Lecture 2: Grain Size Distributions and Soil Particle Characteristics

A. Motivation:

In soil mechanics, it is virtually always useful to quantify the size of the grains in a type of soil. Since a given soil will often be made up of grains of many different sizes, sizes are measured in terms of ***grain size distributions.***

Grain size distribution (GSD) information can be of value in providing initial rough estimates of a soil's engineering properties such as perme− ability, strength, expansivity, etc.

A subject of active ***research*** interest today is the accurate prediction of soil properties based largely on GSDs, void ratios, and soil particle characteristics. At this point in time, though, such research has not yet produced results that are usable in standard engineering practice.

In this period, we will look at methods of measuring GSDs of soils, and also different measures of soil grain shapes.

When measuring GSDs for soils, two methods are generally used:

−> For grains larger than 0.075mm sieving is used;
−> For grains in the range of .075mm > D > 0.5μm, the hydrometer test is used.

B. Sieve Testing (for coarse−grained soils with D > 75μm)

	Sieve	Passes soil of diameter less than:	
i=1	3"	3"	Gravels
i=2	1.5"	1.5"	Gravels
i=3	0.75"	0.75"	Gravels
.	0.375"	0.375"	Gravels
.	#4	4.750mm	Gravels
.	#6	3.350mm	Sands
	#8	2.360mm	Sands
	#10	2.000mm	Sands
	#16	1.180mm	Sands
	#20	0.850mm	Sands
	#30	0.600mm	Sands
	#40	0.425mm	Sands
	#50	0.300mm	Sands
	#60	0.250mm	Sands
	#80	0.180mm	Sands
	#100	0.150mm	Sands
	#140	0.106mm	Sands
	#170	0.088mm	Sands
	#200	0.075mm	Sands
i=n	#270	0.053mm	Fines (Silts & Clays)
	pan	0.000mm	Fines (Silts & Clays)

Procedure for Sieve Testing of Soils:

a) Pour oven−dried soil of mass M_0 into the top sieve of the stack;

b) Shake and agitate the stack of sieves until all soil grains are retained on the finest sized sieve through which they can possibly pass;

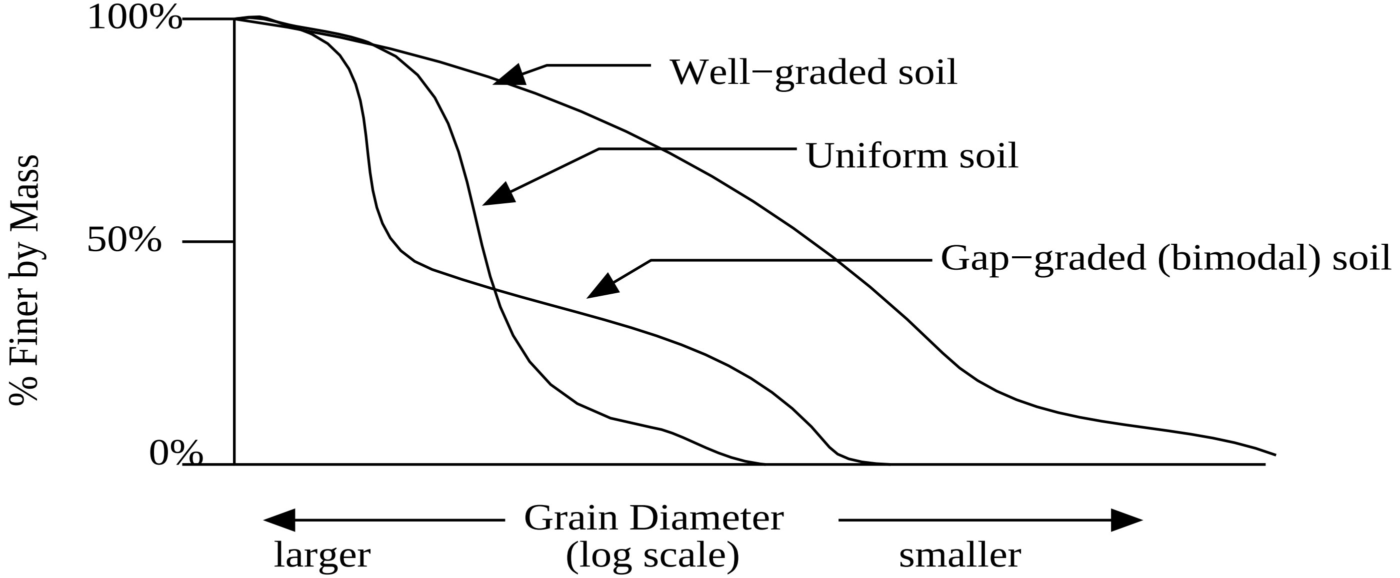
c) Weigh the mass of soil M_i retained on each sieve.

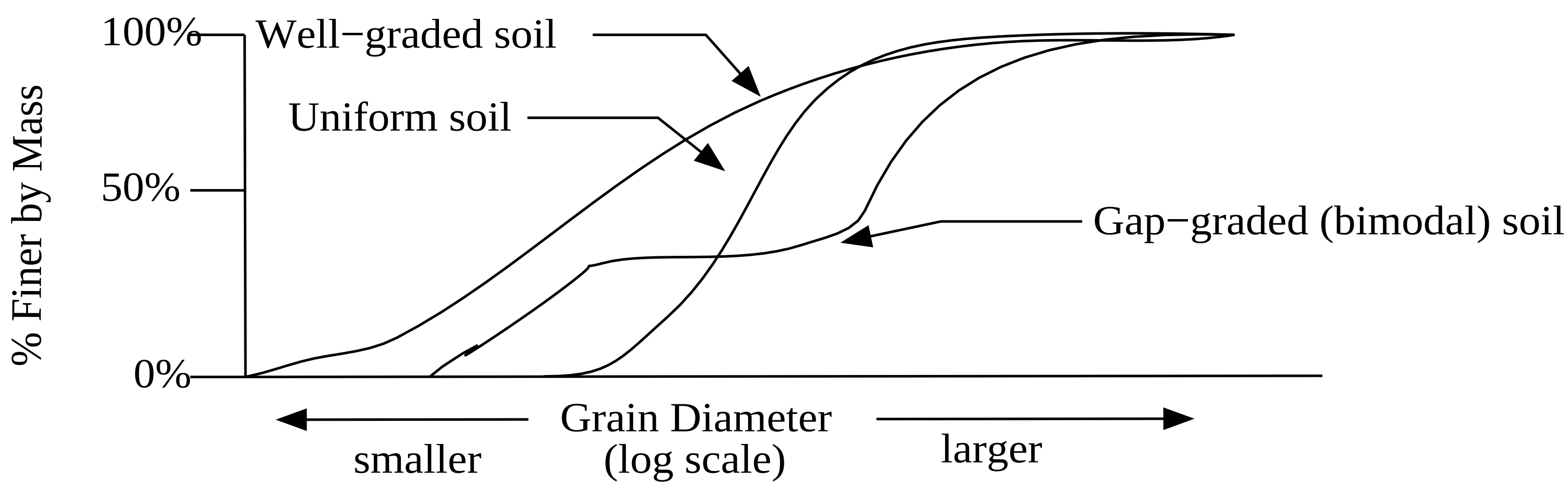
d) For each sieve size used, compute N_i, the percentage by mass of the soil sample that is **finer** than the i^{th} sieve size.

For example:

$$N_i = (1/M_0) \sum_{j=i+1}^{n} M_j * 100\% = \left(1 - \sum_{j=1}^{i} M_j/M_0\right) * 100\%$$

e) Plotting N_i versus D_i for i = 1, 2, . . . , n on special five−cycle semi−logarithmic GSD paper gives the following types of curves:





When GSDs are plotted on standard semi−log paper, they look different since the grain size will increase from left to right.

Example Problem:

C. Hydrometer Testing (for fine−grained soils: 0.5μm < D < 75 μm)

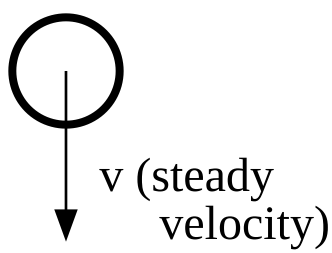
It is assumed, as a first approximation, that fine−grained soil particles can be idealized as small spheres.

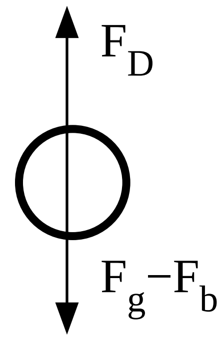
According to Stokes Law, the viscous drag force F_D on a spherical body moving through a laminar fluid at a steady velocity v is given by:

$F_D = 3\pi\mu v D$ where: μ is the viscosity of the fluid (Pa.s)
v is the steady velocity of the body (m/s)
D is the diameter of the sphere (m)

If we drop a grain of soil into a viscous fluid, it eventually achieves a terminal velocity v where there is a balance of forces between viscous drag forces, gravity weight forces, and buoyant forces, as shown below:

Falling particle





$F_g - F_b = (1/6)(G_s - 1)\gamma_w \pi D^3$ where: G_s is the specific gravity of the soil grain and
γ_w is the unit weight of water (kN/m^3)

For equilibrium of the soil grain: $F_D = F_g - F_b$. From this equation, we solve for the equilibrium or terminal velocity v of the soil grain as :

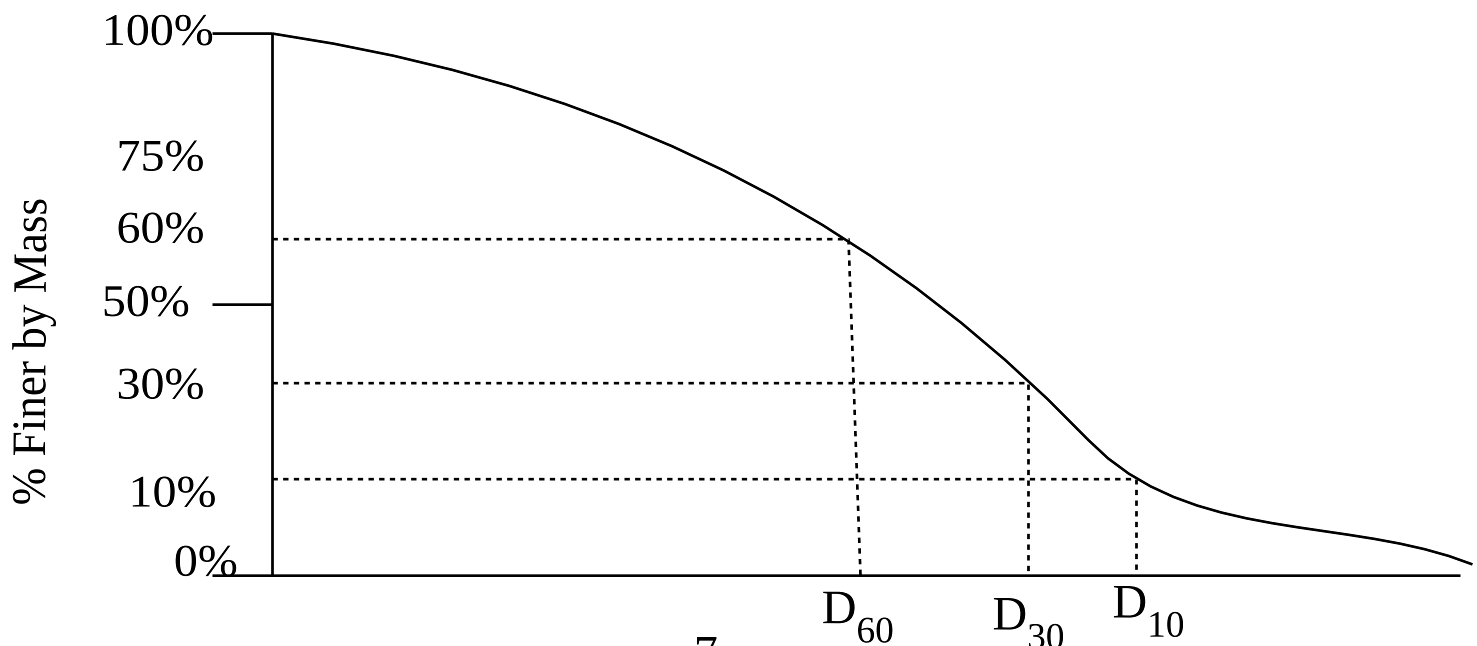
$$v = \frac{(G_s - 1)\gamma_w D^2}{18\mu}$$

Observe: $v \propto D^2$

Thus, the larger a soil grain is, the faster it settles in water. This critical fact is used in the hydrometer testing to obtain GSDs for fine−grained soil.

D. Measures of Gradation

Engineers frequently like to use a variety of coefficients to describe the uniformity versus the well−gradedness of soils.



Some commonly used measures are:

1) The Uniformity Coefficient: $C_u = D_{60}/D_{10}$

Soils with $C_u <= 4$ are considered to be "poorly graded" or uniform.

2) The Coefficient of Gradation: $C_c = (D_{30})^2/(D_{60}*D_{10})$

For well−graded soils, $C_c \sim 1$

3) The Sorting Coefficient: $S_o = (D_{75}/D_{25})^{1/2}$

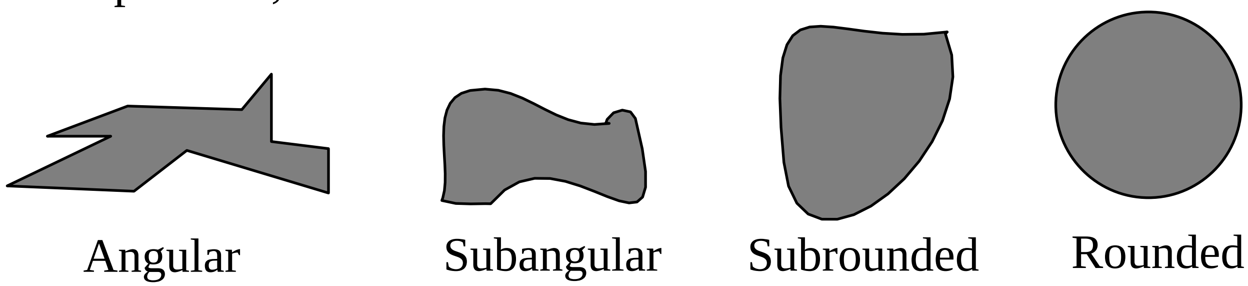
This measure tends to be used more by geologists than engineers.
The larger S_o, the more well−graded the soil.

4) The "effective size" of the soil: D_{10}

Empirically, D_{10} has been strongly correlated with the permeability of fine−grained sandy soils.

E. Soil Grain Shapes

While soil GSDs are relatively easy to measure, particle *shapes* are somewhate more difficult to quantify. An infinite number of shapes are possible, a few of which below:



One way to characterize particle shape is to consider the following measurements of individual soil grains:

L = maximum dimension of a grain
B = intermediate dimension of a grain
H = minimum dimension of a grain
V = volume of a grain
$D_e = (6V/\pi)^{1/3}$ = equivalent diameter of a grain

$E = L/B$ (elongation)

$\chi = D_e/L$ (operational spherecity)

$0 <= \chi <= 1$

$\chi \sim 0$ --> flaky grains

$\chi \sim 1$ --> bulky, spherical grains

$F = B/H$ (flatness)

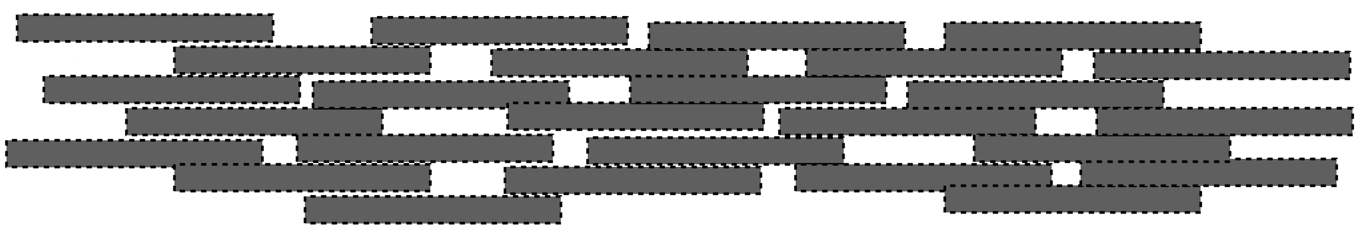
Effects of Particle Shape on Mechanical Behavior of Granular Soils:

--> Higher spherecity reduces the tendency of particles to fracture, crush, and degrade into smaller particles under loading.

--> Smoother grains of high spherecity do not interlock, but do resist crushing and breakage.

--> Angular particles interlock and resist relative displacements, but corners break and crush under loading.

--> Flat particles, if oriented, can potentially form planes of weakness.



Bottom Line:

Although particle shape and angularity definitely affect the macroscopic behavior of soils, they are very difficult to quantify. Hence these measures are not used in practice nearly as often as grain−size distributions and related grading coefficients.

GSD measurements, which can be performed quickly and inexpensively, tell us whether a given soil is predominantly sandy, silty, or clayey. This simple information is often of great help in trying to anticipate a soil's possible mechanical properties.