Engineering Geology CE1301

Lecture #6 Engineering Properties of Rocks

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Rocks properties

From engineering point of view, rocks are significant for two major reasons:

- Many engineering structures are founded on rock;
- They are an important building material with numerous applications.

The **physical properties** of rocks determine their mechanical behaviour. Physical properties are commonly determined by:

* Testing small laboratory samples to determine "rock properties"

* Testing intact rocks in the field to obtain "rock mass properties'. These properties are controlled by weakness planes in the rock rather than by the properties of the intact material .

Rock	**Stone**
Refers to geological formation in its natural location as a part of the bedrock mass.	Refers to blocks or fragments excavated from quarry ledges that have been prepared for construction use.

1- Specific gravity, Mass density, Absorption

Specific gravity, Gs:

$$G_s = \frac{\text{Mass of solid in Air}}{\text{Mass of solid in Air} - \text{Mass of solid in Air}}$$

if A= mass of solid in air, dried for 24 hrs in an oven;
B=mass of solid in air, saturated surface dried;
C=mass of solid in water, saturated, then:

Bulk Gs=A/(B-C);

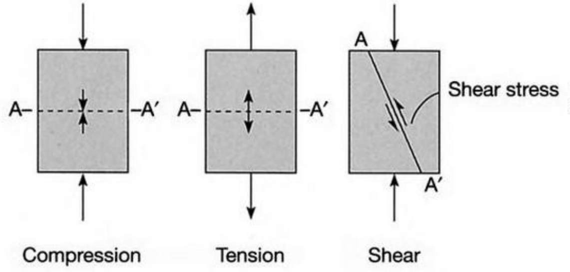
Bulk Gs, saturated surface dried=B/(B-C);

Apparent Gs=A/(A-C)

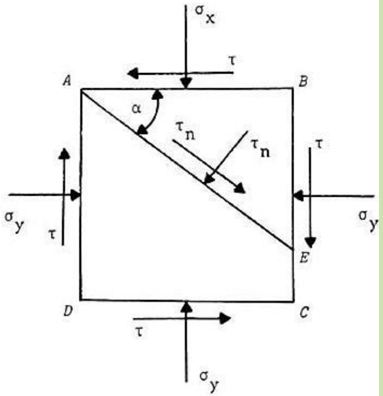
The density can be calculated as=Gs* the density of water.

%absorption=(B-A)/A *100

2- Rock strength



Only normal stresses



Normal and shear stresses

- The compressive strength: is the compressive stress required to break the specimen, calculated for the unconfined case as:

$$\sigma = \frac{F}{A}$$

where F is the maximum applied axial load and A is the cross section area of the specimen.

- The tensile strength of rock are considerably less than their compressive strength (10% or even less). Tensile strength governs behaviour when a rock is under bending stresses.

ROCKS PROPERTIES

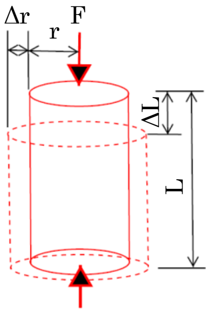
3- Elasticity of rocks

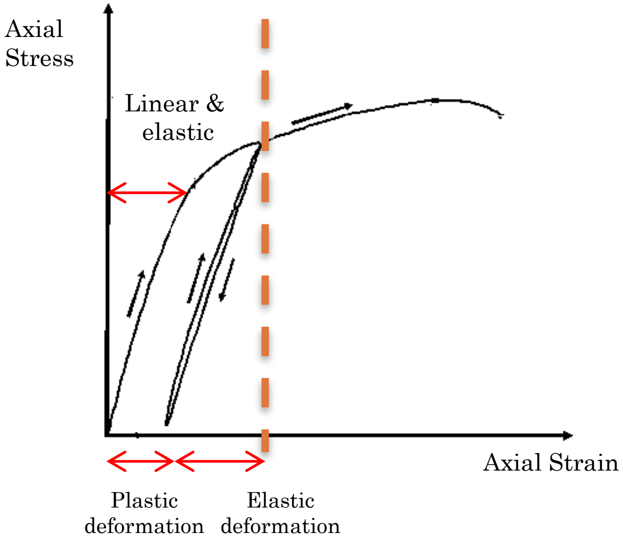
Material deforms under loading. When the load is removed, some of the deformation is recovered (elastic deformation). The unrecoverable amount is termed (plastic deformation).

- Commonly, the elastic deformation of rock is directly proportional to the applied stress:

$$E = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{\Delta L/L}$$

where L is the original length, ΔL is axial deformation and E is the elastic modulus (Young's modulus).

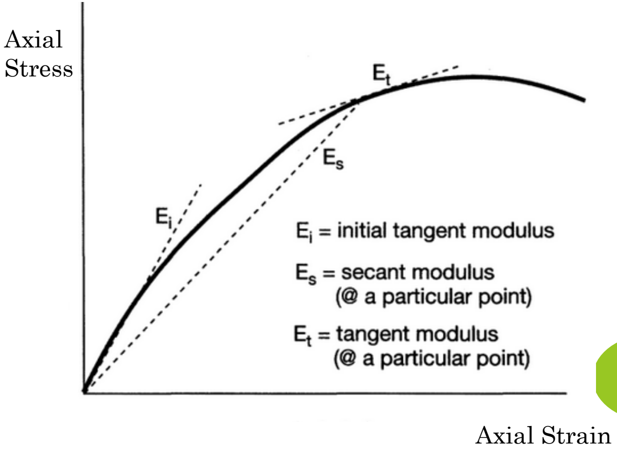




- Rocks as a natural material show different properties for different directions (anisotropic). This is specially true for those rocks with bedding or foliation.
- The E value is lower when a rock is loaded perpendicular to the bedding or foliation than that when the rock is loaded parallel to those directional features.
- During axial compression, some lateral deformation happens that expressed as a ratio of the axial deformation:

$$\nu = \frac{\text{Lateral strain}}{\text{Axial strain}} = \frac{\Delta B/B}{\Delta L/L} \text{ or } \nu = \frac{\Delta r/r}{\Delta L/L}$$

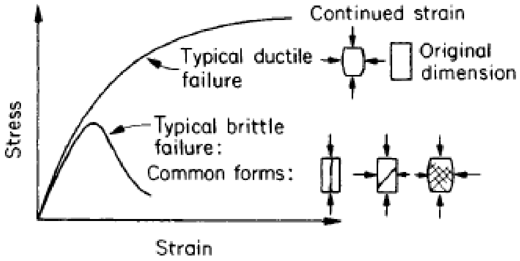
where B is the lateral dimension, r is the radius and ν is the Poisson's ratio ranging for most rocks between 0.10 and 0.5.



General material behaviour

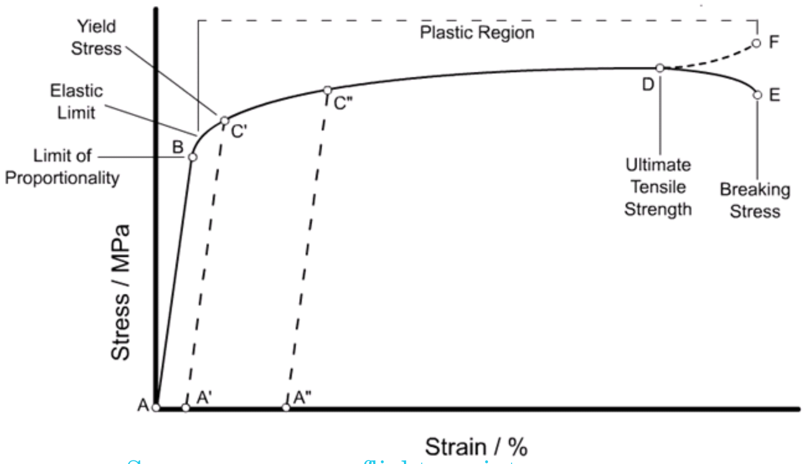
Brittle materials

Such as rocks, cast iron, and glass. Rupture occurs in these materials without any clear previous change in the rate of elongation.



Ductile materials

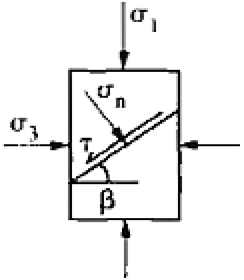
Such as reinforcing steel and many alloys of other metals. They have the ability to yield at normal temperatures.



Source: www.spaceflight.esa.int

Failure criteria in rocks

❖ ***The Mohr-Coulomb Criterion:*** Rock fails at a critical combination of normal and shear stresses:



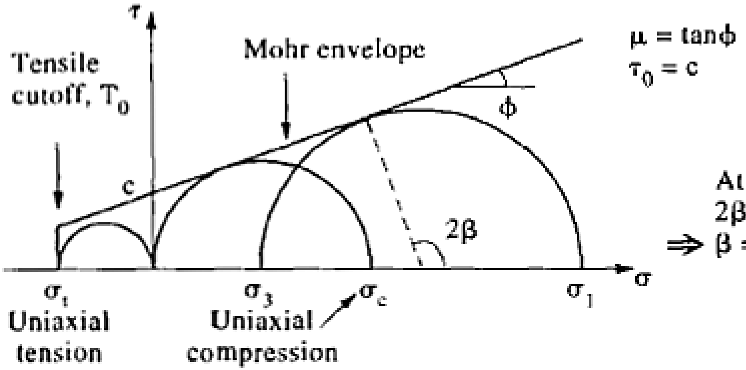
$$|\tau| = \tau_0 + \mu\sigma_n$$

τ_0 = cohesion μ = coeff. of friction

$$|\tau| = \tfrac{1}{2}(\sigma_1 - \sigma_3)\sin 2\beta$$

$$\sigma_n = \tfrac{1}{2}(\sigma_1 + \sigma_3) + \tfrac{1}{2}(\sigma_1 - \sigma_3)\cos 2\beta$$

The equation for $|\tau|$ and σ_n are the equations of a circle in (σ, τ) space:



At failure,
$2\beta = 90 + \phi$
$\Rightarrow \beta = 45 + \frac{\phi}{2}$

See engineering rock mechanics book, Section 6.5

Engineering classification of intact rocks

1- Based on compressive strength

- The following classification is proposed by Deere and Miller (1966) based on the uniaxial compressive strength and the modulus of elasticity;
- Intact rock is that which can be tested in the laboratory and is free of large scale weakness planes such as joining, bedding and shear planes;
- The modulus of elasticity is the tangent modulus at one-half the ultimate strength (one-half of the ultimate strength is commonly assumed as the allowable strength);
- Rock is subdivided in to five categories as shown the following table

Table 6.2 Ref# , Engineering classification of intact rock based on ultimate strength (Deere and Miller, 1966)

		Uniaxial Compressive Strength	
Class	Level of Strength	psi	kPA
A	Very high	32,000	220,000
B	High	16,000–32,000	110,000–222,000
C	Medium	8,000–16,000	55,000–110,000
D	Low	4,000–8,000	27,500–55,000
E	Very low	4,000	27,500

Class	Typical Rocks
A	Quartzite, diabase, and dense basalt
B	Most igneous rocks, some metamorphic rocks, most limestones, and dolomite, well-cemented, sandstones and shales
C	Most shales, porous sandstones, and limestones
D	Friable sandstones, porous tuff
E	Clay-shale, rock salt

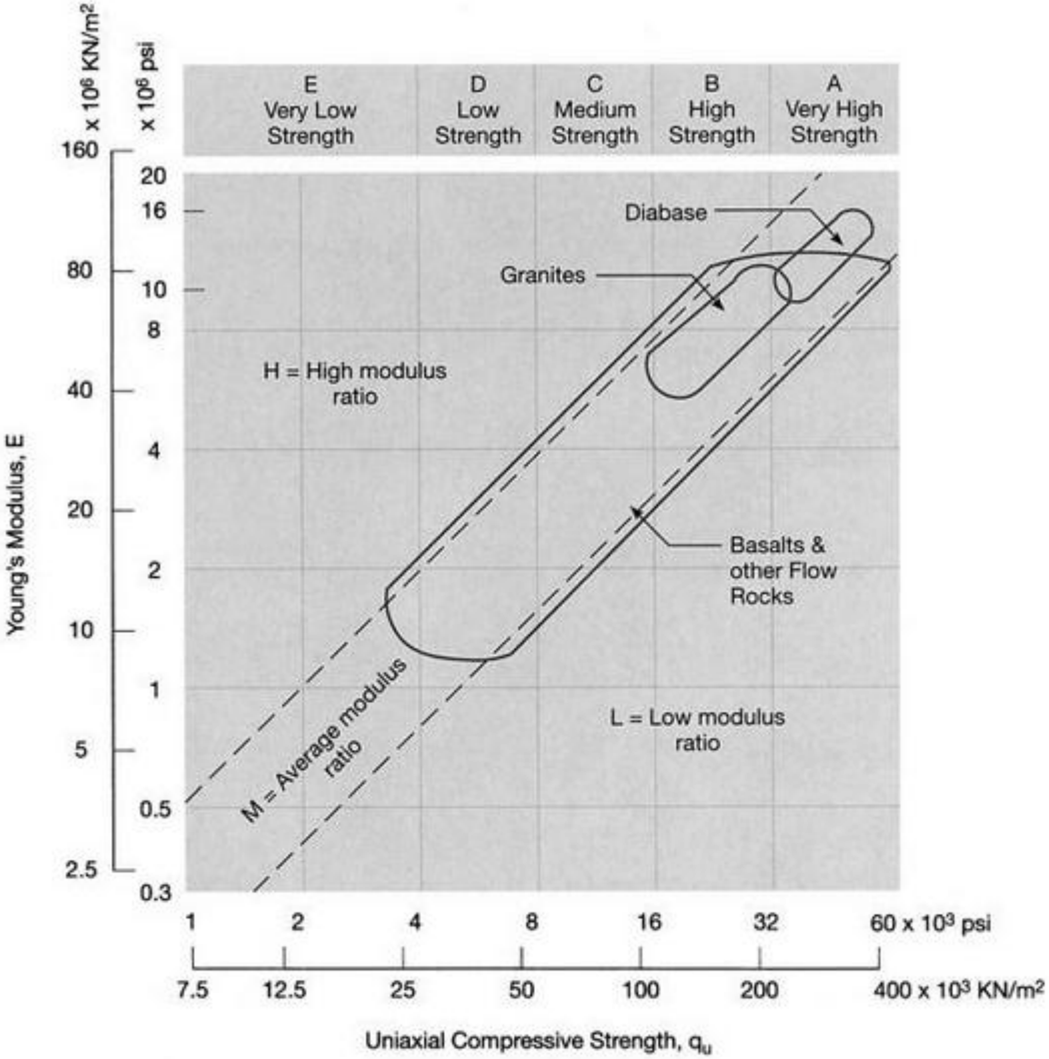
Engineering classification of intact rocks

2- Based on modulus ratio of (E/unconfined compressive strength)

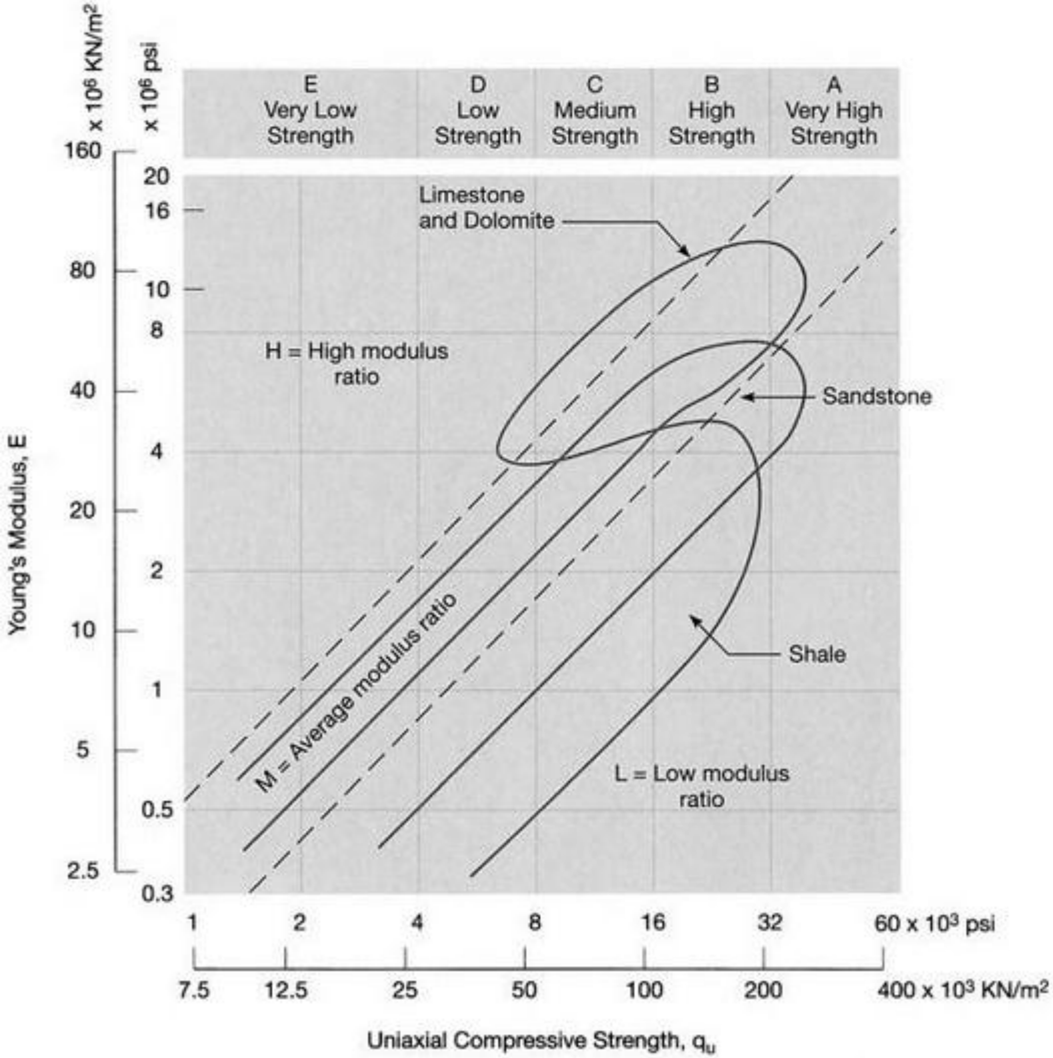
Table 6.3 Ref# , (Deere and Miller, 1966)

Class	Level of Modulus Ratio	Modulus Ratio Value
H	High	500
M	Average or medium	200–500
L	Low	200

Summary plot: Engineering classification of intact rocks- **Igneous rocks**, see Geology Applied to Engineering book.



Summary plot: Engineering classification of intact rocks-**Sedimentary rocks**, see Geology Applied to Engineering book.



Summary plot: Engineering classification of intact rocks- **Metamorphic rocks**, see Geology Applied to Engineering book.

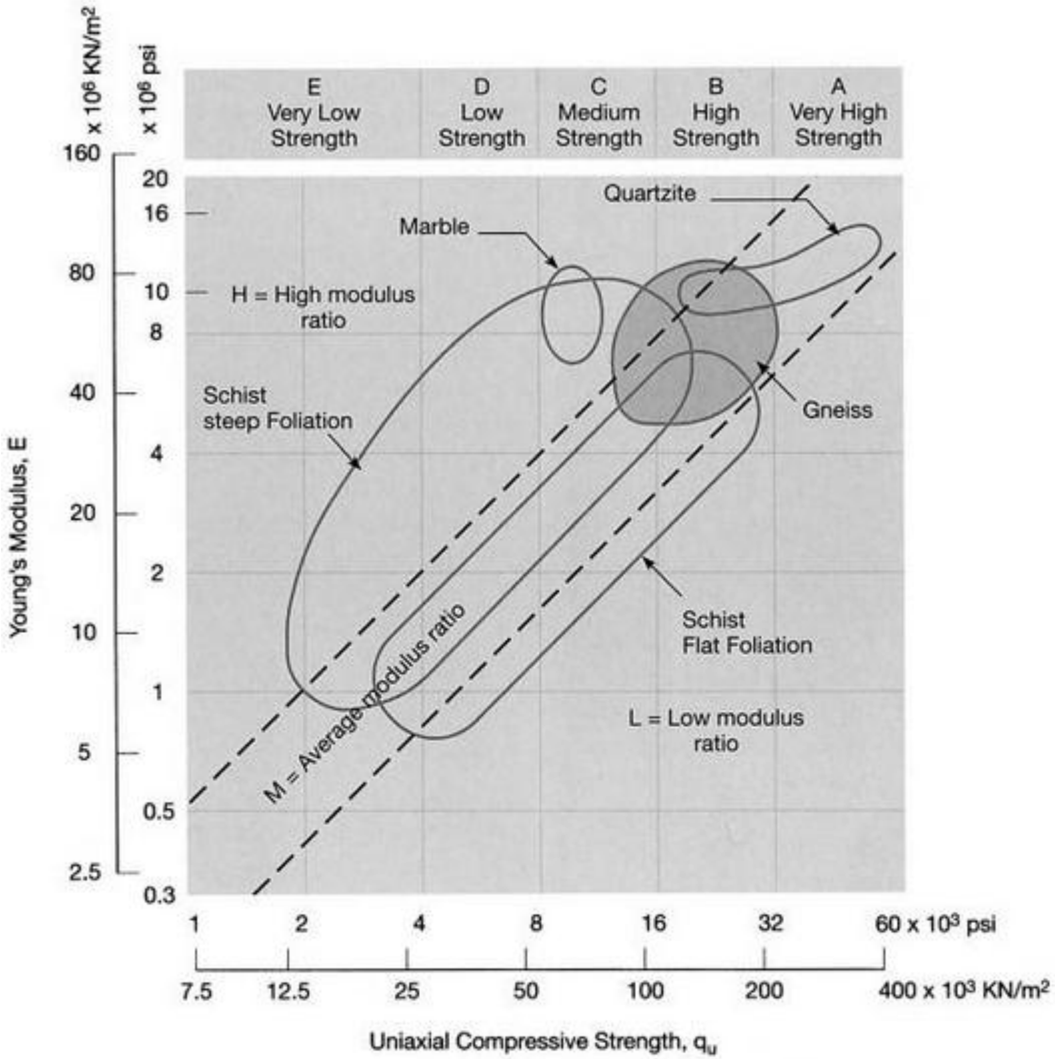


Table 6.1 in Geology Applied to Engineering book. Physical properties of rocks

Rock	Compressive Strength (psi) q_u	Shear Strength (psi) S_0	Tensile Strength (psi) T	Modulus of Elasticity × 10^6 psi E	Angle of Shearing Resistance ϕ	Poisson's Ratio μ	Unit Weight (pcf) γ	Porosity n%
Igneous								
Granite	13,900–34,720	1950–6940	970–3470	2.77–8.3	45–60	0.15–0.24	162–175	0.5–1.5
Coarse	7630–10,460	1500–2000			48–56			
Pegmatitic	6190	1040			58			
Fine	31,900	2700			70			
Slightly altered	9460	1420			58			
Syenite				8.33–11.1			162–170	0.5–1.5
Quartz monzonite	30,500	3650			63	0.17		
Monzonite porphyry	18,100	2390			59			
Diorite	25,000–41,700	2010	2080–4170	9.31–13.9	54		168–175	0.1–0.5
Diabase (dolerite)	27,800–48,600	3470–8330	2080–4860	11.1–15.3	55–60		168–190	0.1–0.5
Gabbro	25,000–41,700		2080–4170	9.31–15.3			175–193	0.1–0.2
Basalt	20,800–41,700	2780–8330	1390–4170	8.33–13.9	50–55		175–181	0.1–1.0
Andesite	18,700–19,100						137–144	10–15
Tuff	530					0.11		
Metamorphic								
Gneiss	7000–27,800		700–2800	2.7–8.3	48–73	0.11	175–187	0.5–1.5
Massive granite gneiss	32,390	4500			66			
Granite gneiss	7630–12,000	1500–1800			48–56			
Schistose	12,000	1800			73			
Weathered schistose	7700–13,400	1800–2200			59			
Quartzite	20,830–41,660	2780–8330	1390–4170	5.7–8.3	50–60		162–168	0.1–0.5
Marble	7150–34,720	2080–4170	970–2800		35–50	0.25–0.38	162–168	0.5–2.0
Slate	12,110–34,720		970–2800				162–168	0.5–2.0
Schist	1160–17,000			0.6–2.8		0.08–0.20		
Biotite	7750–12,000							
Biotite-chlorite	5300–17,000							
Sedimentary								
Sandstone	2780–23,600	1100–5560	560–3470	0.69–11.1	35–50	0.17	120–161	0.5–26
Graywacke	7900	1700			47			
Shale, general	1390–13,900	417–4170		1.4–4.9	15–30			
Clayshale	180–1040	40–160						
Siltstone	4120–7290	750–1000			57–64			
Mudstone				2.8–6.9				
Coal	700–7000		280–700	1.4–2.8				
Limestone	4170–34,700	1100–6940	700–3470	1.4–11	35–50	0.16–0.23	137–162	5–20
Chalk	750	60			23			
Dolomite	11,100–34,700		2080–3470	5.5–11.6	50–65		156–162	1–5

Note: Compressive strength, English units, 1 psi = 6.895 kN/m^2 or 6.895 kPa in SI units 1 megapascal = 10^6 Pa = 10^3 kPa = 145 psi.
Unit weight, 1 pcf = 16.02 kg/m^3 density.

Los Angeles Abrasion test

The test designed to aggregate resistance to crushing, degradation and disintegration.

Testing material for engineering use

- **Strength** and **durability** are the most important aspects to be investigated to decide the suitability of a given rock as a construction material.
- Durability: generally, refers to the ability to resist wear, pressure, or damage.
- Strength of construction material is normally evaluated by conducting abrasion test rather than conducting compression test.
- Durability test is performed by using the sulfate soundness test and freezing and thawing test.

Source: www.globalgilson.com

The concept

A coarse aggregate sample retained on the No. 12 (1.70 mm) sieve is placed in a rotating drum with steel balls. As the drum rotates the aggregate degrades by abrasion due to the rotation and the contact with the other aggregates and the steel balls. The drum is rotated for certain number of cycles. Then, the aggregate is removed from the drum and sieved again on the No. 12 (1.70 mm) sieve. Percentage of the finer aggregate indicates the abrasion level.

Lower loss values means more resistant to abrasion and higher toughness aggregate.

$$loss = \frac{Mass_{original} - Mass_{final}}{Mass_{original}} \times 100$$

Aggregate mineralogy	Typical Los Angeles Abrasion loss values %
Basalt	10-20
Dolomite	15-30
Gneiss	30-60
Granite	25-50
Lomestone	20-30
Quartzite	20-35

Source:
http://www.pavementinteractive.org/article/los-angeles-abrasion/

<u>Sulfate soundness by use of sodium sulfate or magnesium sulfate :</u>

Used to describe the ability of an aggregate (both coarse and fine) to withstand the effects of freezing and thawing.

Test concept:

- ❖ The sulfate is used to subject an aggregate sample to the effects of salt crystallisation inside the pores, which simulate ice crystal formation during freezing.
- ❖ The test is performed by exposing an aggregate sample to repeated immersions in the sulfate solution and later oven drying it to simulate the thawing process.
- ❖ One immersion and drying is considered a soundness cycle.
- ❖ Typically, five cycles are specified by agencies.
- ❖ Sample is then washed to remove the salt and then dried and sieved on specific set of sieves.
- ❖ The loss in weight for each specific sieve size is calculated and a weighted average percent loss for the whole sample is obtained.
- ❖ Low values of soundness loss are necessary to ensure that an aggregate is not likely to weathering by freezing and thawing.

Source: www.pavementinteractive.org