Rock Characterizations and Classification

by

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Geotechnical Engineer Task

- Predict effect of rock variability
- Uncertainties - Implication of rock variability for geotechnical design and construction
- Reliability based-design
- *Impact to & from environment*

Quote, Evert Hoek.1986

- The cornerstone of any *practical rock mechanics analysis or rock engineering* is the geological data base upon which the definition of rock types, structural discontinuities and material properties is based.

  Even the most sophisticated geological information upon which it is based is inadequate or inaccurate

Rock types

- Geological

Rock or soil
Igneous
Metamorphic
Sedimentary

Standardize Legend

- Engineering

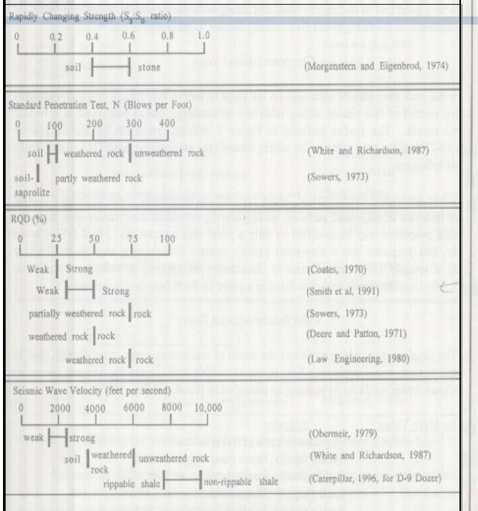
Rock or Soil
Competent rock
Incompetent rock
Hard rock
Weak rock
Soft rock
Shaley rock

Rock Mass Assessment

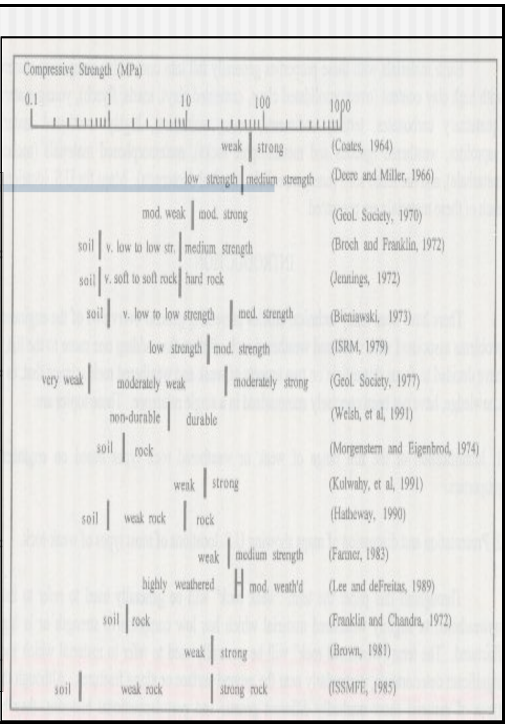
Rock Mass = rock materials + discontinuities + weathering

- Physical properties that contribute to mechanical properties : rock types, mineralogy, texture and structure, density, discontinuities, etc.
- Material and mass characterization for potential geotechnical problems in tropical climate (***uniqueness***)
- *Reaction with moisture and temperature changes*
- Swell, shrink and collapse potential characteristics
- Design for immediate and long term stability

Engineering Definitions



igure 2. Identification of weak rock on the basis of strength-related tests.



ROCK MATERIAL STRENGTH

- **rock mass strength >>*material strength***
- **discontinuities >> dominancy?**
- **others>>>tropical weathering impact is crucial**

Design parameters :

- Material quality – hardness, durability, weathering grade
- Material strength- intact samples
- Discontinuities - quality and its favour to the rock structure stability
- Ground water, environmental loads, others

Rock Characterization Testing and Monitoring

ISRM Suggested Methods of Testing – 1981, 1985

a) Site Characterization

- Qualitative description of discontinuities
- Geophysical logging of boreholes

b) Laboratory and Field Testing

Laboratory Index Tests for Characterization

- *Physical properties: water content, porosity,void index*
- Swelling pressure and swelling strain
- *Slake durability*
- *Uniaxial compressive strength*
- Uniaxial deformability (E, v)
- *Point load strength index*
- *Resistance to abrasion (LA test)*
- *Hardness (Schmidt Rebound)*
- Sonic velocity
- *Petrographic description (demo)*

Rock Characterization Testing and Monitoring

ISRM Suggested Methods of Testing – 1981, 1985

- **Laboratory Design tests**
- Triaxial strength
- Direct tensile strength
- *Indirect (Brazil) tensile strength*
- Direct shear test (field method)
- *Permeability (demo)*
- Time dependent and plastic properties

Field 'Design Tests'
Field Monitoring (*Early warning system for monitoring slopes*..?)
Field 'Quality Control tests'

ROCK STRENGTH

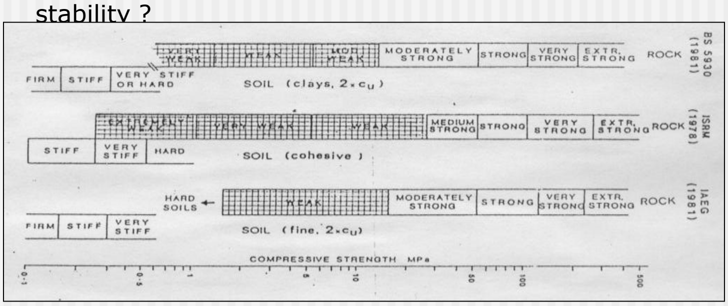
Material strength vs Mass strength

Geological definitions:

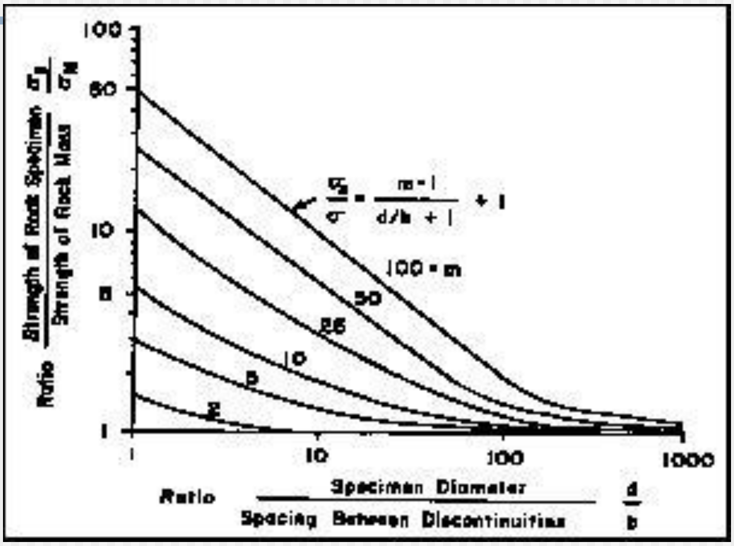
Fresh rock , un-weathered rock, weathered hard rock, weathered weak rock, soil like – rock like material ?
Residual soil?

Engineering definitions:

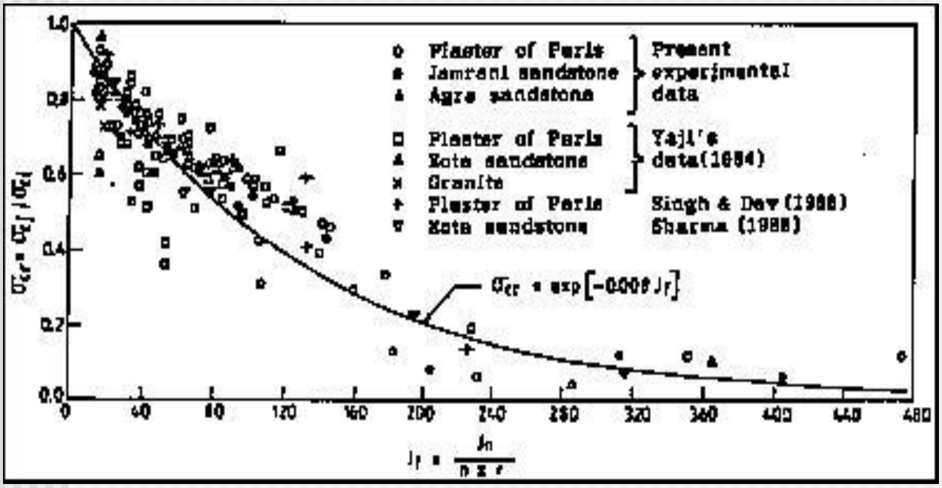
rock mass competency, excavate ability, rock strength, stability ?



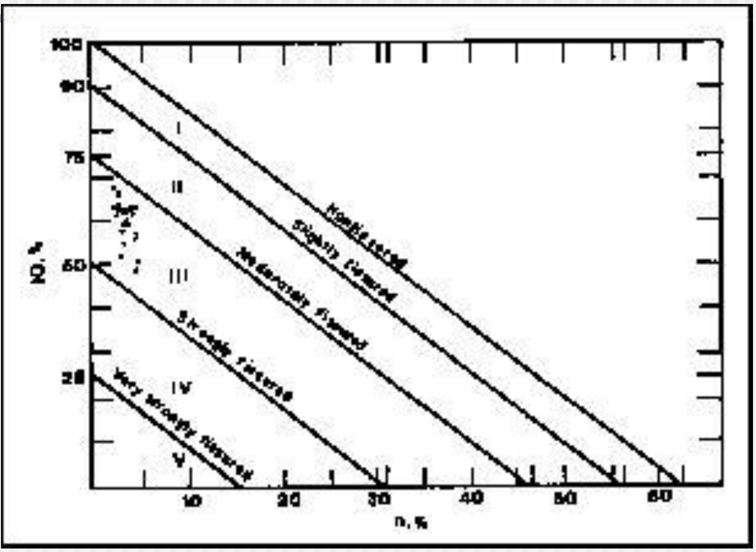
Relationship of discontinuities spacing and the strength of rock mass Jeremic 1987.



Changes in compressive strength wrt discontinuities factor , Arora 1992



Classification scheme for fissuring in rock specimens , Ulusay 1994 (quality index vs porosity)



Rock strength- laboratory testing

-Bigger sample has lower strength due to presence of fracture and fissures

-Mechanical properties of rock has strong correlation with its petrography characteristics

-Higher rock density has higher strength linearly proportionate

-Uniaxial compressive strength reduces with increase in pore volume

-There is a correlation between rock density, Elastic modulus and stiffness modulus

Sampling and Scale effects

Scale effects on the uniaxial compressive strength depend upon 3 mechanisms:

- Degree of rock structure disturbance during sampling
- Rule of statistical analysis , and
- Change in rock structure stability due to an increase in overburden

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Effect of sizes on UCS

Diameter:

Jackson dan Lau (1990) $\sigma c_d = \sigma c_{63} (63/d)^{0.16}$

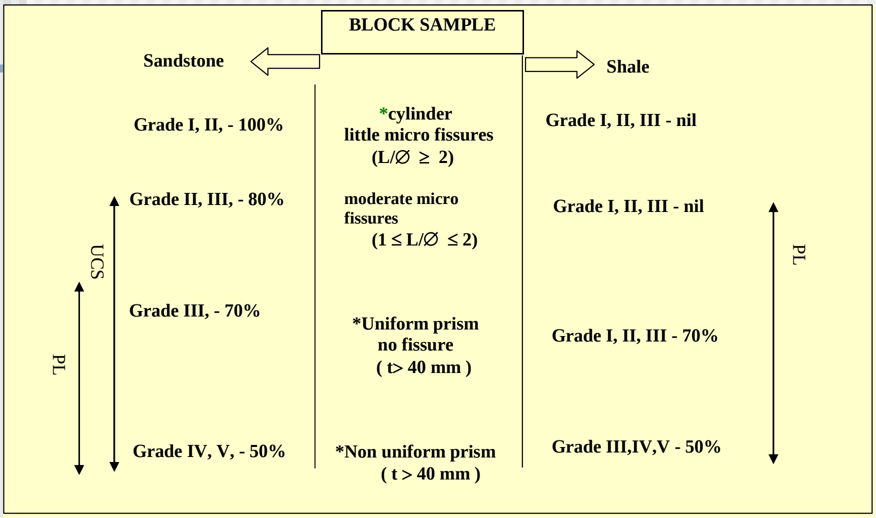
Hoek dan Brown (1980) $\sigma c_d = \sigma c_{50} (50/d)^{0.18}$

Ratio Length to Diameter:

$2 > p/\varnothing > 1/3$ $\sigma c1 = \sigma p / (0.778 + 0.22\, p/\varnothing)$

$p/\varnothing$ #2, $\sigma c = 8\, \sigma p / (7 + 2(\varnothing/p))$

Design Laboratory Strength Test



BLOCK SAMPLE

Sandstone

Shale

Grade I, II, - 100%

***cylinder**
little micro fissures
(L/∅ ≥ 2)

Grade I, II, III - nil

Grade II, III, - 80%

moderate micro fissures
(1 ≤ L/∅ ≤ 2)

Grade I, II, III - nil

Grade III, - 70%

***Uniform prism**
no fissure
(t> 40 mm)

Grade I, II, III - 70%

Grade IV, V, - 50%

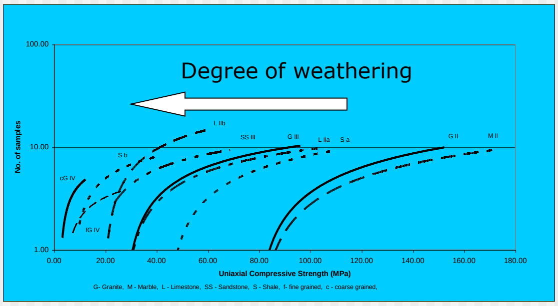
***Non uniform prism**
(t > 40 mm)

Grade III,IV,V - 50%

UCS – Uniaxial compressive strength PL – Point load

Uniaxial Compressive strength test

Failure load at > 50% breakage

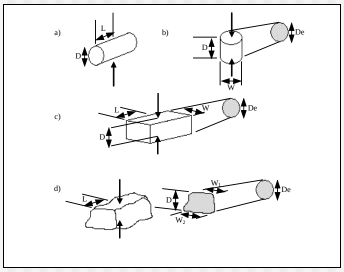


Sample sizes, L/D ratio
Rate of loading
Capping rigidity and sample flatness

NUMBER	SAMPLE	FAILURE LOAD (P) (kN)	EFFECTIVE AREA (A) (mm^2)	L/D	D/L	EXPERIMENTAL $\sigma_{C\ exp.}$ (MPa) (P*1000 / A)	CORRECTED $\sigma_{C\ corrected}$ (MPa) $[\sigma_{C\ exp.}/(0.778+0.222(D/L))]$	% DIFFERENCE
1	sa	95.238	2402.68	1	1	39.64	39.64	0
2	sb	76.678	2416.61	0.91	1.09	31.73	31.11	1.96
3	sc	69.352	2425.33	0.97	1.03	28.59	28.41	0.66
4	sd	44.444	2413.99	0.99	1.01	18.41	18.37	0.22
5	se	32.234	2415.74	0.98	1.02	13.34	13.28	0.44
6	sf	23.931	2432.32	1	1	9.84	9.84	0
7	sg	26.373	2414.86	1	1	10.92	10.92	0
8	sh	29.792	2420.97	1	1	12.31	12.31	0

POINT LOAD TEST

Flexible shape
No sample preparation
Very reliable for strength determination of weathered rock

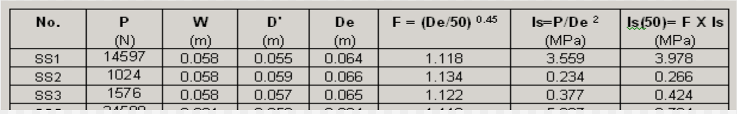


JADUAL 4.2(b) Pengelasan batuan terluluhawa berdasarkan kekuatan beban titik (MPa)

Batuan	Gred	Luluhawa /	Kekuatan	Beban	Titik	Rujukan
	I	II	III	IV	V	
Agglomerat	6.08	3.14	0.98	0.39	-	Turk et al.(1994)
Andesit	5.40	3.04	2.60	0.64	-	Turk et al.(1994)
Syal (klo)	2.82	1.68	1.13	1.23	0.82	Beavis et al.(1982)
Syal (dol)	3.98	2.42	2.33	1.20	-	Beavis et al.(1982)
Andesit	13.40	4.12	2.50	0.20	-	Pasamehmetoglu et al.(1981)
Granodiorit	11.00	9.00	7.00	6.00	0.60	Irfan & Powel (1985)
Granit	10.00	5.20	1.70	0.30	-	Irfan & Dearman (1978)
Granit	7.10	4.10	2.70	2.00	1.10	Dearman & Irfan (1978)
Granit	9.10	7.20	4.70	3.00	-	Dearman & Irfan (1978)

Sumber:Gupta 1998

EXAMPLE OF POINT LOAD TEST STRENGTH RESULTS



No.	P (N)	W (m)	D' (m)	De (m)	F = (De/50) $^{0.45}$	Is=P/De ^{2} (MPa)	Is(50)= F X Is (MPa)
SS1	14597	0.058	0.055	0.064	1.118	3.559	3.978
SS2	1024	0.058	0.059	0.066	1.134	0.234	0.266
SS3	1576	0.058	0.057	0.065	1.122	0.377	0.424

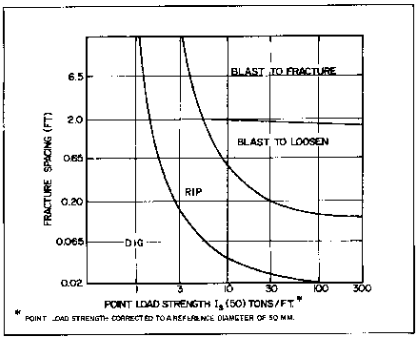


FIGURE 9
Suggested Guide for Ease of Excavation

Indirect tensile properties for ease of rock excavate ability
Ref Design Manual 7.02 pp 45

Classification by Strength

Class	Description	Uniaxial Compressive Strength p.s.i	kN/m ^{2}
A	Very High Strength	>32000	> 220000
B	High Strength	16000 – 32000	110000 – 220000
C	Medium Strength	8000 – 16000	55000 –110000
D	Low Strength	4000 – 8000	27500 – 55000
E	Very Low strength	<4000	< 27500

Rock Type	Compressive Strength MN/m ^{2}	Tangent Modulus MN/m ^{2} x 10 ^{3}	Modulus of Rupture MN/m ^{2}
Granite	160 – 295	15 – 75	8 – 27
Greenstone	115 – 315	50 – 60	12 – 46
Sandstone	33 – 235	10 – 50	4 – 25
Limestone	35 – 260	30 – 85	3 – 36
Marlstone	70 – 195	5 – 35	3 – 33
Shale	75 – 230	10 – 50	2 – 29

CLASSIFICATION BY UNIAXIAL COMPRESSIVE STRENGTH

Table 2 Classification of rock by strength (from Attewell & Farmer 1976).

Strength classification	**Strength range (MPa)**	**Typical rock types**
Very weak	10-20	Weathered and weakly-compacted sedimentary rocks
Weak	20-40	Weakly-cemented sedimentary rocks, schists
Medium	40-80	Competent sedimentary rocks; some low-density coarse-grained igneous rocks
Strong	80-160	Competent igneous rocks; some metamorphic rocks and fine-grained sandstones
Very strong	160-320	Quartzites; dense fine-grained igneous rocks

Correlation of rock mass and material strength (Bhasin *et al* 1998)

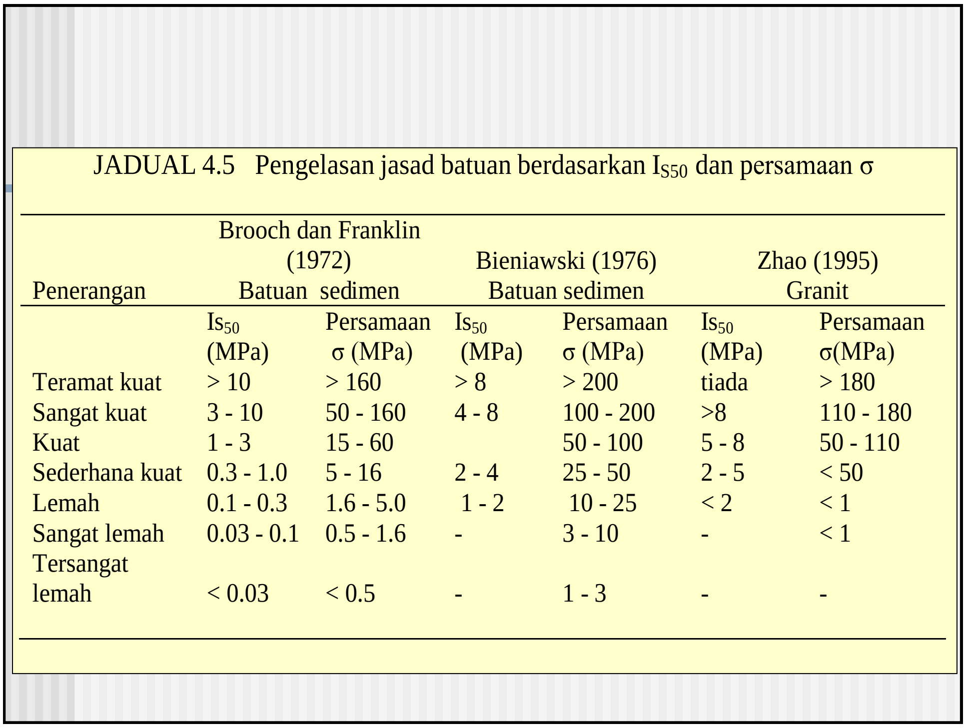
$$q\ max = 4.83\ (\sigma c)0.51$$
$$q\ max = (5\text{-}8)\sigma c$$
$$q\ max = 3\sigma c$$
$$q\ max = 2.7\sigma c$$

Foundation on rock:
Presumed bearing capacity?

Correlation Point load strength and Uniaxial Compressive strength

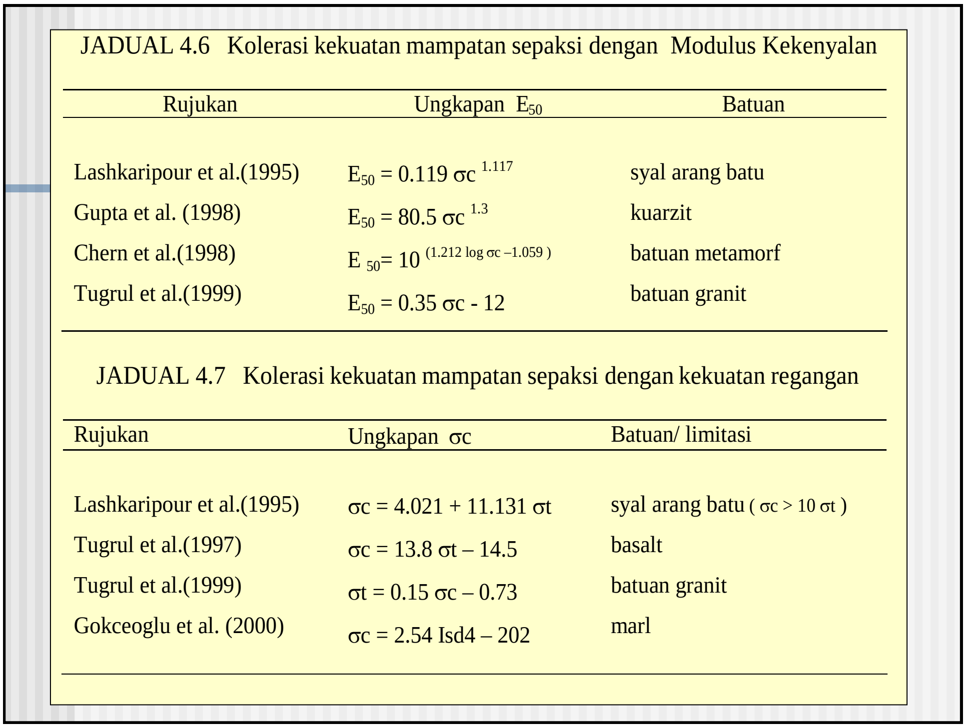
JADUAL 4.4 Kolerasi kekuatan mampatan sepaksi dengan kekuatan beban titik

Rujukan	Ungkapan σ (MPa)	Jenis Batuan
D'Andrea et al.(1964)	$\sigma = 15.3\ Is_{50} + 16.3$	-
Deere & Miller (1966)	$\sigma = 20.7\ Is_{50} + 29.6$	ignious,sedimen, metamorf
Broch & Franklin (1972)	$\sigma = 24\ Is_{50}$	granit
Bieniawski (1975)	$\sigma = 23\ Is_{50}$	kuarzit dan batu pasir
Hassani et al.(1980)	$\sigma = 29\ Is_{50}$	-
Gunsallus & Kulhawy (1984)	$\sigma = 16.5\ Is_{50} + 51$	arang batu
Singh (1981)	“$\sigma = 18.7\ Is_{50} - 132$	batuan lemah
Mehrotra et al.(1991)	$\sigma = 26\ Is_{50}$	-
O’Rourke (1989)	* $\sigma = 21.8\ Is_{50} + 6210$	-
Ghosh & Srivastava (1991)	$\sigma = 16\ Is_{50}$	-
Tsidzi (1991)	#$\sigma = (Is_{50}/0.03) + 0.003 Is_{50}$	-
Unal et al.(1992)	$\sigma = 16.57\ Is_{50} + 2.127$	batuan sedimen
Ulusay et al.(1994)	$\sigma = 19\ Is_{50} + 12.7$	batu pasir
Lashkaripour et al.(1995)	$\sigma = 20.238\ Is_{50}$	syal
Wiesner et al.(1997)	$\sigma = 18.6\ Is_{50} \pm 11.7$	batu pasir
Tugrul et al.(1999)	$\sigma = 15.25\ Is_{50}$	basalt



JADUAL 4.5 Pengelasan jasad batuan berdasarkan I_{S50} dan persamaan σ

Penerangan	Brooch dan Franklin (1972) Batuan sedimen		Bieniawski (1976) Batuan sedimen		Zhao (1995) Granit	
	Is_{50} (MPa)	Persamaan σ (MPa)	Is_{50} (MPa)	Persamaan σ (MPa)	Is_{50} (MPa)	Persamaan σ(MPa)
Teramat kuat	> 10	> 160	> 8	> 200	tiada	> 180
Sangat kuat	3 - 10	50 - 160	4 - 8	100 - 200	>8	110 - 180
Kuat	1 - 3	15 - 60		50 - 100	5 - 8	50 - 110
Sederhana kuat	0.3 - 1.0	5 - 16	2 - 4	25 - 50	2 - 5	< 50
Lemah	0.1 - 0.3	1.6 - 5.0	1 - 2	10 - 25	< 2	< 1
Sangat lemah	0.03 - 0.1	0.5 - 1.6	-	3 - 10	-	< 1
Tersangat lemah	< 0.03	< 0.5	-	1 - 3	-	-



JADUAL 4.6 Kolerasi kekuatan mampatan sepaksi dengan Modulus Kekenyalan

Rujukan	Ungkapan E_{50}	Batuan
Lashkaripour et al.(1995)	$E_{50} = 0.119\ \sigma c^{1.117}$	syal arang batu
Gupta et al. (1998)	$E_{50} = 80.5\ \sigma c^{1.3}$	kuarzit
Chern et al.(1998)	$E_{50} = 10^{(1.212 \log \sigma c - 1.059)}$	batuan metamorf
Tugrul et al.(1999)	$E_{50} = 0.35\ \sigma c - 12$	batuan granit

JADUAL 4.7 Kolerasi kekuatan mampatan sepaksi dengan kekuatan regangan

Rujukan	Ungkapan σc	Batuan/ limitasi
Lashkaripour et al.(1995)	$\sigma c = 4.021 + 11.131\ \sigma t$	syal arang batu ($\sigma c > 10\ \sigma t$)
Tugrul et al.(1997)	$\sigma c = 13.8\ \sigma t - 14.5$	basalt
Tugrul et al.(1999)	$\sigma t = 0.15\ \sigma c - 0.73$	batuan granit
Gokceoglu et al. (2000)	$\sigma c = 2.54\ Isd4 - 202$	marl

JADUAL 4.8 Kolerasi kekuatan mampatan sepaksi dengan sifat fizikal

Rujukan	Ungkapan σc	Batuan
Lashkaripour et al.(1995)	$\sigma c = 206.54\, n^{-0.945}$	syal arang batu
Tugrul et al.(1997)	$\sigma c = 134\, n^{-0.8}$	basalt
Bhasin & Loset (1998)	$\sigma c = 1.01 \times e^{(0.001\, \gamma R)}$	batuan lemah
Kate et al.(1998)	$\sigma c = 0.0007\, (\gamma R)^{1.697}$	batuan sedimen
Tugrul et al.(1999)	$\sigma c = 8.36\, R - 416$	batuan granit

n- keliangan

γ - berat batuan seunit

R- nombor tukul pantulan

σc and Is_{50} unit MPa

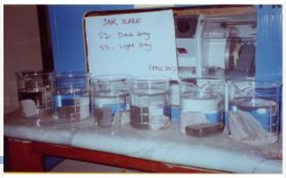
#σ - hubungkait lengkung linear

Rock Engineering in Malaysia

- Wet tropical weathering impact is very significant that caused strength reduction
- Influence of weathering differ with rock type
- Uniaxial strength index determination needs to be carefully correlated with the behaviour of rock mass
- A point load index can be an alternative testing method for weak and weathered rock material

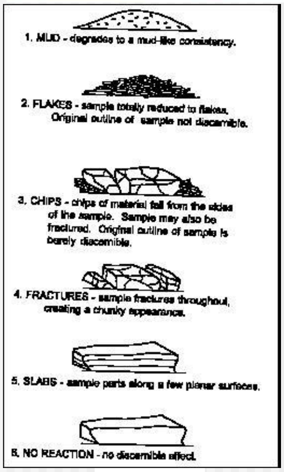
Slake durability test

To assesses the resistance offered by a rock samples to weakening and disintegration when subjected to drying and wetting cycles



Slake Durability Index (Id2) is calculated by:

$$Id2 = \frac{C - D}{A - D} \times 100\%$$



1. MUD - degrades to a mud-like consistency.

2. FLAKES - sample totally reduced to flakes. Original outline of sample not discernible.

3. CHIPS - chips of material fall from the sides of the sample. Sample may also be fractured. Original outline of sample is barely discernible.

4. FRACTURES - sample fractures throughout, creating a chunky appearance.

5. SLABS - sample parts along a few planar surfaces.

6. NO REACTION - no discernible affect.

Santi 1997

Figure 4 Influence of the number of slaking cycles on slakedurability (Gamble, 1971)

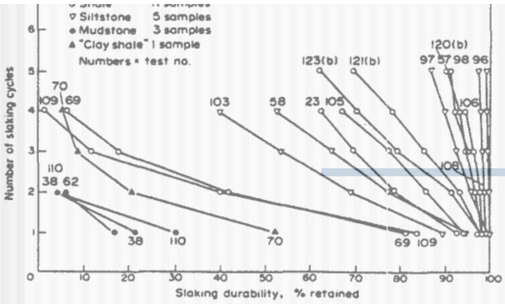


Table 2 Description of the degree of slaking by Franklin and Chandra (1972)

Amount of slaking	Slake-durability index (%)*
Very low	0 – 25
Low	25 – 50
Medium	50 – 75
High	75 – 95
Very High	over 95

Rebound Hardness (R)

To classify surface hardness and estimate the equivalent uniaxial compressive strength of rock indirectly and quickly

- Types of hammer
- Size of samples
- Condition of surfaces before and after test

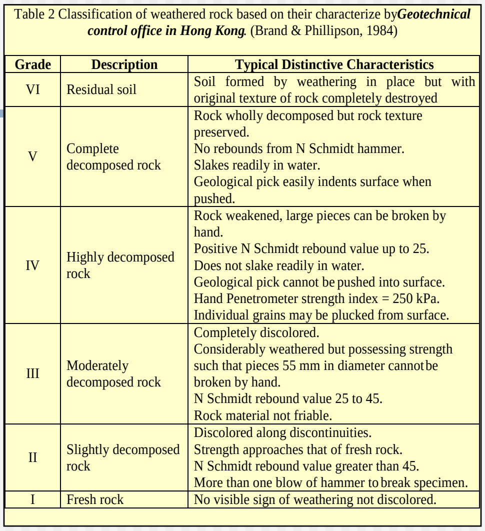
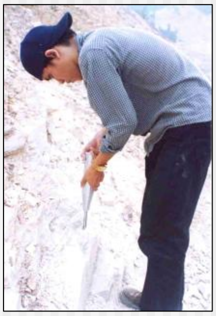


Table 2 Classification of weathered rock based on their characterize by ***Geotechnical control office in Hong Kong***. (Brand & Phillipson, 1984)

Grade	Description	Typical Distinctive Characteristics
VI	Residual soil	Soil formed by weathering in place but with original texture of rock completely destroyed
V	Complete decomposed rock	Rock wholly decomposed but rock texture preserved. No rebounds from N Schmidt hammer. Slakes readily in water. Geological pick easily indents surface when pushed.
IV	Highly decomposed rock	Rock weakened, large pieces can be broken by hand. Positive N Schmidt rebound value up to 25. Does not slake readily in water. Geological pick cannot be pushed into surface. Hand Penetrometer strength index = 250 kPa. Individual grains may be plucked from surface.
III	Moderately decomposed rock	Completely discolored. Considerably weathered but possessing strength such that pieces 55 mm in diameter cannot be broken by hand. N Schmidt rebound value 25 to 45. Rock material not friable.
II	Slightly decomposed rock	Discolored along discontinuities. Strength approaches that of fresh rock. N Schmidt rebound value greater than 45. More than one blow of hammer to break specimen.
I	Fresh rock	No visible sign of weathering not discolored.



Estimation of geomaterials strength base on hardness

Code	Strength (kN/m^2)	Description
	(MN/m^2)	**ROCK & INDURATED MATERIALS**
9	Very weak (0.6-1.25)	Easily broken by hand. Penetrated about 5mm with knife.
10	Weak (1.25-5.0)	Broken by leaning on sample with hammer. No penetration with knife. Scratched with thumbnail.
11	Mod. Weak (5.0-12.5)	Broken in hand with hammer. Scratched with knife.
12	Mod. Strong (12.5-50)	Broken against solid object with hammer.
13	Strong (50-100)	Difficult to break against solid object with hammer.
14	Very strong (100-200)	Requires many blows of hammer to fracture sample.
15	Extra strong (>200)	Sample only be chipped by hammer.

INDIRECT BRAZILIAN TENSILE TEST

To determine uniaxial tensile strength
To find the weakest point of rock specimen due to tensile load

$$\text{Tensile strength, } \sigma t = \frac{0.636\ P}{D \times t} \times 100\%$$

Where;
P = Load at failure (N)
D = Diameter of specimen (mm)
t = Thickness of specimen (mm)

Physical properties

- Water content
- Porosity
- Void index
- Mineralogy
- Texture

END OF LECTURE