ENGINEERING & HYDROGEOLOGIC CHARACTERISTICS OF ROCKS (03)

I Main Topics
- A Engineering & hydrogeologic characteristics of rocks
- B Engineering uses of rocks: *Recognition of potential uses*

II Engineering & hydrogeologic characteristics of rocks: general trends
- A "Hard" rocks generally have higher unconfined compressive strengths and higher Young's moduli (E) than "soft" rocks.
- B Compressive strength generally less than tensile strength
- C Poisson's ratio (ν; $\nu \approx 0.25$)
  1. Effect of Poisson's ratio for 1-D strain (for isotropic materials)
     - a $\varepsilon_y = -\nu \varepsilon_x$; $\varepsilon_z = -\nu \varepsilon_x$: $\varepsilon_y = \varepsilon_z$.
     - b $\nu > 0$: shortening in x-direction $\Rightarrow$ lengthening in y and z
     - c $\nu < 0$: shortening in x-direction $\Rightarrow$ shortening in y and z
  2. Effect of Poisson's ratio for 3-D strain (for isotropic materials)
     - a $e = \Delta V/V_o = (V_1-V_o)/V_o \approx \varepsilon_x + \varepsilon_y + \varepsilon_z = \varepsilon_x (1-2\nu)$
     - b $\nu < 0.5$: shortening in x-direction $\Rightarrow$ volume decrease
     - c $\nu = 0.5$: shortening in x-direction $\Rightarrow$ no volume change
     - d $\nu > 0.5$: shortening in x-direction $\Rightarrow$ volume increase
- D Chemical stability of rocks depends on chemical environment
- E Hydraulic conductivity (K) of continuous porous media
  1. $K_{\text{hard rocks}} > K_{\text{soft rocks}}$
  2. $K_{\text{fractured rocks}} > K_{\text{unfractured rocks}}$
- F Shape of rock bodies relevant to isotropy and continuity of rock
- G Wide range in properties requires site-specific characterization

III Engineering uses of rocks
- A Building stone
  1. Granite (Good if fractures are not closely spaced)
  2. Slate (Very durable, high tensile strength, difficult to work)
  3. Sandstone (Durability depends on porosity and cement)
  4. Marble (e.g. Washington Monument)

B Crushed stone (for road fill, dams, riprap; $3 B in 1973)
  1 Limestone! (Needs to be pure; location & hardness keys)
  2 Basalt
  3 Granite
C Sand & gravel
  1 Greatest extracted tonnage of any resource
  2 Expensive to transport; needs to be available locally
D Concrete Aggregate
  1 Material should be clean, *poorly* sorted, strong, and stable
  1 Good rocks: granite, clean sandstone
  2 Reactive (bad) rocks: chert, opal, rhyolite, andesite, phyllite, shale, tuff, siliceous limestone, sulfide-bearing rocks
E Lime (CaO), Cement, and plaster
  1 *Slightly* impure limestone
  2 Coral
  3 Gypsum
F Clay and sand (ceramics, glass, & abrasives)
  1 Kaolinite clay for china, paper, paint, plastic, etc.
  2 Bentonite (Na-rich montmorillonite) for drilling mud and sealer; from devitrified volcanic ash
  3 Clays for bricks (e.g. kaolinite, gibbsite)
  4 Sand - needs to be 93%+ pure to avoid reactions and discoloration
    a Foundry molds
    b Glass
    c Abrasives

Crystalline Rocks ("Hard" rocks)											
	Mineral Composition	confined Stren mpressive/Tens (MPa)	Young's Modulus (GPa)	Poisson's ratio	Chemical Stability	Grain size	Discont.	Nature of Permeability	Hydraulic Conductivity m/sec	Porosity	Shape
Plutonic Rocks								No frax Fracture	<1E-13 - 2E-10 6E-9 -- 2E-4		
Granite	Silicate	00-900/15-3	16-86	(0.28)-0.30	Stable	mm-cm	Fractures	Fractures and pores		<0.01-0.05	Spheroidal or sheets
Gabbro	Silicate	30-300/15-3	85-119	0.33	Stable	mm-cm	Fractures	Fractures and pores		<0.01-0.05	Spheroidal or sheets
Diorite	Silicate	00-800/15-3	55-107	0.22-0.30	Stable	mm-cm	Fractures	Fractures and pores		<0.01-0.05	Spheroidal or sheets
Volcanic Rocks											
Basalts	Silicate	50-300/10-3	18-78	0.09-0.35	Stable	mm	Fractures Beds	Fractures and pores	3E-9 -- 3E-5	~0.10	Tongues/sheets
Andesite	Silicate	???	65	0.18	Stable	mm	Fractures Beds	Fractures and pores	3E-9 -- 3E-5	~0.10	Tongues/sheets
Welded Tuffs	Ash (Silicate glass)	???	???	???	"Stable"	µm-dm	Fractures Beds	Fractures	3E-9 -- 3E-5	0.10-0.80	Tongues/sheets
Unwelded Tuffs	Ash (Silicate glass)	???	???	???	"Stable"	µm-dm	Beds Fractures	Fractures and pores			Sheets
Metamorphic rocks								No frax Fracture	<1E-13 - 2E-1 6E-9 -- 2E-4	Similar to plutonic rx	
Slate	Silicate	100-200/7-20	88	?	Stable	µm	Foliation Fractures	Fractures			Sheets
Schists	Silicate	25-162/?	14-98	?	Stable	mm-cm	Foliation Fractures	Fractures			Sheets
Gneisses	Silicate	50-230/5-20	37-103	0.06-0.29	Stable	mm-cm	Foliation Fractures	Fractures			Spheroidal or sheets
Quartzite	Silicate	50-629/10-3	1-171	0.10-0.20	Stable	mm	Fractures	Fractures			Sheets
Marble	Carbonate	55-274/7-20	48-89	0.17-0.30	Soluble	mm	Fractures	Fractures and pores			Sheets

Sources: Costa and Baker, 1981, p. 120, p.320; Carmichael, 1989, p. 689-707; Freeze and Cherry, 1979, p. 29.

Sedimentary Rocks ("Soft" rocks)

	Mineral Composition	confined Stren mpressive/Tens (MPa)	Young's Modulus (MPa)	Poisson's ratio	Chemical Stability	Grain size	Discont.	Nature of Permeability	Hydraulic Conductivity	Porosity	Shape
Shale*	Clay	2-216/2-10	0.4-68	(0.43)-0.34	Stable	µm	Beds Fractures	Fractures and pores	<1E-13 - 8E-10		Sheets
Siltstone*	Silica	3-256/??	0.1-26	0.05-0.35	Stable	µm	Beds Fractures	Fractures and pores			Sheets
Sandstone*	Varies	3-256/4-25	0.4-69	(0.51)-0.36	Depends on cement	mm	Beds Fractures	Fractures and pores	E-10 -- 3E-6	0.05-0.30	Tongues/sheets
Conglom.*	Varies	epends on ceme	??	??	Depends on cement	mm-cm	Beds	Fractures and pores	E-10? -- 3E-5	0.05-0.30	Tongues/sheets
Breccia*	Varies	epends on ceme	??	??	Depends on cement	mm-cm	Beds	Fractures and pores			Tongues/sheets
Limestone†*	CaCO3	6-245/5-25	2.9-97	(0.13)-0.64	Soluble	µm-mm	Beds Fractures	Fractures and pores	3E-10 -- E-2	0.01-0.10	Sheets
Dolomite	CaMg (CO3)2	44-322	12.7-95	(0.09)-0.51	Stable	µm-mm	Beds Fractures	Fractures and pores	6E-10 -- 3E-6		Sheets
Evaporite†*	laCl, KCl, CaSO3	-31 (salts flo	3.0-35	0.03-0.19	Soluble	µm-cm	Beds	Fractures and pores	††		Sheets

Sources: Costa and Baker, 1981, p. 120, p.320; Carmichael, 1989, p. 689-707; Freeze and Cherry, 1979, p. 29.

† Sedimentary crystalline rock

†† Hydraulic conductivities may be off scale at both ends for evaporites

*Note: The strength and permeability depend heavily on the degree of cementationand the orientation of bedding or foliation