in competent rock with unfilled joints	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	0.33
E	Exceptionally high inflow or water pressure decaying with time. Causes outwash of material and perhaps cave in	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay. Causes outwash of material and perhaps cave in	0.1-0.05
Note: i) Factors C to F are crude estimates. Increase J_w if the rock is drained or grouting is carried out ii) Special problems caused by ice formation are not considered		

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

6. Stress Reduction Factor (SRF)

- SRF用於描述開挖面周遭應力與岩體強度之關係。
- a: 開挖面存在弱帶如(斷層)剪裂帶，且會造成岩體鬆動
- b: 岩體為巨積岩層狀況佳，主要為應力問題
  - 需評估現地應力與單壓強度
- c: 擠壓性岩盤，應力高且岩體強度低，塑性變形大
- d: 膨脹性岩盤，遇水時產生化學性膨脹

6	Stress Reduction Factor			SRF
a) Weak zones intersecting the underground opening, which may cause loosening of rock mass				
A	Multiple occurrences of weak zones within a short section containing clay or chemically disintegrated, very loose surrounding rock (any depth), or long sections with incompetent (weak) rock (any depth). For squeezing, see 6L and 6M			10
B	Multiple shear zones within a short section in competent clay-free rock with loose surrounding rock (any depth)			7.5
C	Single weak zones with or without clay or chemical disintegrated rock (depth ≤ 50m)			5
D	Loose, open joints, heavily jointed or "sugar cube", etc. (any depth)			5
E	Single weak zones with or without clay or chemical disintegrated rock (depth > 50m)			2.5
Note: I) Reduce these values of SRF by 25-50% if the weak zones only influence but do not intersect the underground opening				
b) Competent, mainly massive rock, stress problems		σ_c / σ_1	σ_θ / σ_c	SRF
F	Low stress, near surface, open joints	>200	<0.01	2.5
G	Medium stress, favourable stress condition	200-10	0.01-0.3	1
H	High stress, very tight structure. Usually favourable to stability. May also be unfavourable to stability dependent on the orientation of stresses compared to jointing/weakness planes*	10-5	0.3-0.4	0.5-2 2-5*
J	Moderate spalling and/or slabbing after > 1 hour in massive rock	5-3	0.5-0.65	5-50
K	Spalling or rock burst after a few minutes in massive rock	3-2	0.65-1	50-200
L	Heavy rock burst and immediate dynamic deformation in massive rock	<2	>1	200-400
Note: II) For strongly anisotropic virgin stress field (if measured): when $5 \le \sigma_1 / \sigma_3 \le 10$, reduce σ_c to 0.75 σ_c. When $\sigma_1 / \sigma_3 > 10$, reduce σ_c to 0.5 σ_c, where σ_c = unconfined compression strength, σ_1 and σ_3 are the major and minor principal stresses, and σ_θ = maximum tangential stress (estimated from elastic theory) III) When the depth of the crown below the surface is less than the span; suggest SRF increase from 2.5 to 5 for such cases (see F)				
c) Squeezing rock: plastic deformation in incompetent rock under the influence of high pressure			σ_θ / σ_c	SRF
M	Mild squeezing rock pressure		1-5	5-10
N	Heavy squeezing rock pressure		>5	10-20
Note: IV) Determination of squeezing rock conditions must be made according to relevant literature (i.e. Singh et al., 1992 and Bhasin and Grimstad, 1996)				
d) Swelling rock: chemical swelling activity depending on the presence of water				SRF
O	Mild swelling rock pressure			5-10
P	Heavy swelling rock pressure			10-15

沒有不連續面的岩體最強?

RMR & Q system

- **岩體評分法(RMR)**
  - 發展於南非
  - 六項評分項目之加總
  - Uniaxial compressive strength of intact rock. 單壓強度 (15%) 岩石材料強度
  - Degree of fracturing (RQD). 破裂程度 (RQD) (20%)
  - Spacing of discontinuities. 不連續面間距 (20%) 不連續面幾何
  - Condition of discontinuities. 不連續面狀態 (20%)
  - Groundwater conditions. 地下水狀態 (30%) 水
  - Orientation of discontinuities. 不連續面位態 (-60~0%)

- **Q System**
  - 發展於挪威
  - $Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$

1. Rock Quality Designation (RQD)
2. Joint Set Number (J_n)
3. Joint Roughness Number (J_r)
4. Joint Alteration Number (J_a)
5. Joint Water Reduction Factor (J_w) 水
6. Stress Reduction Factor (SRF)

不連續面幾何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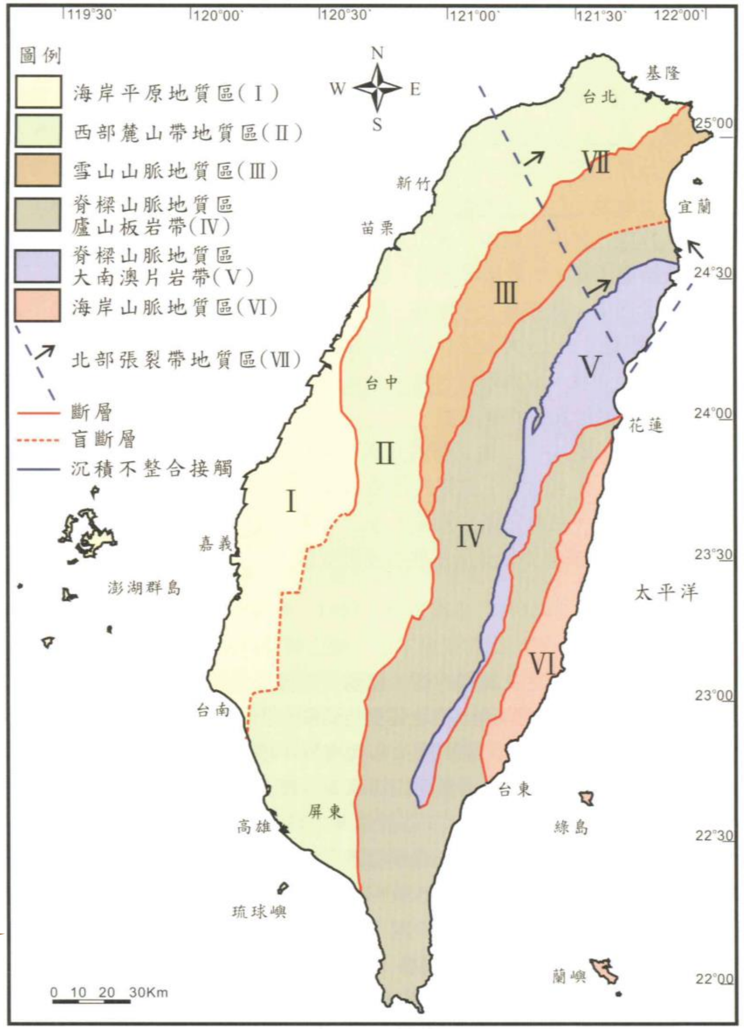
台灣岩體分類法

- 台灣地質年代輕，且位處板塊衝撞帶，岩石種類及強度等條件迥異於與南非RMR法與挪威Q系統。
- 回顧：台灣地質分區
- 西部麓山帶**卵礫石層**及**砂泥岩**等地層，已超出目前岩體分類系統之適用範圍。
- 公共工程委員會：”台灣岩體分類與隧道支撐系統”

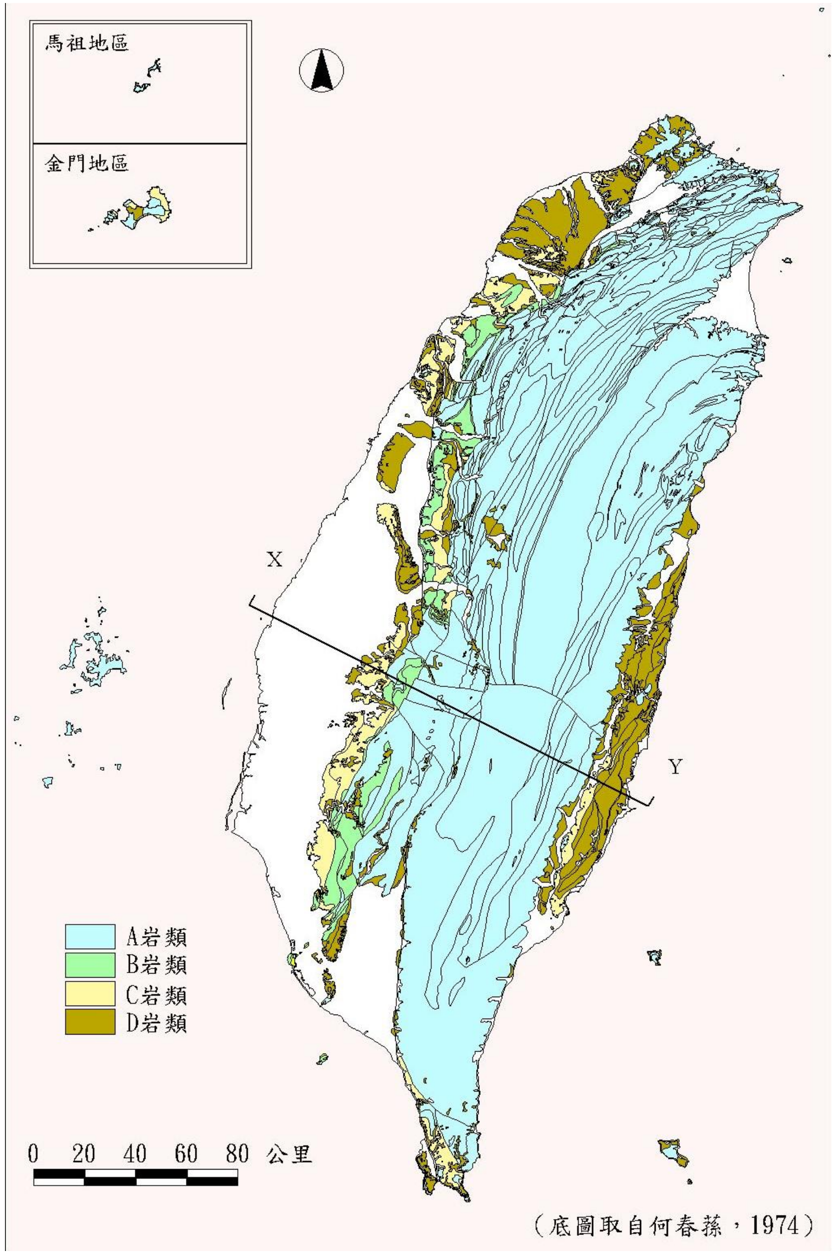
別人的岩體分類法不適合台灣，創一個台灣岩體分類法!



陳文山等(2016)：四十萬分之一台灣地質圖

台灣岩體分類法

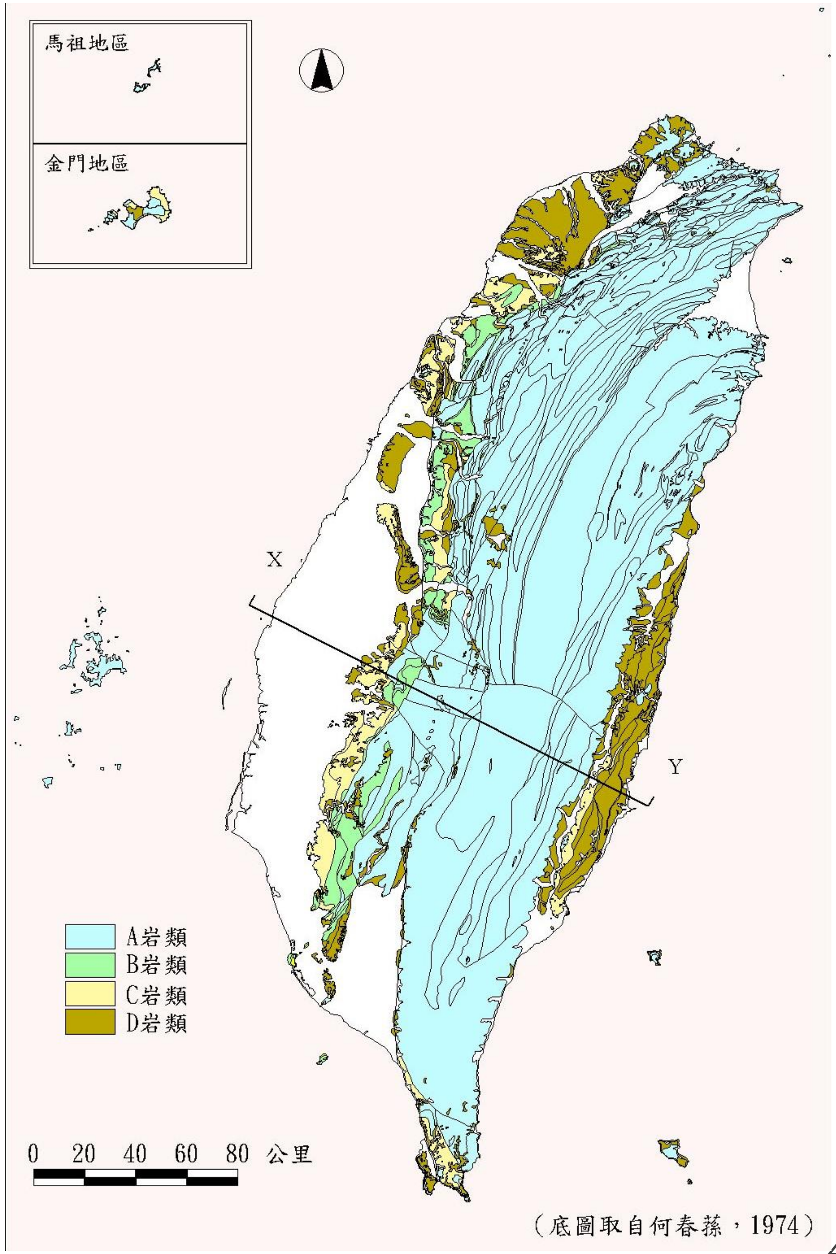
- 將台灣全區地層劃分為**A、B、C、D四種**岩類(rock type)，每類之下再分**岩體分級標準**(rock mass classification)，並標示為不同**岩體級別**(rock mass class)
- 根據各重大公共工程案例之岩石試驗結果劃分
- 定量分類以**RMR系統**為主
- 斷層帶、大量湧水、擠壓、膨脹、高岩爆潛能、高地溫、含有害氣體等特殊地質狀況應視個案特性加以特別考量。



A岩類

岩類
- 岩體分級標準
- 岩體級別

- ISRM地質材料強度分類中，強度高於或等於中強岩之地質材料，岩質堅脆，易因大地應力影響而產生發達節理。
- 岩體破壞機制屬受節理、劈理等**弱面控制之構造破壞**。
- **所有變質岩類**及**亞變質岩類**，**火成岩類**中除火山角礫岩的岩層，**沉積岩**中岩化程度高、具高強度者

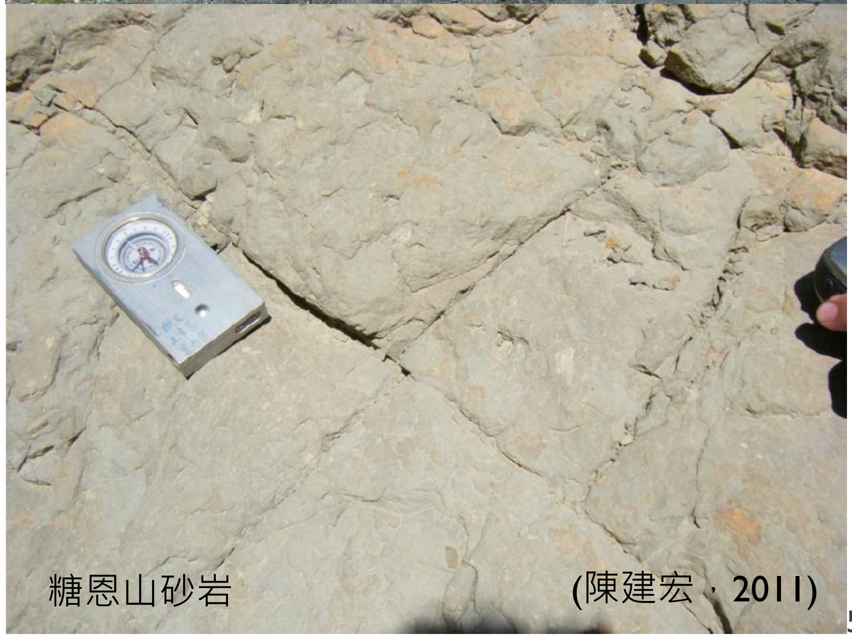


A岩類

岩類
- 岩體分級標準
- 岩體級別

- ISRM地質材料強度分類中，強度高於或等於中強岩之地質材料，岩質堅脆，易因大地應力影響而產生發達節理。
- 岩體破壞機制屬受節理、劈理等**弱面控制之構造破壞**。
- **所有變質岩類及亞變質岩類**，**火成岩類**中除火山角礫岩的岩層，**沉積岩**中岩化程度高、具高強度者


大南澳片岩


糖恩山砂岩

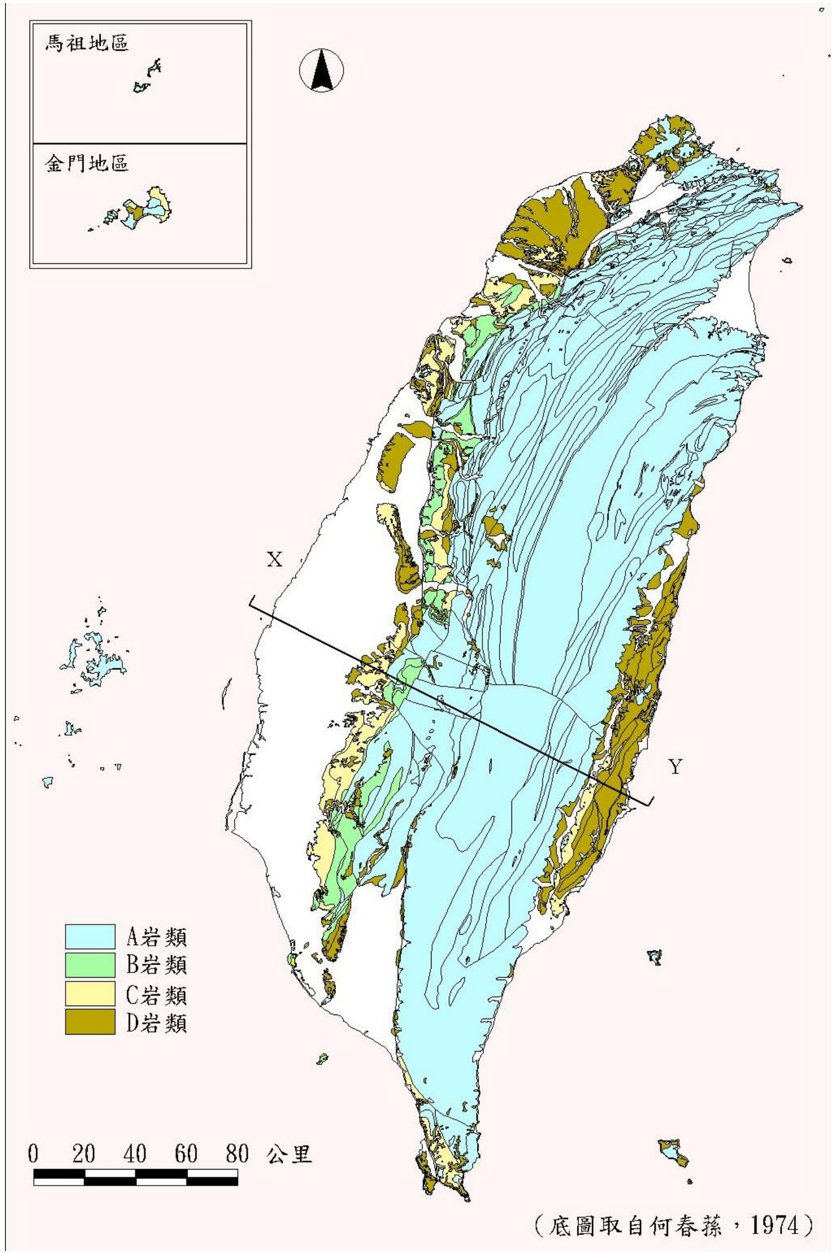
(陳建宏，2011)

陳建宏(2011)：小林村獻肚山深層崩塌地質構造及地質材料特性之研究

B岩類

岩類
├ 岩體分級標準
└ 岩體級別

- ISRM地質材料強度分類中相當於弱岩之地質材料。
- 不如A岩類般堅脆，在大地應力作用下不容易產生發達之節理，且因膠結較差，會因含水量提高而產生不容忽視之強度降低現象。
- 泛指**沉積岩中之較軟弱已固結岩層**，多位處**西部麓山帶西緣丘陵區**。



B岩類

岩類
- 岩體分級標準
- 岩體級別

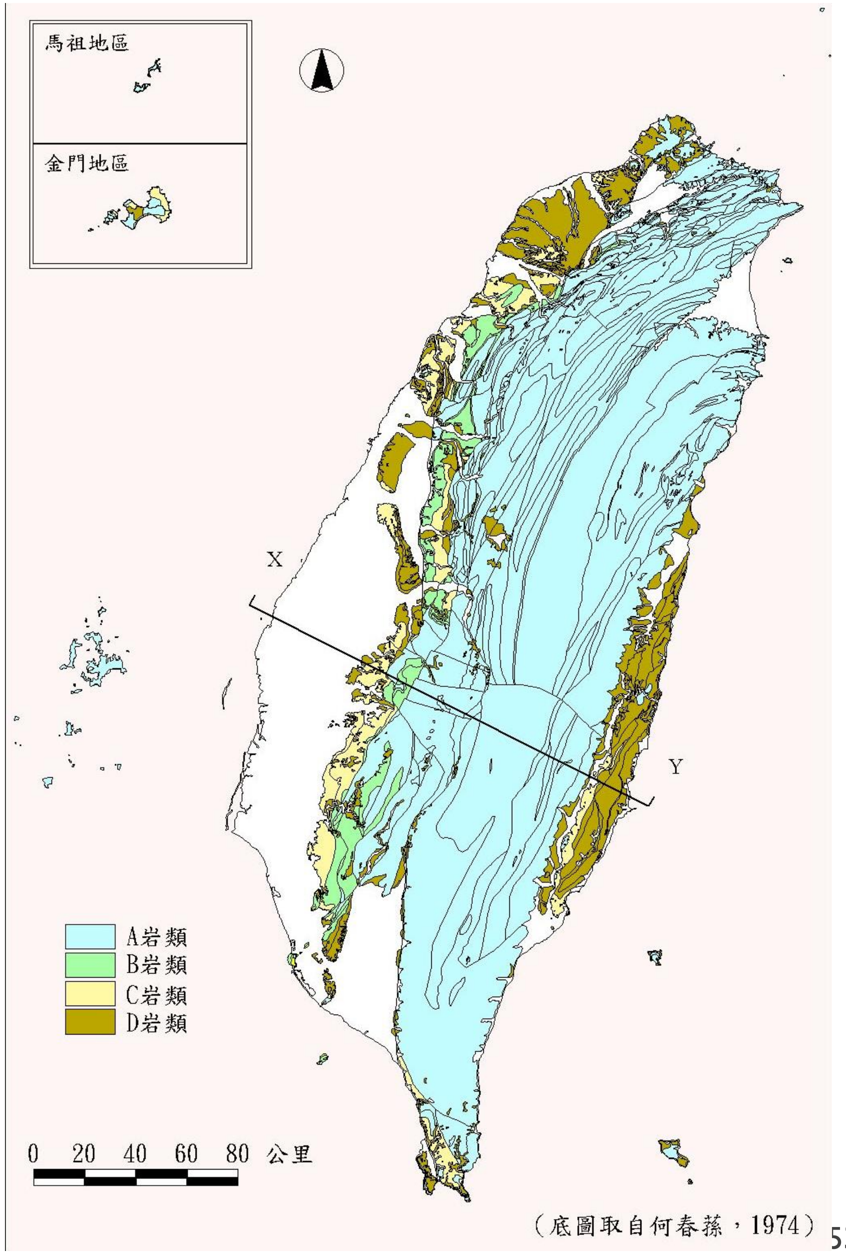
- ISRM地質材料強度分類中相當於弱岩之地質材料。
- 不如A岩類般堅脆，在大地應力作用下不容易產生發達之節理，且因膠結較差，會因含水量提高而產生不容忽視之強度降低現象。
- 泛指**沉積岩中之較軟弱已固結岩層**，多位處**西部麓山帶西緣丘陵區**。

(楊貴三與葉志杰，2017)

C岩類

岩類
├ 岩體分級標準
└ 岩體級別

- 所有**粗顆粒含量少於50%**，力學行為受控於細粒料之複合材料地層。
- 遇水軟化現象極明顯，岩體少有明顯的地質弱面，破壞機制以材料破壞為主。
- 岩盤強度的決定因素主要為組成材料性質、膠結程度與含水量高低。
- 包括**台灣南部**晚**上新世**至**更新世**，**東部海岸山脈**地質區膠結不佳之**沉積岩**或**混同層**。



C岩類

岩類
- 岩體分級標準
- 岩體級別

- 所有**粗顆粒含量少於50%**，力學行為受控於細粒料之複合材料地層。
- 遇水軟化現象極明顯，岩體少有明顯的地質弱面，破壞機制以材料破壞為主。
- 岩盤強度的決定因素主要為組成材料性質、膠結程度與含水量高低。
- 包括**台灣南部**晚**上新世**至**更新世**，**東部海岸山脈**地質區膠結不佳之**沉積岩**或**混同層**。

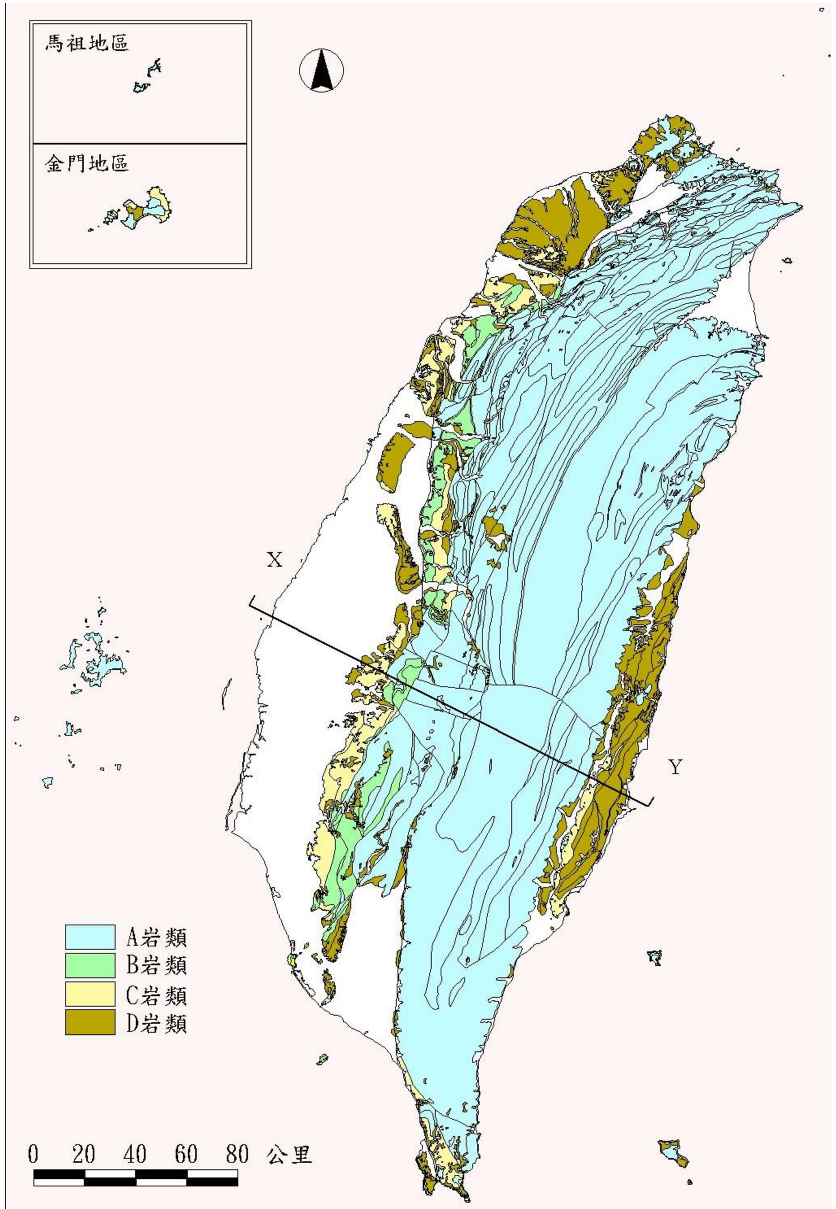
(齊士崢，2018)

(楊貴三與葉志杰，2017)

D岩類

岩類
- 岩體分級標準
- 岩體級別

- 以**粗顆粒為主(含量超過50%)**，夾有細粒料之**複合地質材料**，包含**礫石層**、**火山角礫岩**、**火山集塊岩**等等。
- **單壓**強度**變異**範圍相當**大**，因而影響弱面產生的多寡。**含水量高低**對於整個岩體強度所造成的影響程度大小，係視個案而異。
- **粗顆粒含量**介於**50%至75%**時，岩體破壞行為主要受控於**細粒料膠結程度**；**粗顆粒含量大於75%時**，岩體破壞行為則由**粗顆粒**主控。

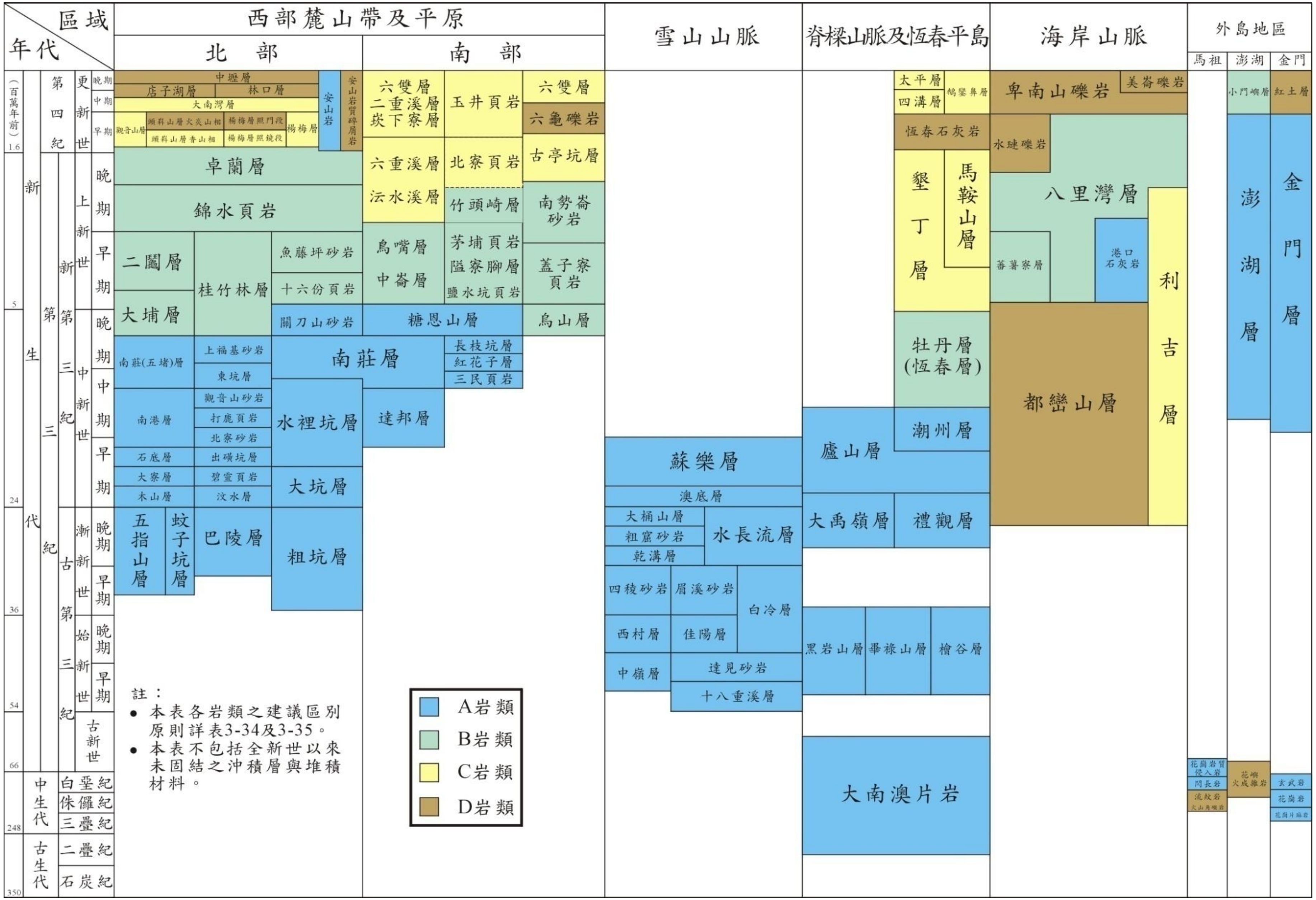


（底圖取自何春蓀，1974）

D岩類

岩類
- 岩體分級標準
- 岩體級別

- 以**粗顆粒為主(含量超過50%)**，夾有細粒料之**複合地質材料**，包含**礫石層**、**火山角礫岩**、**火山集塊岩**等等。
- **單壓**強度**變異**範圍相當**大**，因而影響弱面產生的多寡。**含水量高低**對於整個岩體強度所造成的影響程度大小，係視個案而異。
- **粗顆粒含量**介於**50%至75%**時，岩體破壞行為主要受控於**細粒料膠結程度**；**粗顆粒含量大於75%時**，岩體破壞行為則由**粗顆粒**主控。


區域
年代
西部麓山帶及平原
北　部
南　部
雪山山脈
脊樑山脈及恆春半島
海岸山脈
外島地區
馬祖
澎湖
金門
(百萬年前)
1.6
5
24
36
54
66
248
350
新生代
第四紀
第三紀
新第三紀
古第三紀
更新世
上新世
中新世
漸新世
始新世
古新世
晚期
中期
早期
中生代
白堊紀
侏儸紀
三疊紀
古生代
二疊紀
石炭紀
中壢層
店子湖層
林口層
大南灣層
觀音山層
楊梅層
安山岩
安山岩質碎屑岩
卓蘭層
錦水頁岩
二鬮層
桂竹林層
魚藤坪砂岩
十六份頁岩
大埔層
關刀山砂岩
南莊(五堵)層
上福基砂岩
東坑層
觀音山砂岩
打鹿頁岩
北寮砂岩
南港層
石底層
出礦坑層
大寮層
碧靈頁岩
木山層
汶水層
南莊層
水裡坑層
大坑層
五指山層
蚊子坑層
巴陵層
粗坑層
六雙層
二重溪層
崁下寮層
玉井頁岩
六龜礫岩
六重溪層
北寮頁岩
古亭坑層
沄水溪層
竹頭崎層
南勢崙砂岩
烏嘴層
中崙層
茅埔頁岩
隘寮腳層
鹽水坑頁岩
蓋子寮頁岩
糖恩山層
烏山層
長枝坑層
紅花子層
三民頁岩
達邦層
蘇樂層
澳底層
大桶山層
粗窟砂岩
乾溝層
水長流層
四稜砂岩
眉溪砂岩
白冷層
西村層
佳陽層
中嶺層
達見砂岩
十八重溪層
大南澳片岩
太平層
四溝層
恆春石灰岩
墾丁層
馬鞍山層
牡丹層
(恆春層)
潮州層
廬山層
大禹嶺層
禮觀層
黑岩山層
畢祿山層
檜谷層
卑南山礫岩
美崙礫岩
水璉礫岩
八里灣層
蕃薯寮層
港口石灰岩
利吉層
都巒山層
小門嶼層
紅土層
澎湖層
金門層
閃長岩
流紋岩
花崗岩
玄武岩
註：
• 本表各岩類之建議區別原則詳表3-34及3-35。
• 本表不包括全新世以來未固結之沖積層與堆積材料。
A岩類
B岩類
C岩類
D岩類

岩體分級標準

岩類(rock type)
- **岩體分級標準**(rock mass classification)
- **岩體級別**(rock mass class)

- 經認定屬於**A**、**B類**之岩體，採用**RMR**系統評分，再對照表3-2找出岩體級別。
- A類：等同RMR但多一類
- B類：評完RMR後降一級

RMR共五種岩體分類，第一類最佳
- RMR=81-100, Class 1 第一類岩體
- RMR=61-80, Class 2 第二類岩體
- RMR=41-60, Class 3 第三類岩體
- RMR=21-40, Class 4 第四類岩體
- RMR<20, Class 5 第五類岩體

表 3-2 A、B 岩類之岩體分級標準表

岩體級別	A 岩類 RMR 值範圍	B 岩類 RMR 值範圍	岩體級別
A_{I}	RMR≧81	----	----
A_{II}	RMR80～61	RMR≧81	B_{II}
A_{III}	RMR60～41	RMR80～61	B_{III}
A_{IV}	RMR40～21	RMR60～41	B_{IV}
A_{V}	RMR20～11	RMR40～21	B_{V}
A_{VI}	RMR≦10	RMR≦20	B_{VI}

岩體分級標準

- 岩類(rock type)
- **岩體分級標準(rock mass classification)**
- 岩體級別(rock mass class)

- 屬於**C、D類**之岩體，依據**地質材料組成**、**粗粒料比例**、**膠結良窳程度**等特性組成之定性評級標準決定岩體分級(**表3-3**)。

表 3-3　C、D 岩類之岩體分級標準表

岩體級別		分類標準	
		膠結程度	地質材料組成
C岩類	$C_{I(C)}$	膠結程度良好或尚可 (大姆指無法壓出凹痕)	泥泥、黏土含量>50%
	$C_{I(MIX)}$		砂、沉泥、黏土、礫石交雜個別含量均未超過 50%
	$C_{I(S)}$		砂含量>50%
	$C_{II(C)}$	膠結程度不佳或疏鬆 (大拇指可壓出凹痕)	沉泥、黏土含量>50%
	$C_{II(MIX)}$		砂、沉泥、黏土、礫石交雜個別含量均未超過 50%
	$C_{II(S)}$		砂含量>50%
D岩類	$D_{I(G)}$	膠結程度極佳 (需以地質鎚用力敲 方能將塊石或礫石敲落)	塊石、粗顆粒(大於 4 號篩)之含量>75% 或相互接觸
	$D_{I(M)}$		塊石、粗顆粒(大於 4 號篩)之含量 50% ~ 75% 或相互不接觸
	$D_{II(G)}$	膠結程度良好或尚可 (需以地質鎚方能將 塊石或礫石敲落)	塊石、粗顆粒(大於 4 號篩)之含量>75% 或相互接觸
	$D_{II(M)}$		塊石、粗顆粒(大於 4 號篩)之含量 50% ~ 75% 或相互不接觸
	$D_{III(G)}$	膠結程度不佳或疏鬆 (以手即可將塊石或礫石剝落)	塊石、粗顆粒(大於 4 號篩)之含量>75% 或相互接觸
	$D_{III(M)}$		塊石、粗顆粒(大於 4 號篩)之含量 50% ~ 75% 或相互不接觸

註一：鑑於含水之多寡對 C、D 兩岩類之工程施工影響甚鉅，故本表需在地下水已預先排除至可施工之前提下方能使用。

註二：C、D 岩類隧道可能遭遇砂層與礫石層混合斷面，其中砂層出露位置影響開挖面穩定性甚鉅，需選用適當之輔助工法加以克服。

表 3-4　台灣地區 A、B 岩類隧道標準支撐建議表（16m ≥ 隧道跨度 ≥ 10m，最大覆蓋. 400m）

A 岩類	B 岩類	岩體級別		開挖工法	噴凝土厚度 (cm)	鋼支保		岩栓		
						尺寸(mm)	間距(m)	長度(m)	縱距(m)	橫距(m)
RMR ≥ 81		I	very good	台階工法	5 ~ 10	—	—	4 (視需要)	—	—
RMR 80～61	RMR ≥ 81	II	good							
RMR 60～41	RMR 80～61	III	fair	台階工法	15	H100x100 (視需要)	—	4 ~ 6	1.5 ~ 2.0	1.5 ~ 2.0
RMR 40～21	RMR 60～41	IV	poor	台階工法	15 ~ 20	H125x125	1.2 ~ 1.5	4 ~ 6	1.2 ~ 1.5	1.5 ~ 2.0
RMR 20～11	RMR 40～21	V	very poor	台階工法或側導坑工法	25	H125x125	1.0 ~ 1.5	6 ~ 9	1.0 ~ 1.5	1.5 ~ 2.0
RMR ≤ 10	RMR ≤ 20	VI	extremely poor	台階工法或側導坑工法	25	≥ H150x150	0.8 ~ 1.2	6 ~ 9	0.8 ~ 1.2	1.0 ~ 1.5

表 3-5　台灣地區 A、B 岩類隧道標準支撐建議表（隧道跨度 < 10m，最大覆蓋. 400m）

A 岩類	B 岩類	岩體級別		開挖工法	噴凝土厚度 (cm)	鋼支保		岩栓		
						尺寸(mm)	間距(m)	長度(m)	縱距(m)	橫距(m)
RMR ≥ 81		I	very good	全斷面開挖或台階工法	5	—	—	4 (視需要)	—	—
RMR 80～61	RMR ≥ 81	II	good							
RMR 60～41	RMR 80～61	III	fair	全斷面開挖或台階工法	10	H100x100 (視需要)	—	4	1.5 ~ 2.0	1.5 ~ 2.0
RMR 40～21	RMR 60～41	IV	poor	台階工法	15	H125x125	1.5 ~ 2.0	4 ~ 6	1.5 ~ 2.0	1.5 ~ 2.0
RMR 20～11	RMR 40～21	V	very poor	台階工法	20 ~25	≥ H150x150	1.0 ~ 1.5	4 ~ 6	1.0 ~ 1.5	1.2 ~ 2.0
RMR ≤ 10	RMR ≤ 20	VI	extremely poor							

附註：表中噴凝土及鋼支保，均得依個案評估結果，視需要以鋼纖維噴凝土或桁型鋼支保替代。

表 3-6　C 岩類隧道標準支撐建議表（最大覆蓋. 100m）

16m ≥ 隧道跨度 ≥ 10m

岩體級別	支撐型式		開挖工法	噴凝土厚度 (cm)	鋼支保 尺寸(mm)	鋼支保 間距(m)	岩栓 長度(m)	岩栓 縱距(m)	岩栓 橫距(m)
$C_{I(c)}$	I	先撐保護工(視需要)	台階工法	20 ~ 25	H125x125	1.0 ~ 1.5	4~9	1.0~1.5	1.0
$C_{I(mix)}$		鋼支保基腳保護工、先撐保護工(視需要)							
$C_{I(s)}$									
$C_{II(c)}$	II	鋼支保基腳保護工、先撐保護工	台階工法或側導坑工法	25 ~ 30	H150x150	0.8 ~ 1.2	視需要(見附註)	-	-
$C_{II(mix)}$									
$C_{II(s)}$									

隧道跨度 < 10m

岩體級別	支撐型式		開挖工法	噴凝土厚度 (cm)	鋼支保 尺寸	鋼支保 間距(m)	岩栓 長度(m)	岩栓 縱距(m)	岩栓 橫距(m)
$C_{I(c)}$	I	—	台階工法或全斷面工法	15	H100x100 或 H125x125	1.0 ~ 1.5	4~6	1.2~1.5	1.2~1.5
$C_{I(mix)}$		鋼支保基腳保護工(視需要)							
$C_{I(s)}$									
$C_{II(c)}$	II	鋼支保基腳保護工、先撐保護工(視需要)	台階工法或全斷面工法	15 ~ 20	H150x150	0.8 ~1.2	視需要(見附註)	-	-
$C_{II(mix)}$									
$C_{II(s)}$									

附註：表中噴凝土及鋼支保，均得依個案評估結果，視需要以鋼纖維噴凝土或桁型鋼支保替代；岩栓則建議選用傘狀擴座式成效較佳。在此類岩盤中，岩栓具有內壓功效、拱的形成功效及地盤改良功效，可對隧道穩定提供相當之貢獻。

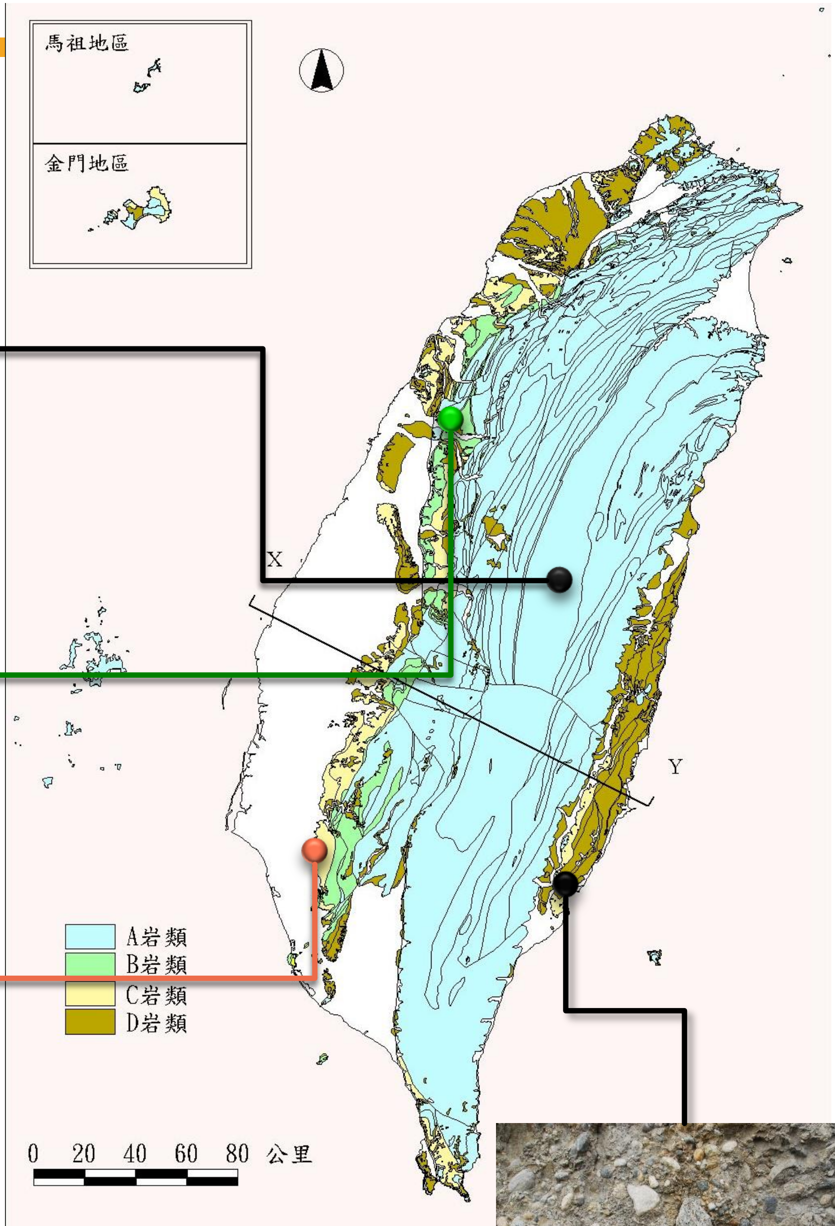
表 3-7　D 岩類隧道標準支撐建議表（隧道跨度≦12m）

岩體級別	最大覆蓋≦100m	100m<最大覆蓋≦290m
$D_{I(G)}$	I	
$D_{I(M)}$		
$D_{II(G)}$	II	
$D_{II(M)}$	II	II 先撐保護工(視需要)
$D_{III(G)}$	III 鋼支保基腳保護工(視需要)	IV 鋼支保基腳保護工(視需要)
$D_{III(M)}$	III 先撐保護工 鋼支保基腳保護工	IV 先撐保護工 鋼支保基腳保護工

支撐	開挖工法	噴凝土	鋼支保 尺寸(mm)	鋼支保 間距(m)	岩栓 長度(m)	岩栓 縱距(m)	岩栓 橫距(m)
I	短台階工法	15	H100x100	1.5~2.0	-	-	-
II	短台階工法	20	H125x125	1.2~1.5	4(H>100m) 視需要(H≦100m)	1.2~1.5	1.5~2.0
III	短台階或微台階工法	25	H150x150 或 H175x175	1.0~1.2	4 或 6	1.0~1.2	1.0~1.5
IV	短台階或微台階工法	25~30	H150x150 或 H175x175	0.8~1.0	6	0.8~1.0	1.0

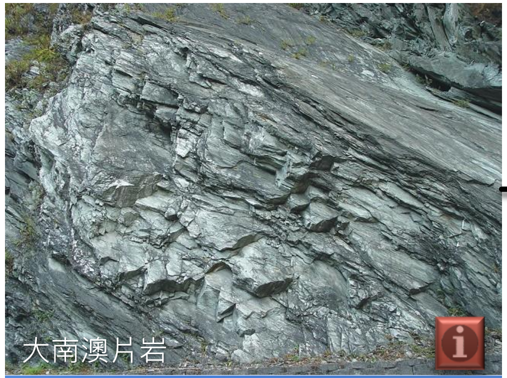
附註：表中噴凝土及鋼支保，均得依個案評估結果，視需要以鋼纖維噴凝土或桁型鋼支保替代。

台灣岩體分類



A岩類

所有變質岩類及亞變質岩類，**火成岩類**中除火山角礫岩的岩層，**沉積岩**中岩化程度高、具高強度者



B岩類

沉積岩中之較軟弱已固結岩層，多位處**西部麓山帶西緣丘陵區**。

C岩類

台灣南部晚**上新世**至**更新世**，**東部海岸山脈**地質區膠結不佳之**沉積岩**或**混同層**。

D岩類

以**粗顆粒為主(含量超過50%)**，夾有細粒料之複合地質材料，包含**礫石層**、**火山角礫岩**、**火山集塊岩**等等。