Particle Size Analysis II – Hydrometer Analysis

GEL 324 Sedimentology

Introduction

Hydrometer analysis provides an approximate particle-size distribution for particles whose median diameters smaller than 4ϕ (0.0625mm), which includes silt and clay size particles. The procedure utilizes Stoke's Law of settling velocity for spherical particles in a fluid;

$$V = \frac{2}{9}\frac{g(\rho_s - \rho_f)}{\eta}\left(\frac{D}{2}\right)^2 \quad (1)$$

where;

V = settling velocity (cm/s);
ρ_s = density of the solids (g/cm^3);
ρ_f = density of the fluid (g/cm^3);
η = dynamic viscosity of the fluid $(dyn \cdot s/cm^2)$;
g = acceleration due to gravity $(980.7\, cm/s^2)$;
D = particle diameter (cm)

Solving this equation for D yields;

$$D = \sqrt{\frac{18\eta V}{g(\rho_s - \rho_f)}} \quad (2)$$

The equation is valid for the range of particle diameters;

$$0.002mm \le D \le 0.02mm$$

Larger particles cause turbulence in the fluid and finer particles are subject to Brownian motion (i.e. particles that are subject to interparticle forces). The irregular shape and density of natural particles and temperature variations, which affect fluid density and viscosity, may contribute to analytical errors.

To solve equation 2 the settling velocity, particle and fluid densities, and fluid viscosity must be known. A hydrometer is used to measure settling velocity and the remaining variables can be measured or estimated.

Analysis

The sediment to be analyzed is thoroughly dispersed in 1000ml solution of distilled water and dispersing agent. The dispersing agent, such as sodium hexametaphosphate (or Calgon), is needed to neutralize the particle charges on fine clay particles and prevent flocculation. The hydrometer is inserted at varying time intervals and the depth to which it sinks is recorded. These data are used to calculate settling velocity (V) according to the formula;

$$V = \frac{L}{t} \qquad (3)$$

where;

V = settling velocity (cm/s)

L = distance (cm) particles fall in time t

t = time interval

The hydrometer used is an ASTM Type 152H (Figure 1), which reads grams of sediment in 1000ml of suspension. The percent finer is read directly from the hydrometer when the particle density is 2.65 g/cm^3 and fluid density is 1.00 g/ cm^3 (see Table 1 for water density and viscosity at different temperatures). These conditions, however, are rarely met and corrections must be made for deviation from the standard conditions. The correction factors are available in the tables attached to this laboratory exercise.

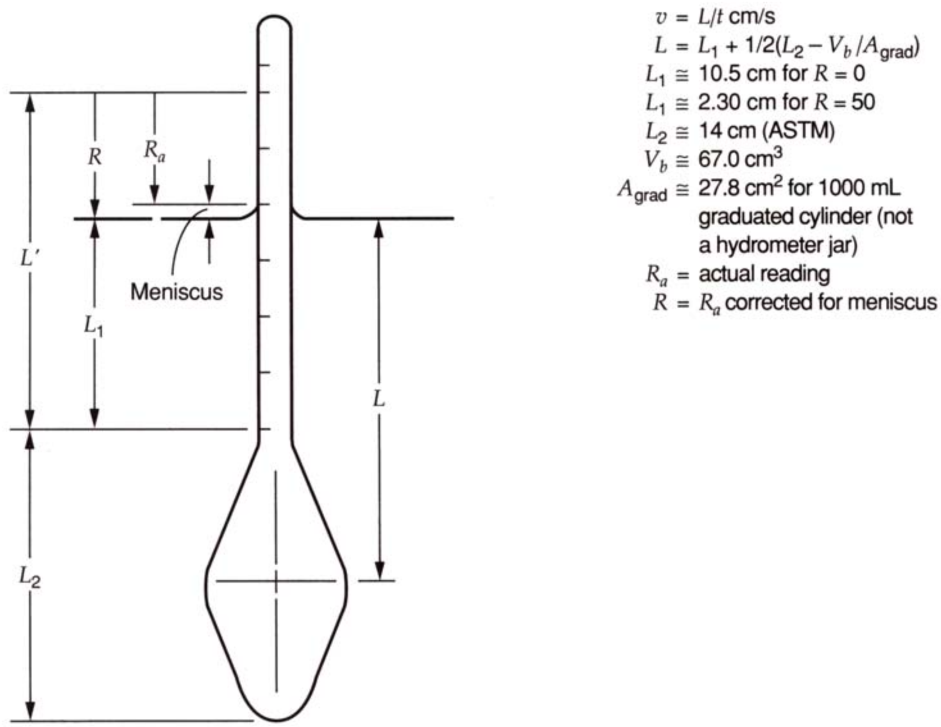


Figure 1. Dimensions of the ASTM 152H hydrometer (from: Bowles, J.E., 1992, Engineering Properties of Soils and Their Measurement, Fourth Edition: McGraw-Hill, New York, 241p.

Calculations

1. Hydrometer Correction (R_c)

$$R_c = R_a - Z_c + C_T \qquad (4)$$

where;

R_a = actual hydrometer reading

Z_c = zero correction

C_T = Temperature correction (from Table 3)

2. Percent Finer (assume ρ_s = 2.65 g/cm^3)

$$\%Finer = \frac{aR_c}{W_s} \times 100 \qquad (5)$$

where;

R_c = corrected hydrometer reading (g/1000ml)

W_s = original dry mass (g)

a = correction factor for particle density (a = 1.00 for $\rho_s = 2.65\, g/cm^3$) (from Table 2)

3. Settling Velocity (V)

The settling velocity can be computed as the distance (L) a particle of diameter D falls in time t (Equation 2). The value of L (or effective depth) can be determined for a standard ASTM Type 152H hydrometer from the meniscus-corrected hydrometer reading (R) by the equation;

$$L = 16.3 - 0.1641R$$

Note that the distance L changes throughout the course of the test as particles settle and the hydrometer sinks deeper into the solution.

4. Particle Diameter (D)

The particle diameter from Equation 2 can be written using L in cm and t in minutes as shown below;

$$D = \sqrt{\frac{18\eta V}{g(\rho_s - \rho_f)}} = \sqrt{\frac{30\eta}{980.7(\rho_s - \rho_f)} \cdot \frac{L}{t}}$$

which can be further simplified to:

$$D = K\sqrt{\frac{L}{t}}$$

The value K is a function of temperature and particle density and can be obtained from the Table 4 provided. The value of effective depth (L) for the ASTM 152H hydrometer can be found on Table 5.

Procedure

1. Obtain 15 to 40 grams of oven-dried sample. For clayey samples use a less sample, for siltier samples use more. The sample should be wet-sieved to remove sand-size particles prior to the test.
2. Transfer the sample to a 250 ml beaker, add 1 gram of sodium hexametaphosphate and approximately 150 to 200 ml of deionized water, and let the solution stand overnight.
3. Carefully transfer the sediment and solution to a blender jar and agitate the sample on the lowest setting for several minutes.
4. Carefully transfer the content of the blender jar to a 1000 ml graduated cylinder and bring the cylinder to full volume with deionized water at room temperature.
5. Thoroughly mix the sediment suspension using the long-handled stirring rod provided. Be careful not to introduce air into the suspension during the stirring.
6. Begin timing the test immediately after stirring. Insert the hydrometer into the solution according to the following schedule;

    Elasped Time

    1 min
    2 min
    4 min
    8 min
    15 min
    30 min
    1 hr
    2 hr
    4 hr
    8 hr
    16 hr
    1 day
    2 days, etc…

It is important to insert and remove the hydrometer carefully when taking each reading. Inserting or removing the hydrometer too quickly will create turbulence in the column and disrupt the free fall of particles. Do not leave the hydrometer in the cylinder between readings because particles will adhere to the sides of the bulb. You may resuspend the sediment and restart timing at any time during the test. You may wish to repeat the first few readings since these are the most difficult to obtain accurately.

7. At the conclusion of the experiment, pour the contents of the graduated cylinder through a pre-wetted 4ϕ sieve. Transfer the contents of the sieve into an evaporating dish, oven dry the sample and record its mass.
8. Complete the data sheet provided and calculate the Folk and Ward graphical moments of the particle size distribution.

All tables are from Bowles, J.E., 1992, Engineering Properties of Soils and Their Measurement, Fourth Edition: McGraw-Hill, New York, 241p.

Table 1 Properties of distilled water (η = absolute)

Temp., °C	Unit weight of water, g/cm³	Viscosity of water, poise*
4	1.00000	0.01567
16	0.99897	0.01111
17	0.99880	0.01083
18	0.99862	0.01056
19	0.99844	0.01030
20	0.99823	0.01005
21	0.99802	0.00981
22	0.99780	0.00958
23	0.99757	0.00936
24	0.99733	0.00914
25	0.99708	0.00894
26	0.99682	0.00874
27	0.99655	0.00855
28	0.99627	0.00836
29	0.99598	0.00818
30	0.99568	0.00801

$$*\text{Poise} = \frac{\text{dyne} \cdot \text{s}}{\text{cm}^2} = \frac{\text{g}}{\text{cm} \cdot \text{s}}$$

Table 2 Correction factors a for unit weight of solids

ϵ_s of soil solids	Correction factor a
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.04

Table 6-3 Temperature correction factors C_T

Temp., °C	C_T
15	1.10
16	−0.90
17	−0.70
18	−0.50
19	−0.30
20	0.00
21	+0.20
22	+0.40
23	+0.70
24	+1.00
25	+1.30
26	+1.65
27	+2.00
28	+2.50
29	+3.05
30	+3.80

Table 4 Values of K^* for use in Eq. (6-9*a*) for several unit weights of soil solids and temperature combinations

Temp., °C	ϵ_s of Soil Solids							
	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.0151	0.0148	0.0146	0.0144	0.0141	0.0139	0.0137	0.0136
17	0.0149	0.0146	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134
18	0.0148	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134	0.0132
19	0.0145	0.0143	0.0140	0.0138	0.0136	0.0134	0.0132	0.0131
20	0.0143	0.0141	0.0139	0.0137	0.0134	0.0133	0.0131	0.0129
21	0.0141	0.0139	0.0137	0.0135	0.0133	0.0131	0.0129	0.0127
22	0.0140	0.0137	0.0135	0.0133	0.0131	0.0129	0.0128	0.0126
23	0.0138	0.0136	0.0134	0.0132	0.0130	0.0128	0.0126	0.0124
24	0.0137	0.0134	0.0132	0.0130	0.0128	0.0126	0.0125	0.0123
25	0.0135	0.0133	0.0131	0.0129	0.0127	0.0125	0.0123	0.0122
26	0.0133	0.0131	0.0129	0.0127	0.0125	0.0124	0.0122	0.0120
27	0.0132	0.0130	0.0128	0.0126	0.0124	0.0122	0.0120	0.0119
28	0.0130	0.0128	0.0126	0.0124	0.0123	0.0121	0.0119	0.0117
29	0.0129	0.0127	0.0125	0.0123	0.0121	0.0120	0.0118	0.0116
30	0.0128	0.0126	0.0124	0.0122	0.0120	0.0118	0.0117	0.0115

* Units for K: $\text{mm}\left(\frac{\text{min}}{\text{cm}}\right)^{1/2}$

Table 5 Values of L (effective depth) for use in Stokes' formula for diameters of particles for ASTM soil hydrometer 152H

Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm
0	16.3	21	12.9	42	9.4
1	16.1	22	12.7	43	9.2
2	16.0	23	12.5	44	9.1
3	15.8	24	12.4	45	8.9
4	15.6	25	12.2	46	8.8
5	15.5	26	12.0	47	8.6
6	15.3	27	11.9	48	8.4
7	15.2	28	11.7	49	8.3
8	15.0	29	11.5	50	8.1
9	14.8	30	11.4	51	7.9
10	14.7	31	11.2	52	7.8
11	14.5	32	11.1	53	7.6
12	14.3	33	10.9	54	7.4
13	14.2	34	10.7	55	7.3
14	14.0	35	10.5	56	7.1
15	13.8	36	10.4	57	7.0
16	13.7	37	10.2	58	6.8
17	13.5	38	10.1	59	6.6
18	13.3	39	9.9	60	6.5
19	13.2	40	9.7		
20	13.0	41	9.6		

GRAIN SIZE ANALYSIS–HYDROMETER METHOD Data Sheet 6

Project ______________________ Job No. ______________________

Location of Project ______________________ Boring No. ____________ Sample No. ____________

Description of Soil ______________________ Depth of Sample ____________

Tested By ______________________ Date of Testing ______________________

Hydrometer analysis

General Data: Hydrometer type ____________ Zero correction ____________ Meniscus ____________

Dispersing agent ______________________ Amount used ______________________

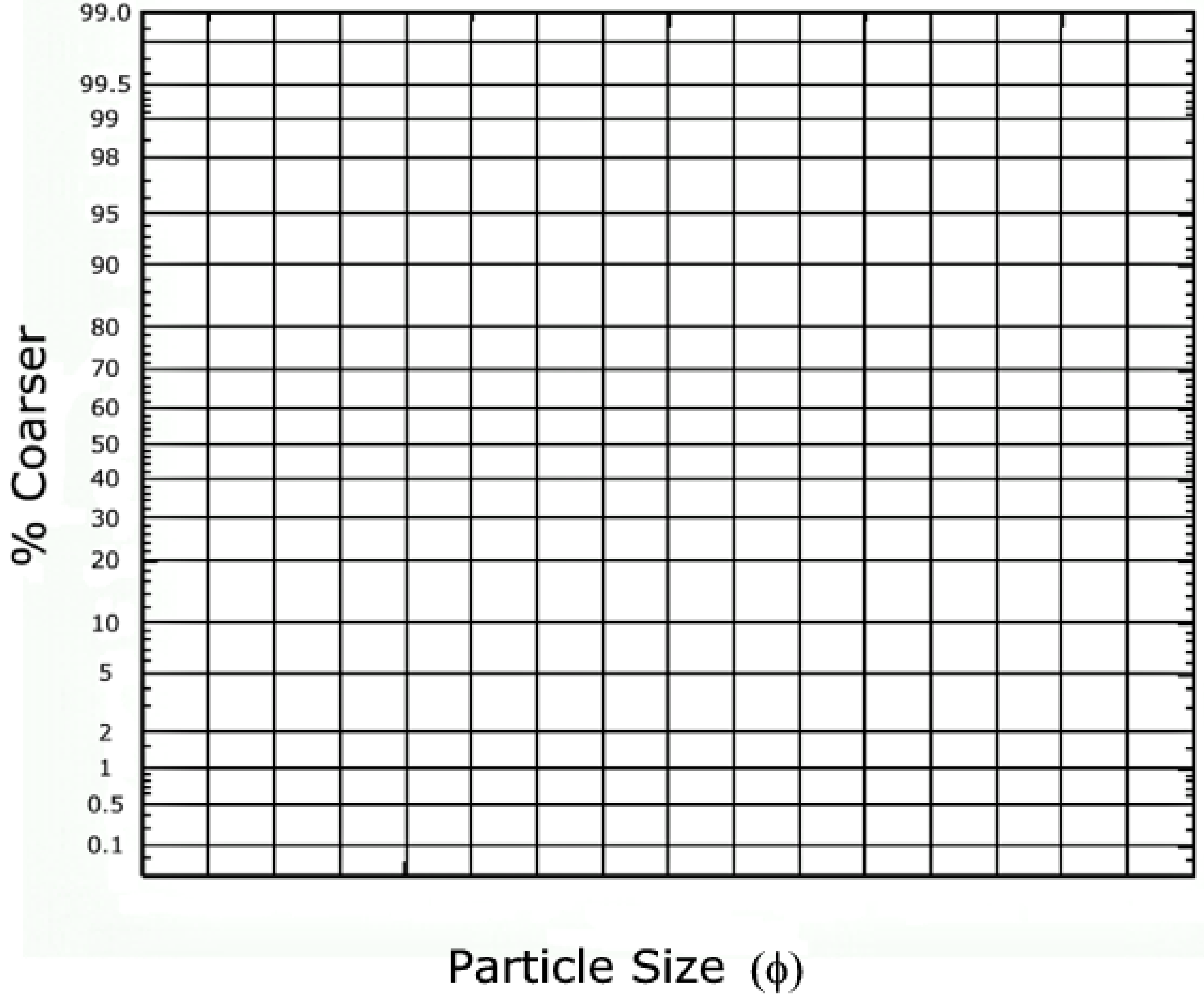
G_s of solids = ____________ CF a = ____________ w (if air-dry) = ____________%

Mass soil (wet, dry) = ____________ g % Finer[1] = ____________ % Control sieve no. ____________

Date	Time of reading	Elapsed time, min	Temp., °C	Actual Hyd. reading, R_a	Corr. Hyd. reading, R_c	Act/Adj % Finer	Hyd. Corr. only for meniscus, R	L from Table 6-5	$\frac{L}{t}$	K from Table 6-4	D, mm

[1]mark out wet or dry; % Finer if applicable; w for air-dry soil only.

$R_c = R_{\text{actual}} - \text{zero correction} + C_T$ Act % finer = $R_c(a)/M_s$ $D = K\sqrt{L/t}$


99.0
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.1
% Coarser
Particle Size (ϕ)