

*Some Useful Numbers on the Engineering Properties of Materials (Geologic and Otherwise)*  
GEOL 615

Coefficient of sliding friction ( $\mu$ )

For most rocks,  $\mu$  varies between 0.8 and 0.5. A value of 0.60 would be a good number for general use.

Glass on glass	0.4
Rubber on concrete	0.75
Steel on steel	0.55

Angle of internal friction ( $\phi$ )

Rock	30°
Sand	30-40°
Gravel	35°
Silt	34°
Clay	20°
Loose sand	30-35°
Medium sand	40°
Dense sand	35-45°
Gravel with some sand	34-48°
Silt	26-35°

Because the angle of internal friction,  $\phi$ , is typically around 25-35°, the coefficient of internal friction ( $\tan\phi$ ) is 0.5 to 0.7

Cohesive strength ( $\tau_0$ )

Rock	10,000 kPa
Silt	75 kPa
Clay	10-20 kPa
Very soft clay	0- 48 kPa
Soft clay	48-96 kPa
Medium clay	96-192 kPa
Stiff clay	192-384 kPa
Very stiff clay	384-766 kPa
Hard clay	>766 kPa

Density ( $\rho$ )

Sandy soil	1800 kg/m <sup>3</sup>
Gravel soil	2000 kg/m <sup>3</sup>
Silty soil	2100 kg/m <sup>3</sup>
Clay soil	1900 kg/m <sup>3</sup>
Mafic igneous rocks	3000 kg/m <sup>3</sup>
Felsic igneous rocks	2700 kg/m <sup>3</sup>
Metamorphic rocks	2700 kg/m <sup>3</sup>
Sedimentary rocks	2600 kg/m <sup>3</sup>
Granite	2700 kg/m <sup>3</sup>
Shale	2500 kg/m <sup>3</sup>

Limestone	2700 kg/m <sup>3</sup>
Chalk	2100 kg/m <sup>3</sup>
Sandstone	2000 kg/m <sup>3</sup>
Steel	8000 kg/m <sup>3</sup>
Concrete	1680-3000 kg/m <sup>3</sup>
Water	1000 kg/m <sup>3</sup>

Unit weight ( $\gamma$ ) (recall that  $\gamma = \rho g$ )

“Rock”	26.5 kN/m <sup>3</sup>
Gravel soil	19 kN/m <sup>3</sup>
Sandy soil	16 kN/m <sup>3</sup>
Silty soil	20 kN/m <sup>3</sup>
Clay soil	18 kN/m <sup>3</sup>
Water	9.8 kN/m <sup>3</sup>
Concrete	23 kN/m <sup>3</sup>
Steel	78 kN/m <sup>3</sup>

Porosity

Gravel	30-40%	
Sand	20-35 %	
Silt	35-50 %	
Clay	33-60 %	
Sand and gravel, mixed	20-35 %	
Glacial till	10-20 %	
Sandstone	5-30%	
Limestone	5-30%	
Shale	10-30 %	
Fractured igneous rock	10-40%	
Granite	0.5-1.5 %	----- (Unfractured) -----
Diabase	0.1-0.5 %	
Gabbro	0.1-0.2 %	
Basalt	0.1-1.0 %	
Gneiss	0.5-1.5 %	
Marble	0.5-2 %	
Slate	0.1-0.5 %	
Quartzite	0.1-0.5 %	

Permeability

Well-sorted gravel	10 <sup>-2</sup> to 1 cm/sec
Well-sorted sands, glacial outwash	10 <sup>-3</sup> to 10 <sup>-1</sup> cm/sec
Silty sands, fine sands	10 <sup>-5</sup> to 10 <sup>-3</sup> cm/sec
Silt, sandy silts, clayey sands, till	10 <sup>-6</sup> to 10 <sup>-4</sup> cm/sec
Clay	10 <sup>-9</sup> to 10 <sup>-6</sup> cm/sec

Soil Sensitivity

Insensitive clays	<1
Low sensitive clays	1-2
Medium sensitive clays	2-4
Sensitive clays	4-8
Extra sensitive clays	8-16
Quick clay	>16

Compressibility ( $C_c$ )

Soft clay	>0.3
Clay	0.3-0.15
Silty clay	0.15-0.075
Sandy clay	<0.075

Poisson's ratio ( $\nu$ )

Sandy Soil	0.25-0.4
Gravel soil	0.15-0.35
Granite	0.1-0.3
Sandstone	0.21-0.38
Shale	0.2-0.4
Limestone	0.18-0.33
Chalk	0.35
Marble	0.06-0.22
Steel	0.3

Young's Modulus (E)

Clay soil	10-200 MPa (soft to stiff)
Sandy soil	10-50 MPa (loose to compact)
Gravel soil	70-170 MPa (loose to compact)
Soft clay	1-3 MPa
Hard clay	6-14 MPa
Loose sand	10-28 MPa
Dense sand	35-69 MPa
Granite	10-70 GPa
Sandstone	1-20 GPa
Shale	1-70 GPa
Limestone	15-55 GPa
Marble	50-70 GPa
Steel	200 GPa
Glass	45 GPa
Wood	6,000-15,000 MPa

Bulk modulus (K)

Granite	50 GPa
Shale	10 GPa
Limestone	65 GPa
Chalk	9 GPa
Sandstone	0.7 GPa

Modulus of rigidity ( $\mu$ )

Granite	24 GPa
Shale	1.6 GPa
Limestone	24 GPa
Chalk	3.2 GPa
Sandstone	0.4 GPa
Steel	80 GPa
Wood	4 GPa
Glass	19 GPa

Lithostatic pressure gradient

26.46 MPa/km (for  $\rho = 2.70$ )

Hydrostatic pressure gradient

9.8 MPa/km

Unconfined compressive strength

Granite	100-250 MPa
Basalt	100-300 MPa
Quartzite	150-300 MPa
Sandstone	20-170 MPa
Shale	5-100 MPa
Limestone	30-250 MPa
Marble	35-60 MPa
Slate	100-200 MPa
Quartzite	150-300 MPa
Concrete	14-42 MPa
High strength concrete	70 MPa
Steel	250 MPa
Wood	5 MPa

Field test for compressive strength of soils and rocks

<b>Term</b>	<b>Diagnostic features</b>	<b>Undrained compressive strength</b>
Very soft soil	Exudes between fingers when squeezed	<25 kPa
Soft soil	Easily indented by fingers	25-50 kPa
Firm soil	Indented only by strong finger pressure	50-100 kPa
Stiff soil	Indented by thumb pressure	100-200 kPa
Very stiff soil	Indented by thumb nail	200-400 kPa
Hard soil	Difficult to indent by thumbnail	400-1000 kPa
Very strong rock	Very hard rock, requires repeated hammer blows	>100 MPa
Strong rock	Hand specimen can be broken with single blow	50-100 MPa
Mod. strong rock	5 mm indentations with hammer pick end	12.5-50 MPa
Mod. weak rock	Too hard to cut by hand	5-12.5 MPa
Weak rock	Crumbles with blows of pick end of hammer	1.25-5 MPa

Shear strength

Granite	14-50 MPa
Diabase	25-60 MPa
Basalt	20-60 MPa
Slate	15-30 MPa
Quartzite	20-60 MPa
Sandstone	8-40 MPa
Shale	3-30 MPa
Limestone	10-50 MPa
Gravel	200-600 kPa
Sand	100-300 kPa
Very soft clay	0-25 kPa
Soft clay	25-50 kPa
Medium clay	50-100 kPa
Stiff clay	100-200 kPa
Very Stiff clay	200-400 kPa
Hard clay	>400 kPa
Wood	10 MPa
Concrete	2 MPa
Steel	230 MPa

Tensile strength

Granite	7-25 MPa
Basalt	10-30 MPa
Gneiss	5-20 MPa
Quartzite	10-30 MPa
Sandstone	4-25 MPa
Shale	2-10 MPa
Limestone	5-25 MPa
Marble	15 MPa
Steel	400 MPa
High strength steel	750 MPa
Cast iron	170 MPa
Aluminum	450 MPa
Concrete	5 MPa
Rubber	15 MPa

P-wave velocity

Soil	100-500 m/sec
Glacier ice	3000-4000 m/sec
Clay (dry)	200-1400 m/sec
Clay (wet)	1200-2200 m/sec
Alluvium	3000-5000 m/sec
Water	1450-1500 m/sec
Sand	400-2300 m/sec
Oil	1300 m/sec
Air	320-340 m/sec
Granite	3000-5900 m/sec
Basalt	4500-6500 m/sec

Quartzite	5000-6500 m/sec
Sandstone	1400-4000 m/sec
Shale	1400-3000 m/sec
Limestone	2500-6000 m/sec
Marble	3500-6000 m/sec
Salt	4500 m/sec

#### S-wave velocity

Clay (dry)	410 m/sec
Clay (saturated)	390 m/sec
Alluvium	1900 m/sec
Water	0 m/sec (because no shear strength)
Oil	0 m/sec (because no shear strength)
Air	0 m/sec (because no shear strength)
Limestone	3100 m/sec
Sandstone	2400 m/sec
Dolomite	3000 m/sec
Shale	2600 m/sec
Granite	3400-3600 m/sec
Dolerite	3500-3600 m/sec
Salt	2700 m/sec

#### Resistivity

Marble	$5 \times 10^7 - 10^9$ Ohm-m
Mica	$10^{11} - 10^{14}$ Ohm-m
Quartz	$10^{12} - 10^{14}$ Ohm-m
Slate	$1 - 2 \times 10^6$ Ohm-m
Petroleum	$2 \times 10^{14}$ Ohm-m
Distilled water	5000 Ohm-m
Saltwater 2 ppm	3.4 Ohm-m
Saltwater 10 ppm	0.72 Ohm-m
Saltwater 20 ppm	0.38 Ohm-m
Saltwater 100 ppm	0.09 Ohm-m