

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

Coefficient of sliding friction (μ)

For most rocks, μ 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 (ϕ)

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

Cohesive strength (τ_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 (ρ)

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

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

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

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

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 ⁻² to 1 cm/sec |
| Well-sorted sands, glacial outwash | 10 ⁻³ to 10 ⁻¹ cm/sec |
| Silty sands, fine sands | 10 ⁻⁵ to 10 ⁻³ cm/sec |
| Silt, sandy silts, clayey sands, till | 10 ⁻⁶ to 10 ⁻⁴ cm/sec |
| Clay | 10 ⁻⁹ to 10 ⁻⁶ 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 (ν)

| | |
|-------------|-----------|
| 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 (μ)

| | |
|-----------|---------|
| 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

| Term | Diagnostic features | Undrained compressive strength |
|------------------|------------------------------------------------|---------------------------------------|
| 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 | 2×10^{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 |