The University of Iowa
Dept. of Civil & Env. Engg.

53:030 Soil Mechanics **Fall Semester**
Lab. No. 2:

Measuring Grain Size Distributions of Soils

Equipment:

Sieving: mass balance, nest of sieves, sieve shaker.

Hydrometer: stirring apparatus, 1000 ml cylinder, beaker, thermometer, evaporating dish.

In this lab session, you will be given two soil samples: a sample of coarse-grained soil named FI-6, and a sample of fine-grained soil named FI-10. You will use sieving to measure the GSD (grain size distribution) of the coarse soil, and hydrometer testing to measure the GSD of the fine-grained soil.

I. Coarse-grained Soils

A. Procedure for sieving coarse-grained soil†.

1. Obtain and weigh approximately 500 grams of oven-dried soil.
2. If necessary, break the soil sample into individual grains using the soil grinder, and/or the mortar and pestle. (*The idea is to break up the soil into individual grains rather than to break the grains themselves.*)
3. Collect the following sieves: #'s 20,40,60,100,140,200 and pan. After making sure that each sieve is clean (free of loose soil grains), obtain the mass of each sieve to within 0.1g.
4. Assemble a nest of sieves with the largest sized openings at the top, and with the smallest at the bottom. Make sure that the pan is in place at the base of the stack.
5. Pour the soil sample into the top of the nest. After placing a cap on the stack, place the stack of sieves into the shaking apparatus. Using the apparatus, shake the stack of sieves for 10–15 minutes.
6. After shaking, remove the stack from the apparatus, and **carefully** separate the sieves, making sure not to spill the soil. Obtain the combined mass of each sieve and the soil it retains.
7. If a significant fraction of the total specimen (*say* $\geq$ 10% *by mass*) is retained on the #200 sieve, then the retained soil must be washed through the sieve. (Ask the lab instructor for assistance in this case.)
8. Compute the mass of dry soil retained on each sieve, and plot the grain size distribution for the soil. The sum of soil masses retained on all the sieves should be almost equal to that of the original soil mass.

II. Hydrometer Testing of Fine-grained Soils

A. Background:

Hydrometer testing is the procedure commonly adopted for determination of the grain size distribution in soils with $D < 0.075$mm. In this test, a soil specimen is dispersed in a calgon-water solution so that the particles will settle individually. For simplicity, it is assumed that the individual soil particles are spheres, and that the average settling velocity v for each particle is given by Stokes law:

$$v = \frac{\rho_s - \rho_f}{18\mu} g D^2 \tag{1}$$

† The procedure described is applicable for soils which are primarily granular, with little or no fines.

where

$$v = \text{particle fall velocity}, \quad \frac{m}{s}$$
$$\rho_{\text{s}} = \text{mass density of soil particles}, \quad \frac{kg}{m^3}$$
$$\rho_{\text{f}} = \text{mass density of calgon-water solution}, \quad \frac{kg}{m^3}$$
$$\mu = \text{viscosity of water}, \quad Pa \cdot s$$
$$g = \text{gravitational acceleration}, \ 9.81\frac{m}{s^2}$$
$$D = \text{soil grain diameter}, \quad (m)$$

The important point to note is that the larger the soil particles are (*i.e.* the larger their diameter, D), the faster they will settle in the suspension. This effect is used to calculate grain size distributions of fine-grained soils in the hydrometer test.

We begin the hydrometer test by uniformly distributing a mass of soil solids M_{s}^o throughout the fluid. Assuming that the soil particles are uniformly distributed throughout the settling column, the initial density of the suspension ρ_{sus}^o throughout the column is simply

$$\rho_{\text{sus}}^o = \frac{M_{\text{f}} + M_{\text{s}}^o}{V}, \tag{2}$$

in which M_{f} is the mass of the fluid in V, and M_{s}^o is the mass of the soil grains in V, and V is total volume 1000 cm^3. Rearrangement of this expression along with insertion of simple relations for the fluid and solid mass terms, allows us to calculate the initial average density of the fluid-soil suspension as follows:

$$\rho_{\text{sus}}^o = \rho_{\text{f}} + \frac{M_{\text{s}}^o}{VG_{\text{s}}}(G_{\text{s}} - 1), \tag{3}$$

in which G_{s} is the specific gravity of the soil grains, ρ_{f} is the density of the fluid in the column (measured from the reference settling column which has no soil in it), and V is taken as 1000 cm^3.

Whenever a hydrometer is inserted into the suspension, the center of its bulb sinks to a depth z, which is functionally dependent upon the density distribution of the suspension. The depth from the water surface to the center of the hydrometer's bulb is denoted by z and is called the **effective depth.** The hydrometer reading r is a direct measurement of the average density ρ_{sus} of the fluid-soil suspension in the sampling volume V_{m} that lies between the effective depth z and the free-surface of the suspension.

At some later time t after the beginning of the test, the soil particles will have begun to settle down toward the bottom of the settling column. When the hydrometer is inserted into the column and sinks to an effective depth z, we can say, based on Stokes Law, that the fluid-soil suspension in the zone of measurement (depth $\leq z$) is free of particles larger than $D(z,t)$, where

$$D(z,t) = K_1\sqrt{\frac{z}{t}}, \tag{4a}$$

in which

$$K_1 \equiv \sqrt{\frac{18\mu}{g(\rho_{\text{s}} - \rho_{\text{f}})}}, \tag{4b}$$

where ρ_{s} is the average mass density of individual soil grains. From the average density measurement, the current mass of soil grains M_{s} in the sampling volume V_{m} can be computed as:

$$M_{\text{s}}|_{V_{\text{m}}} = (\rho_{\text{sus}} - \rho_{\text{f}}) * \frac{V_{\text{m}}G_{\text{s}}}{G_{\text{s}} - 1}. \tag{5}$$

The original mass of solids in the same sampling volume V_{m} at the start of the test would have been:

$$M_{\text{s}}^o|_{V_{\text{m}}} = (\rho_{\text{sus}}^o - \rho_{\text{f}}) * \frac{V_{\text{m}}G_{\text{s}}}{G_{\text{s}} - 1}. \tag{6}$$

Since at depth z and time t, the suspension contains only soil particles smaller in diameter than D(z,t) as expressed by (4a), the fraction N of the hydrometer soil sample finer than D(z,t) is simply:

$$N = \frac{M_{\mathrm{s}}}{M_{\mathrm{s}}^{o}} = \frac{\rho_{\mathrm{sus}} - \rho_{\mathrm{f}}}{\rho_{\mathrm{sus}}^{o} - \rho_{\mathrm{f}}}. \tag{7}$$

In the actual tests, $r = \rho_{\mathrm{sus}}$ and $r_{\mathrm{f}} = \rho_{\mathrm{f}}$, and thus

$$N = K_2(r - r_{\mathrm{f}}), \tag{8a}$$

where

$$K_2 = (\rho_{\mathrm{sus}}^{o} - \rho_{\mathrm{f}})^{-1}. \tag{8b}$$

B. <u>Limitations of the method:</u>

1. For particles larger than 0.2mm in diameter, turbulence becomes a factor; for particles smaller than 0.0002 mm in diameter, Brownian motion affects the fall velocity.
2. The particles are typically not spheres.
3. Adjacent particles can interact with each other and particles near the boundaries are affected by the container wall.
4. The specific gravity of the individual particles is probably not constant.
5. Insertion and removal of the hydrometer disturbs the particles' trajectories.

C. <u>Experimental Procedure for Hydrometer Testing:</u>

1. Take 50g of air-dry soil passing a No. 20 sieve. Using the water content for the soil (provided by the lab instructor), determine the corresponding mass of dry soil solids.
2. Prepare a deflocculating agent (4% solution of sodium hexametaphosphate [Calgon]) by thoroughly mixing 40g of Calgon in 1000 ml of distilled water.
3. Mix 125cc of the dispersing solution with the soil from step 1 in a beaker. After mixing by hand, allow the mixture to soak for at least 12 hours.
4. Take a 1000 cc graduated cylinder and combine 875 cc of distilled water with 125 cc of the dispersing solution. Mix well. This will be the reference settling column.
5. Calibrate the hydrometer as shown on page 5 of the lab handout. Construct lines of z'vs.r and $z_r$vs.r for usage in grain-size distribution computations.
6. Using a spatula, mix the soaked soil mixture from step 4 by hand. Pour the mixture into a blending cup, washing all of the residue from the beaker into the cup with additional distilled water. Using additional distilled water, fill the mixing cup two-thirds full. Mix for about two minutes.
7. Pour the contents of the mixing cup into a new 1000 cc graduated cylinder, making sure that all soil solids are washed out of the mixing cup. Bring the water level in the graduated cylinder up to the 1000cc mark by adding additional distilled water.
8. Using the procedure demonstrated by the lab instructor, invert the cylinder approximately 30 times to achieve a uniform distribution of soil particles in the suspension.
9. Put the cylinder down, and begin recording time immediately. Insert the hydrometer into the suspension for the initial readings.
10. Take hydrometer readings at cumulative times t = 15 sec, 30 sec, 60 sec and 120 sec. Always read the upper level of the meniscus.
11. Take the hydrometer out of the soil-water suspension after two minutes, and take a reading (r_{f}) from the reference cylinder.
12. Take hydrometer readings at t = 4 min, 8 min, 15 min, 30 min, 1 hr, 4hr and 24hr. For each reading, insert the hydrometer into the suspension about 30 seconds before the reading is due. After the reading, remove the hydrometer and take an additional reading (r_{f}) in the reference cylinder.

D. <u>Hydrometer Computations:</u>

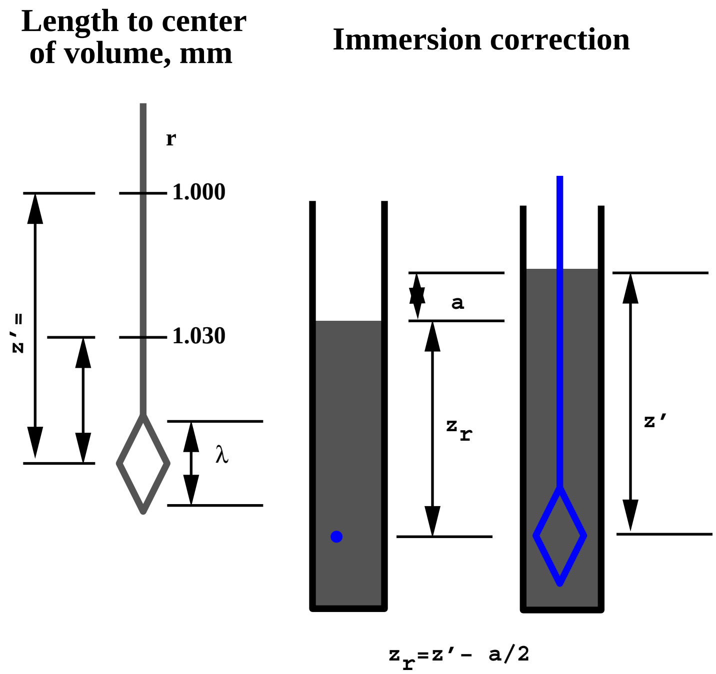
The suggested format for the hydrometer test data collection and related computations is shown on page 6 of this handout. In the writeup for this lab, you will be requested to plot the grain-size distribution for this soil.

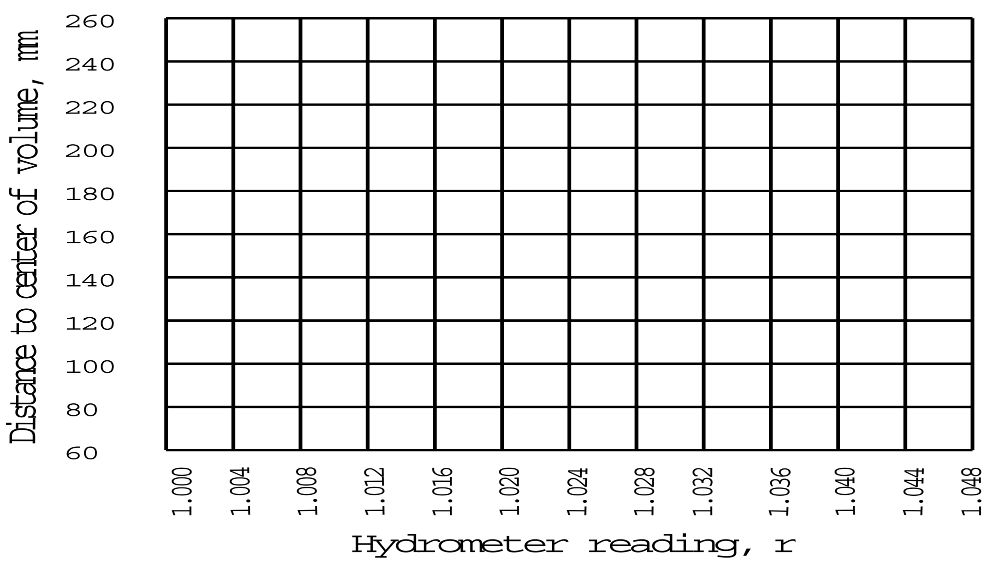
Data Collection: Sieving of Coarse Soil

Testing Group #	
Soil Sample #	
Air-dry mass of soil sample	
Water content, w, of soil	
Corrected (dry) mass, M_s	
Specific gravity, G_s	

Sieve	Opening (mm)	Sieve Mass	Sieve & Soil Mass	Retained Mass	Percent of Total	Percent finer
# 20	0.850					
# 40	0.425					
# 60	0.300					
#100	0.150					
#140	0.106					
#200	0.075					
pan	0.000					

Hydrometer Calibration





Plot z' and z_r on the graph above. This will give you two parallel lines. When you take readings during the actual hydrometer test, you will use this graph to obtain the distance from the water surface to the centroidal depth of the hydrometer bulb. For hydrometer readings up to and including two minutes, leave the hydrometer in the cylinder and use z' in your calculations. For readings beyond two minutes, gently insert the hydrometer before each reading, read r, and remove the hydrometer from the cylinder. Obtain z_r from your graph, and use z_r in your calculations.

Hydrometer Test Data Collection

Soil Sample #		Testing Group #	
Air-dry mass of soil sample		Cylinder volume, V	1000 cm^3
Water content, w, of soil	0.00	Chemical added:	sodium hexametaphosphate
Corrected (dry) mass, M_s		Hydrometer No.	
Specific gravity, G_s	2.664	ρ_f	(g/cm^3)
		$K_2 = (\rho^o_{sus} - \rho_f)^{-1}$	

Date	**Time**	**Elapsed time, t minutes**	**Temp. °C**	**Reading (Sample) r**	**Reading (Control)** r_f	$r - r_f$	**% finer** N♢	**z♠** (m)	z/t (m / s)	K_1	D♣ (m)
		0.25									
		0.50									
		1.00									
		2.00									
		4.00									
		8.00									
		15.00									
		30.00									
		60.00									
		240.00									
		1440.00									

Notes:

In all computations, check your units very carefully.

♢ $N(\%) = K_2(r - r_f) \cdot (100\%)$.

♠ Obtain z from the hydrometer calibration curves on page 5.

♣ $D(z,t) = K_1\sqrt{\frac{z}{t}}$ in which K_1 is given by Eq. (4b).