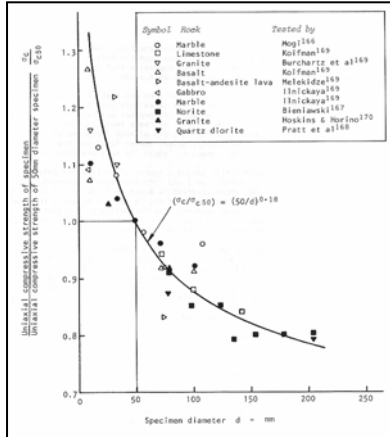
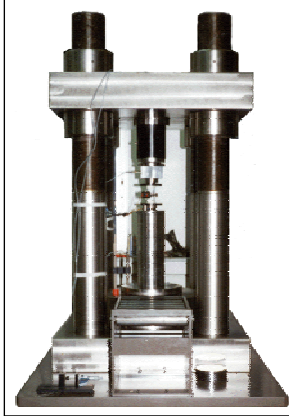




“Intact rock strength”: Uniaxial Compression Test

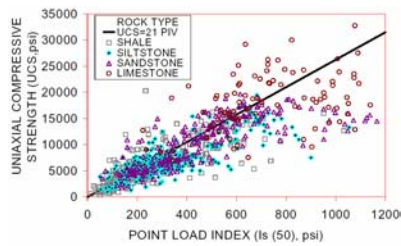
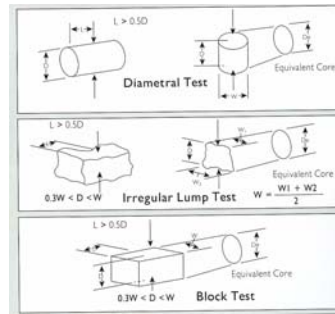
Scale effect:



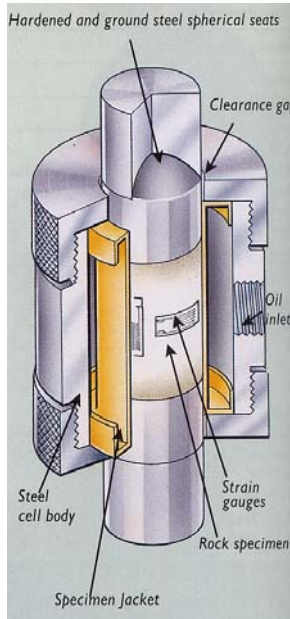
Hoek and Bray (1977) 3

Point Load Test

(Franklin, 1973)

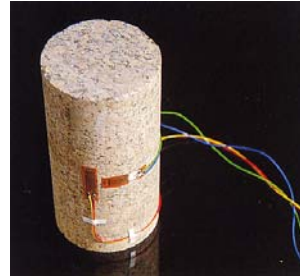


Rusnak J, Mark C., 2002



Triaxial test (Hoek Cell)

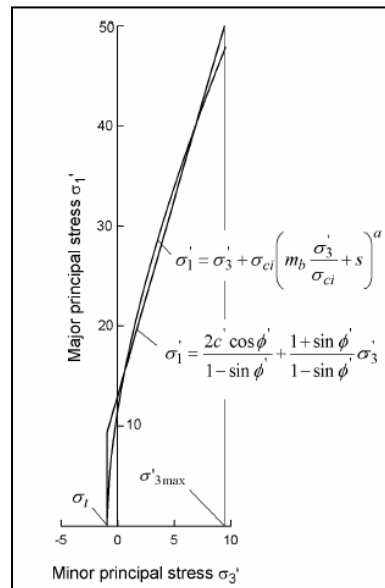
(Hoek and Franklin, 1976)



5

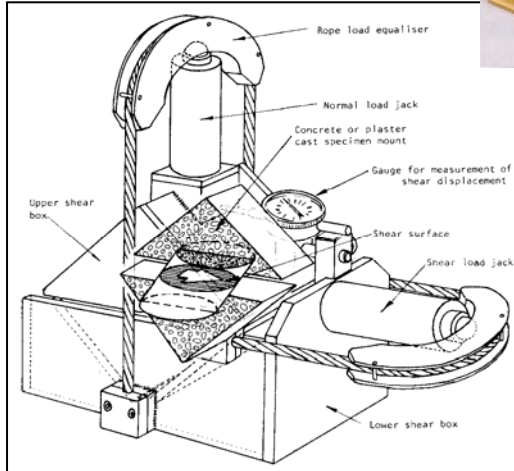
Hoek-Brown strength criterion (1980)

$$\sigma_1' = \sigma_3' + \sigma_{ci}' \left(m_b \frac{\sigma_3'}{\sigma_{ci}'} + s \right)^a$$



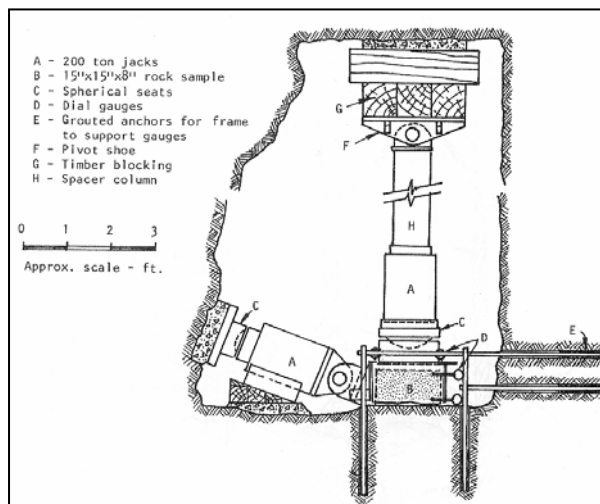
6

Shear strength of rock discontinuities: Hoek field shear box



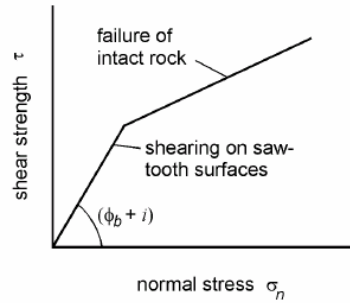
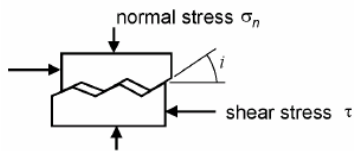
7

“In situ” direct shear test



8

Shear strength of discontinuities in rock

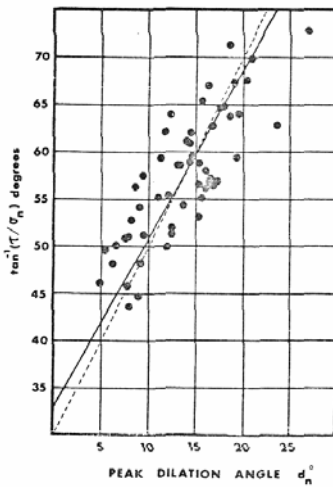


$$\tau = \sigma_n \tan(\phi_b + i)$$

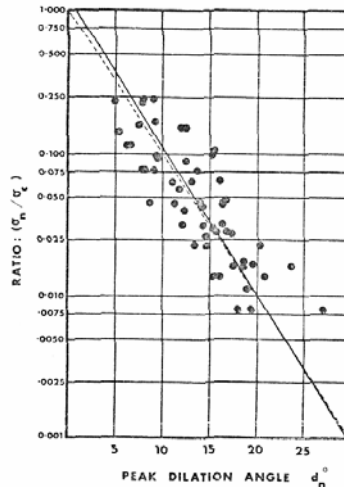
Patton (1966)

“Multiple modes of shear failure..”

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Barton (1973)



σ_c =uniaxial strength

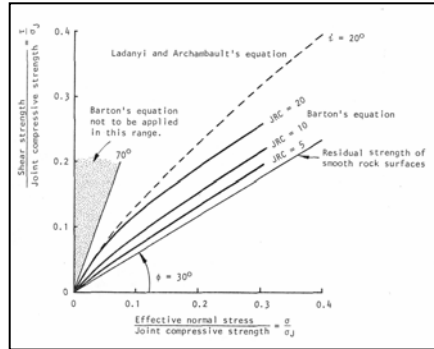
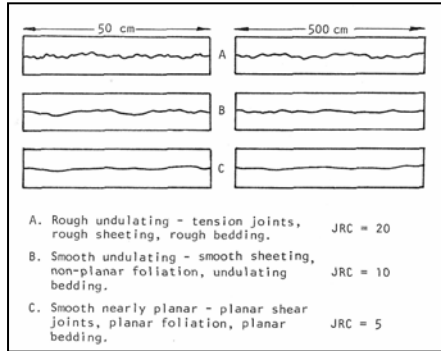
σ_n =normal stress

Barton, N., 1973. Review of a new shear strength criterion for rock joints. Engineering Geology, 7:287-332

10

Barton's shear strength criterion (1973)

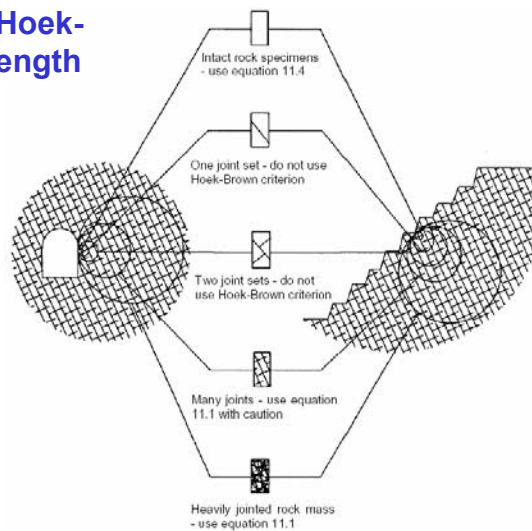
$$\tau = \sigma_n \tan[\phi_b + JRC \log_{10}(\frac{JCS}{\sigma_n})]$$



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Rock mass strength:

empirical Hoek-Brown strength criterion



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Uniaxial Compressive Strength "Hammer Test"

Table 1: Field estimates of uniaxial compressive strength of intact rock.³

Grade*	Term	Uniaxial Comp. Strength (MPa)	Point Load Index (MPa)	Field estimate of strength	Examples
R6	Extremely Strong	> 250	>10	Specimen can only be chipped with a geological hammer	Fresh basalt, chert, diabase, gneiss, granite, quartzite
R5	Very strong	100 - 250	4 - 10	Specimen requires many blows of a geological hammer to fracture it	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, peridotite, rhyolite, tuff
R4	Strong	50 - 100	2 - 4	Specimen requires more than one blow of a geological hammer to fracture it	Limestone, marble, sandstone, schist
R3	Medium strong	25 - 50	1 - 2	Cannot be scraped or pocked with a pocket knife, specimen can be fractured with a single blow from a geological hammer	Concrete, phyllite, schist, siltstone
R2	Weak	5 - 25	**	Can be pocked with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer	Chalk, claystone, potash, marl, siltstone, shale, rocksalt,
R1	Very weak	1 - 5	**	Crumbles under firm blows with point of a geological hammer, can be pocked by a pocket knife	Highly weathered or altered rock, shale
R0	Extremely Weak	0.25 - 1	**	Indented by thumbnail	Stiff fault gouge

* Grade according to Brown (1981).
 ** Point load tests on rocks with a uniaxial compressive strength below 25 MPa are likely to yield highly ambiguous results.

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m_i coefficient (measure of shear strength of the intact rock)

Table 2: Values of the constant m for intact rock, by rock group.⁴ Note that values in parenthesis are estimates. The range of values quoted for each material depends upon the granularity and interlocking of the crystal structure - the higher values being associated with tightly interlocked and more frictional characteristics.

Rock type	Class	Group	Texture			
			Coarse	Medium	Fine	Very fine
SEDIMENTARY	Clastic		Conglomerates	Sandstones	Siltstones	Claystones
				17 ± 4	7 ± 2	4 ± 2
			Breccias		Greywackes (18 ± 3)	Shales (6 ± 2)
	Non-Clastic	Carbonates	Crystalline Limestone (12 ± 3)	Sparitic Limestones (10 ± 2)	Micritic Limestones (9 ± 2)	Dolomites (9 ± 3)
			Evaporites	Gypsum (8 ± 2)	Anhydrite (12 ± 2)	
Organic					Chalk (7 ± 2)	
METAMORPHIC	Non Foliated		Marble (19 ± 3)	Hornfels (19 ± 4)	Quartzites (20 ± 3)	
				Metasandstone (19 ± 3)		
	Slightly foliated		Migmatite (29 ± 3)	Amphibolites (26 ± 6)	Gneiss (28 ± 5)	
	Foliated**			Schists (12 ± 3)	Phyllites (7 ± 3)	Slates (7 ± 4)
IGNEOUS	Plutonic	Light	Granite (32 ± 3)	Diorite (25 ± 5)		
				Granodiorite (29 ± 3)		
	Dark		Gabbro (27 ± 3)	Dolente (16 ± 5)		
			Norite (20 ± 5)			
	Hypabyssal			Porphyries (20 ± 5)	Diabase (15 ± 5)	Peridotite (25 ± 5)
Volcanic	Lava		Rhyolite (25 ± 5)	Dacite (25 ± 3)		
			Andesite (25 ± 5)	Basalt (25 ± 5)		
Pyroclastic			Agglomerate (19 ± 3)	Breccia (19 ± 5)	Tuff (13 ± 5)	

* Conglomerates and breccias may present a wide range of m_i values depending on the nature of the cementing material and the degree of cementation, so they may range from values similar to sandstone, to values used for fine grained sediments (even under 10).

** These values are for intact rock specimens tested normal to bedding or foliation. The value of m_i will be significantly different if failure occurs along a weakness plane.

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“Geological Strength Index (GSI)”

Table 3: Geological strength index for jointed rock masses.

GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS (Hoek and Marinos, 2000)

From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI = 35. Note that this table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the air to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.

STRUCTURE	SURFACE CONDITIONS				
	VERY GOOD Very fresh, fresh unweathered surface	GOOD Fresh, slightly weathered, firm altered surface	FAIR Rough, slightly weathered, firm altered surface	POOR Smooth, moderately weathered and altered surface	VERY POOR Completely, highly weathered surface with compact coating or flake of angular fragments
	DECREASING SURFACE QUALITY →				
INTACT OR MASSIVE - Intact rock specimens or massive in situ rock with few widely spaced discontinuities	100				N/A
BLOCKY - well interlocked undisturbed rock mass consisting of subcubic blocks formed by three intersecting discontinuity sets	80	70			
VERY BLOCKY - interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets		60			
BLOCKY DISTURBED - Blocky with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity			40		
DISINTEGRATED - poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces				20	
LAMINATED/SHEARED - Lack of blockiness due to close spacing of weak schistosity or shear planes	N/A	N/A			10
	← DECREASING INTERLOCKING OF ROCK PIECES				

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“Generalized Hoek-Brown strength criterion for rock masses (1995)”

$$\sigma_1' = \sigma_3' + \sigma_{ci}' \left(m_b \frac{\sigma_3'}{\sigma_{ci}'} + s \right)^a$$

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right)$$

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right)$$

$$a = \frac{1}{2} + \frac{1}{6} \left(e^{-GSI/15} - e^{-20/3} \right)$$

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“Rocklab” (download from www.rockscience.com)

