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Hydrometer Analysis

Introduction

Hydrometer analysis is the procedure generally adopted for determination of the particle-size distribution in a soil for the fraction that is finer than No. 200 sieve size (0.075 mm). The lower limit of the particle-size determined by this procedure is about 0.001 mm.

In hydrometer analysis, a soil specimen is dispersed in water. In a dispersed state in the water, the soil particles will settle individually. It is assumed that the soil particles are spheres, and the velocity of the particles can be given by Stoke's law as

$$v = \frac{\gamma_s - \gamma_w}{18\eta} D^2 \quad (5.1)$$

where v = velocity (cm/s)
 γ_s = specific weight of soil solids (g/cm³)
 γ_w = unit weight of water (g/cm³)
 η = viscosity of water $\left(\frac{\text{g} \cdot \text{s}}{\text{cm}^2} \right)$

D = diameter of the soil particle

If a hydrometer is suspended in water in which soil is dispersed (Fig. 5-1), it will measure the specific gravity of the soil-water suspension at a depth L . The depth L is called the *effective depth*. So, at a time t minutes from the beginning of the test, the soil particles that settle beyond the zone of measurement (i.e., beyond the effective depth L) will have a diameter given by

$$\frac{L \text{ (cm)}}{t \text{ (min)} \times 60} = \frac{(\gamma_s - \gamma_w) \text{ g/cm}^3}{18\eta \left(\frac{\text{g} \cdot \text{s}}{\text{cm}^2} \right)} \left[\frac{D \text{ (mm)}}{10} \right]^2$$

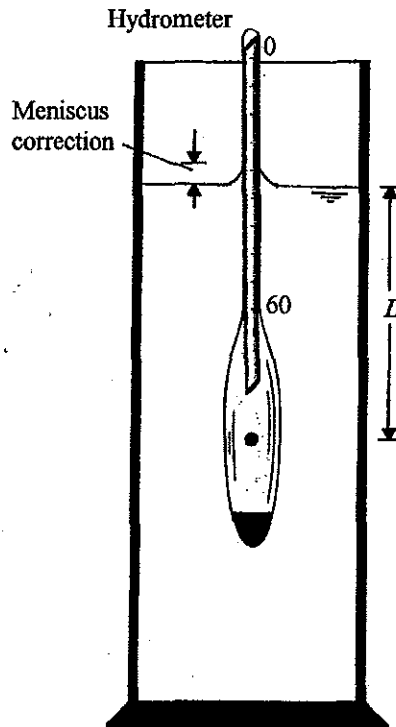


Figure 5-1. Hydrometer suspended in water in which the soil is dispersed.

$$D \text{ (mm)} = \frac{10}{\sqrt{60}} \sqrt{\frac{18\eta}{(\gamma_s - \gamma_w)}} \sqrt{\frac{L}{t}} = A \sqrt{\frac{L \text{ (cm)}}{t \text{ (min)}}} \quad (5.2)$$

$$\text{where } A = \sqrt{\frac{1800\eta}{60(\gamma_s - \gamma_w)}} = \sqrt{\frac{30\eta}{(\gamma_s - \gamma_w)}} \quad (5.3)$$

In the test procedure described here, the *ASTM 152-H* type of hydrometer will be used. From Fig. 5-1 it can be seen that, based on the hydrometer reading (which increases from zero to 60 in the *ASTM 152-H* type of hydrometer), the value of L will change. The magnitude of L can be given as

$$L = L_1 + \frac{1}{2} \left(L_2 - \frac{V_B}{A_C} \right) \quad (5.4)$$

where L_1 = distance between the top of hydrometer bulb to the mark for a hydrometer reading. For a hydrometer reading of zero, $L_1 = 10.5$ cm. Also, for a hydrometer reading of 50 g/liter, $L_1 = 2.3$ cm. Thus, in general, for a given hydrometer reading

$$L_1 \text{ (cm)} = 10.5 - \left(\frac{10.5 - 2.3}{50} \right) \times (\text{hydrometer reading})$$

$$L_2 = 14 \text{ cm}$$

$$V_B = \text{volume of the hydrometer bulb} = 67.0 \text{ cm}^3$$

$$A_c = \text{cross-sectional area of the hydrometer cylinder} = 27.8 \text{ cm}^2$$

Based on Eq. (5.4), the variation of L with hydrometer reading is shown in Table 5-1.

For actual calculation purposes we also need to know the values of A given by Equation (5.3). An example of this calculation is shown below.

$$\gamma_s = G_s \gamma_w$$

where G_s = specific gravity of soil solids

Thus

$$A = \sqrt{\frac{30\eta}{(G_s - 1)\gamma_w}} \quad (5.5)$$

For example, if the temperature of the water is 25°C,

$$\eta = 0.0911 \times 10^{-4} \left(\frac{\text{g} \cdot \text{s}}{\text{cm}^2} \right)$$

and $G_s = 2.7$

$$A = \sqrt{\frac{30(0.0911 \times 10^{-4})}{(2.7 - 1)(1)}} = 0.0127$$

The variations of A with G_s and the water temperature are shown in Table 5-2.

Table 5-1. Variation of L with hydrometer reading—
ASTM 152-H hydrometer

Hydrometer reading	L (cm)	Hydrometer reading	L (cm)
0	16.3	26	12.0
1	16.1	27	11.9
2	16.0	28	11.7
3	15.8	29	11.5
4	15.6	30	11.4
5	15.5	31	11.2
6	15.3	32	11.1
7	15.2	33	10.9
8	15.0	34	10.7
9	14.8	35	10.6
10	14.7	36	10.4
11	14.5	37	10.2
12	14.3	38	10.1
13	14.2	39	9.9
14	14.0	40	9.7
15	13.8	41	9.6
16	13.7	42	9.4
17	13.5	43	9.2
18	13.3	44	9.1
19	13.2	45	8.9
20	13.0	46	8.8
21	12.9	47	8.6
22	12.7	48	8.4
23	12.5	49	8.3
24	12.4	50	8.1
25	12.2	51	7.9

The *ASTM 152-H* type of hydrometer is calibrated up to a reading of 60 at a temperature of 20°C for soil particles having a $G_s = 2.65$. A hydrometer reading of, say, 30 at a given time of a test means that there are 30 g of soil solids ($G_s = 2.65$) in suspension per 1000 cc of soil-water mixture at a temperature of 20°C at a depth where the specific gravity of the soil-water suspension is measured (i.e., L). From this measurement, we can determine the percentage of soil still in suspension at time t from the beginning of the test and all the soil particles will have diameters smaller than D calculated by Equation (5.2). However, in the actual experimental work, some corrections to the observed hydrometer readings need to be applied. They are as follows:

Table 5-2. Variation of A with G_s

G_s	Temperature (°C)						
	17	18	19	20	21	22	23
2.50	0.0149	0.0147	0.0145	0.0143	0.0141	0.0140	0.0138
2.55	0.0146	0.0144	0.0143	0.0141	0.0139	0.0137	0.0136
2.60	0.0144	0.0142	0.1040	0.0139	0.0137	0.0135	0.0134
2.65	0.0142	0.0140	0.0138	0.0137	0.0135	0.0133	0.0132
2.70	0.0140	0.0138	0.1036	0.0134	0.0133	0.0131	0.0130
2.75	0.0138	0.0136	0.0134	0.0133	0.0131	0.0129	0.0128
2.80	0.0136	0.0134	0.0132	0.0131	0.0129	0.0128	0.0126

G_s	Temperature (°C)						
	24	25	26	27	28	29	30
2.50	0.0137	0.0135	0.0133	0.0132	0.0130	0.0129	0.0128
2.55	0.0134	0.0133	0.0131	0.0130	0.0128	0.0127	0.0126
2.60	0.0132	0.0131	0.0129	0.0128	0.0126	0.0125	0.0124
2.65	0.0130	0.0129	0.0127	0.0126	0.0124	0.0123	0.0122
2.70	0.0128	0.0127	0.0125	0.0124	0.0123	0.0121	0.0120
2.75	0.0126	0.0125	0.0124	0.0122	0.0121	0.0120	0.0118
2.80	0.0125	0.0123	0.0122	0.0120	0.0119	0.0118	0.0117

1. Temperature correction (F_T)—The actual temperature of the test may not be 20°C. The temperature correction (F_T) may be approximated as

$$F_T = -4.85 + 0.25T \text{ (for } T \text{ between } 15^\circ\text{C and } 28^\circ\text{C)} \quad (5.6)$$

where F_T = temperature correction to the observed reading
(can be either positive or negative)

T = temperature of test in °C

2. Meniscus correction (F_m)—Generally, the upper level of the meniscus is taken as the reading during laboratory work (F_m is always positive).
3. Zero correction (F_z)—A deflocculating agent is added to the soil-distilled water suspension for performing experiments. This will change the zero reading (F_z can be either positive or negative).

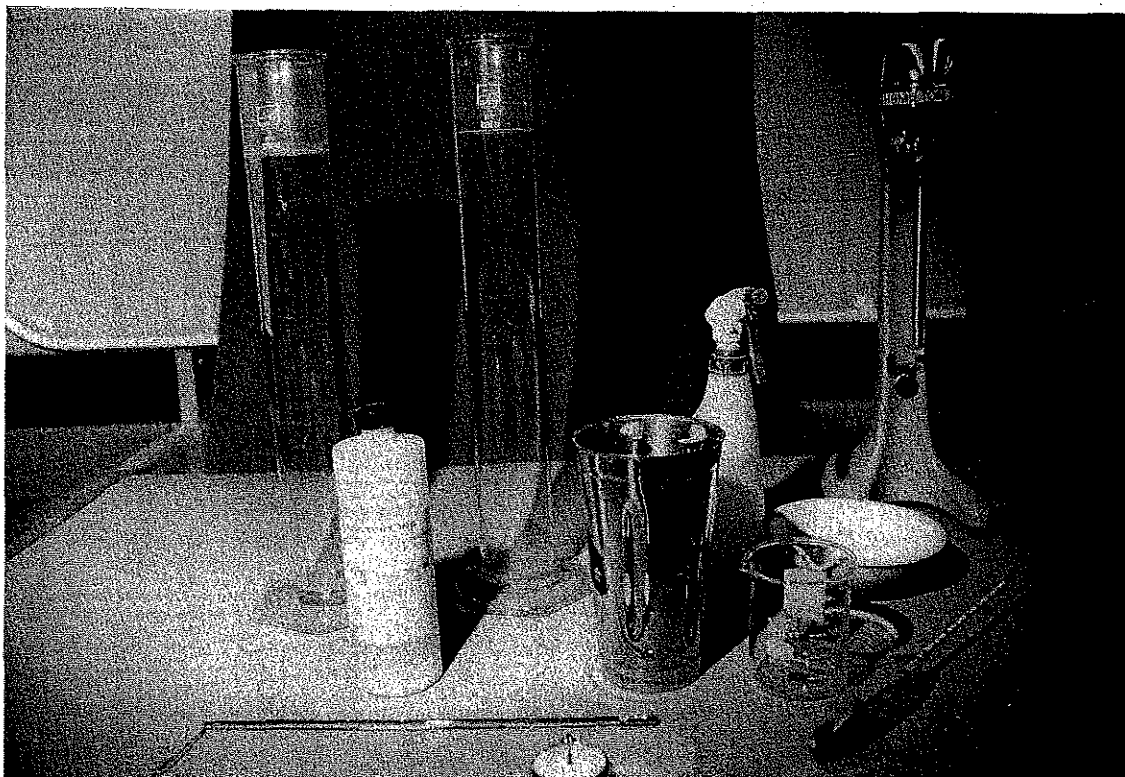


Figure 5-2. Equipment for hydrometer test.

Equipment

1. *ASTM 152-H* hydrometer
2. Mixer
3. Two 1000-cc graduated cylinders
4. Thermometer
5. Constant temperature bath
6. Deflocculating agent
7. Spatula
8. Beaker
9. Balance
10. Plastic squeeze bottle
11. Distilled water
12. No. 12 rubber stopper

The equipment necessary (except the balance and the constant temperature bath) is shown in Fig. 5-2.

Procedure

Note: This procedure is used when more than 90 per cent of the soil is finer than No. 200 sieve.

1. Take 50 g of oven-dry, well-pulverized soil in a beaker.
2. Prepare a deflocculating agent. Usually a 4% solution of sodium hexametaphosphate (Calgon) is used. This can be prepared by adding 40 g of Calgon in 1000 cc of distilled water and mixing it thoroughly.
3. Take 125 cc of the mixture prepared in Step 2 and add it to the soil taken in Step 1. This should be allowed to soak for about 8 to 12 hours.
4. Take a 1000-cc graduated cylinder and add 875 cc of distilled water *plus* 125 cc of deflocculating agent in it. Mix the solution well.
5. Put the cylinder (from Step 4) in a constant temperature bath. Record the temperature of the bath, T (in $^{\circ}\text{C}$).
6. Put the hydrometer in the cylinder (Step 5). Record the reading. (*Note:* The *top of the meniscus* should be read.) This is the zero correction (F_z), which can be +ve or -ve. Also observe the meniscus correction (F_m).
7. Using a spatula, thoroughly mix the soil prepared in Step 3. Pour it into the mixer cup.

Note: During this process, some soil may stick to the side of the beaker. Using the plastic squeeze bottle filled with distilled water, wash all the remaining soil in the beaker into the mixer cup.

8. Add distilled water to the cup to make it about two-thirds full. Mix it for about two minutes using the mixer.
9. Pour the mix into the second graduated 1000-cc cylinder. Make sure that all of the soil solids are washed out of the mixer cup. Fill the graduated cylinder with distilled water to bring the water level up to the 1000-cc mark.
10. Secure a No. 12 rubber stopper on the top of the cylinder (Step 9). Mix the soil-water well by turning the soil cylinder upside down several times.
11. Put the cylinder into the constant temperature bath next to the cylinder described in Step 5. Record the time immediately. This is cumulative time $t = 0$. Insert the hydrometer into the cylinder containing the soil-water suspension.
12. Take hydrometer readings at cumulative times $t = 0.25$ min., 0.5 min., 1 min., and 2 min. Always read the upper level of the meniscus.
13. Take the hydrometer out after two minutes and put it into the cylinder next to it (Step 5).
14. Hydrometer readings are to be taken at time $t = 4$ min., 8 min., 15 min., 30 min., 1 hr., 2 hr., 4 hr., 8 hr., 24 hr. and 48 hr. For each reading, insert the hydrometer into the cylinder containing the soil-water suspension about 30 seconds before the reading is due. After the reading is taken, remove the hydrometer and put it back into the cylinder next to it (Step 5).

Calculation

Refer to Table 5-4.

Column 2—These are observed hydrometer readings (R) corresponding to times given in Column 1.

Column 3— R_{cp} = corrected hydrometer reading for calculation of percent finer

$$= R + F_T - F_z \quad (5.7)$$

Column 4—Percent finer = $\frac{a R_{cp}}{W_s} (100)$

where W_s = dry weight of soil used for the hydrometer analysis

a = correction for specific gravity (since the hydrometer is calibrated for

$$G_s = 2.65) \\ = \frac{G_s (1.65)}{(G_s - 1)2.65} \quad (\text{See Table 5-3}) \quad (5.8)$$

Table 5-3. Variation of a with G_s [Eq. 5.8]

G_s	a
2.50	1.04
2.55	1.02
2.60	1.01
2.65	1.00
2.70	0.99
2.75	0.98
2.80	0.97

Column 5— R_{cL} = corrected reading for determination of effective length = $R + F_m$ (5.9)

Column 6—Determine L (effective length) corresponding to the values of R_{cL} (Col. 5) given in Table 5-1.

Column 7—Determine A from Table 5-2.

Column 8—Determine D (mm) = $A \sqrt{\frac{L \text{ (cm)}}{t \text{ (min)}}$

Table 5-4. Hydrometer Analysis

Description of soil Brown silty clay Sample No. _____
 Location _____
 G_s 2.75 Hydrometer type ASTM 152-H
 Dry weight of soil, W_s 50 g Temperature of test, T 28 °C
 Meniscus correction, F_m 1 Zero correction, F_s +7 Temperature correction, F_T +2.15
 [Eq. (5.6)]
 Tested by _____ Date _____

Time (min)	Hydrometer reading, R	R_{cp}	Percent finer, $\frac{a \cdot R_{cp}}{50} \times 100$	R_{cl}	L^\dagger (cm)	A^\ddagger	D (mm)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0.25	51	46.15	90.3	52	7.8	0.0121	0.068
0.5	48	43.15	84.4	49	8.3		0.049
1	47	42.15	82.4	48	8.4		0.035
2	46	41.15	80.5	47	8.6		0.025
4	45	40.15	78.5	46	8.8		0.018
8	44	39.15	76.6	45	8.95		0.013
15	43	38.15	74.6	44	9.1		0.009
30	42	37.15	72.7	43	9.25		0.007
60	40	35.15	68.8	41	9.6		0.005
120	38	33.15	64.8	39	9.9		0.0035
240	34	29.15	57.0	35	10.5		0.0025
480	32	27.15	53.1	33	10.9		0.0018
1440	29	24.15	47.23	30	11.35		0.0011
2880	27	22.15	43.3	28	11.65		0.0008

* Table 5.3; † Table 5.1; ‡ Table 5.2

Graph

Plot a grain-size distribution graph on semi-log graph paper with percent finer (Col. 4, Table 5-4) on the natural scale and D (Col. 8, Table 5-4) on the log scale. A sample calculation and the corresponding graph are shown in Table 5-4 and Fig. 5-3, respectively.

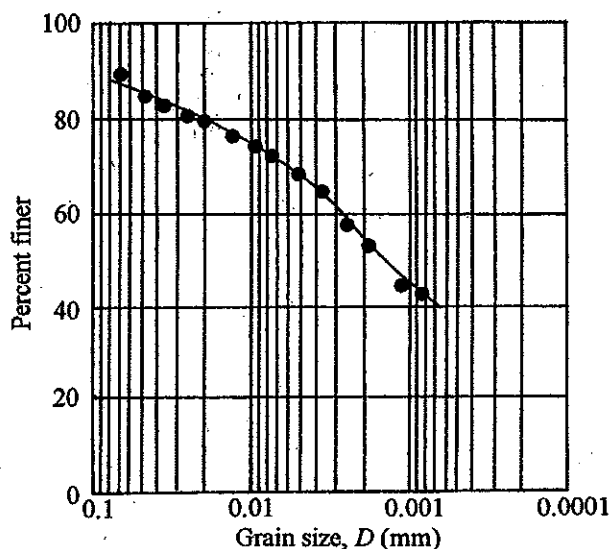


Figure 5-3. Plot of percent finer vs. grain size from the results given in Table 5-4.

Procedure Modification

When a smaller amount (less than about 90%) of soil is finer than No. 200 sieve size, the following modification to the above procedure needs to be applied.

1. Take an oven-dry sample of soil. Determine its weight (W_1).
2. Pulverize the soil using a mortar and rubber-tipped pestle, as described in Chapter 4.
3. Run a sieve analysis on the soil (Step 2), as described in Chapter 4.
4. Collect in the bottom pan the soil passing through No. 200 sieve.
5. Wash the soil retained on No. 200 sieve, as described in Chapter 4. Collect all the wash water and dry it in an oven.
6. Mix together the minus No. 200 portion from Step 4 and the dried minus No. 200 portion from Step 5.
7. Calculate the percent finer for the soil retained on No. 200 sieve and above (as shown in Table 4-1).
8. Take 50 g of the minus 200 soil (Step 6) and run a hydrometer analysis. (Follow Steps 1 through 14 as described previously.)

9. Report the calculations for the hydrometer analysis similar to that shown in Table 5-4. Note, however, that the percent finer now calculated (as in Col. 8 of Table 5-4) is *not the percent finer based on the total sample*. Calculate the percent finer based on the total sample as

$$P_T = (\text{Col. 8 of Table 5-4}) \left(\frac{\text{percent passing No. 200 sieve}}{100} \right)$$

Percent passing No. 200 sieve can be obtained from Step 7 above.

10. Plot a combined graph for percent finer versus grain-size distribution obtained from *both the sieve analysis and the hydrometer analysis*. An example of this is shown in Fig. 5-4. From this plot, note that there is an overlapping zone. The percent finer calculated from the sieve analysis for a given grain size does not match that calculated from the hydrometer analysis. The grain sizes obtained from a sieve analysis are the least sizes of soil grains, and the grain sizes obtained from the hydrometer are the diameters of equivalent spheres of soil grains.

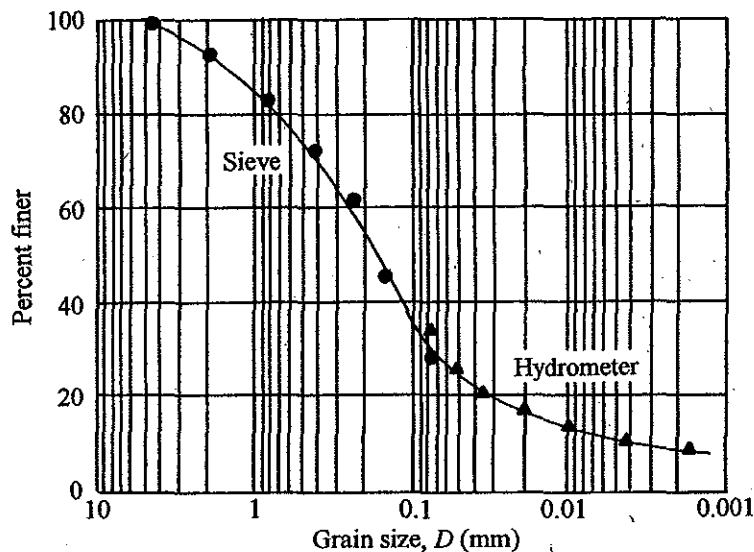


Figure 5-4. A grain-size distribution plot—combined results from sieve analysis and hydrometer analysis.

General Comments

A hydrometer analysis gives results from which the percent of soil finer than 0.002 mm in diameter can be estimated. It is generally accepted that the percent finer than 0.002 mm in size is clay or clay-size fractions. Most clay particles are smaller than 0.001 mm, and 0.002 mm is the upper limit. The presence of clay in a soil contributes to its plasticity.