2 Physical Properties of Soils

2.2 Origin of Soils

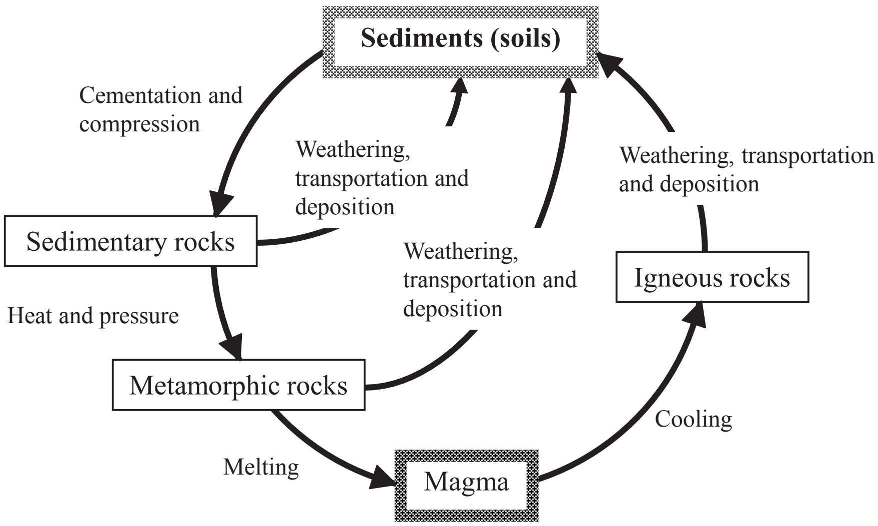


Fig. 2.1 Rock cycle

2.3 Soil Particle Shapes

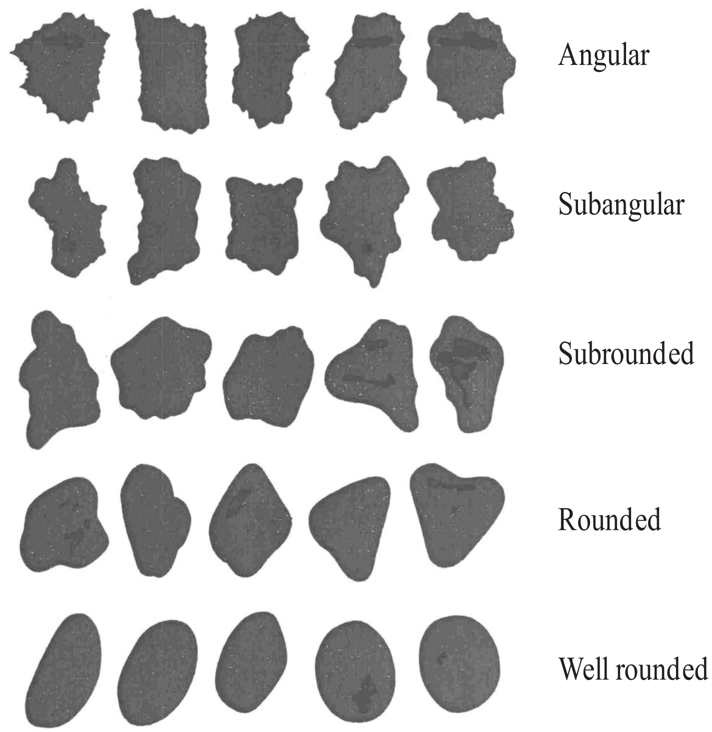


Fig. 2.2 Soil’s angularity (Müller 1967)

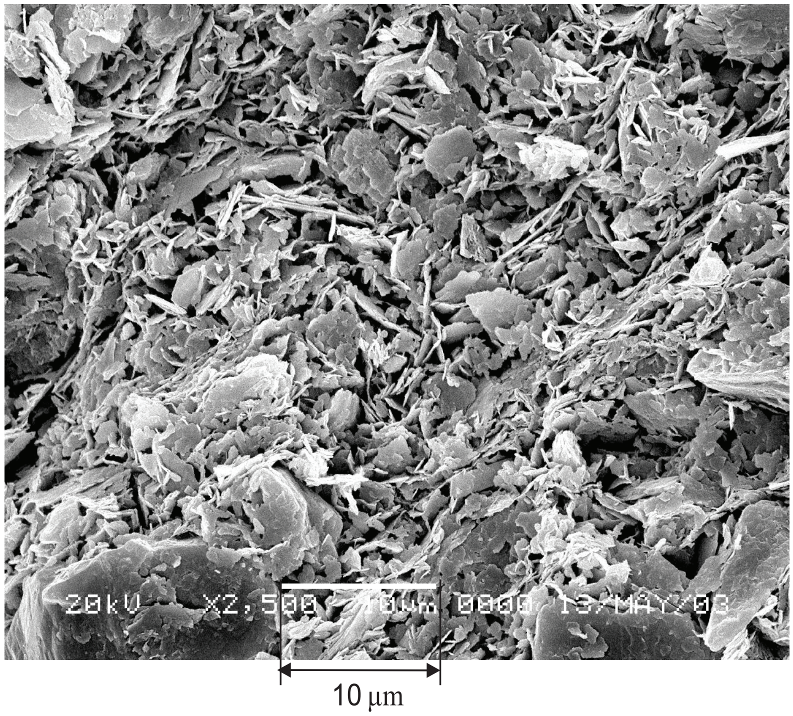


Fig. 2.3 Scanned Electron Microscope (SEM) picture of clay particle assembly (Hai-Phong (Vietnam) clay: 50 % Kaolinite and 50 % Illite) (**Watabe et al. 2004**)

2.4 Definitions of Terms with Three Phase Diagram

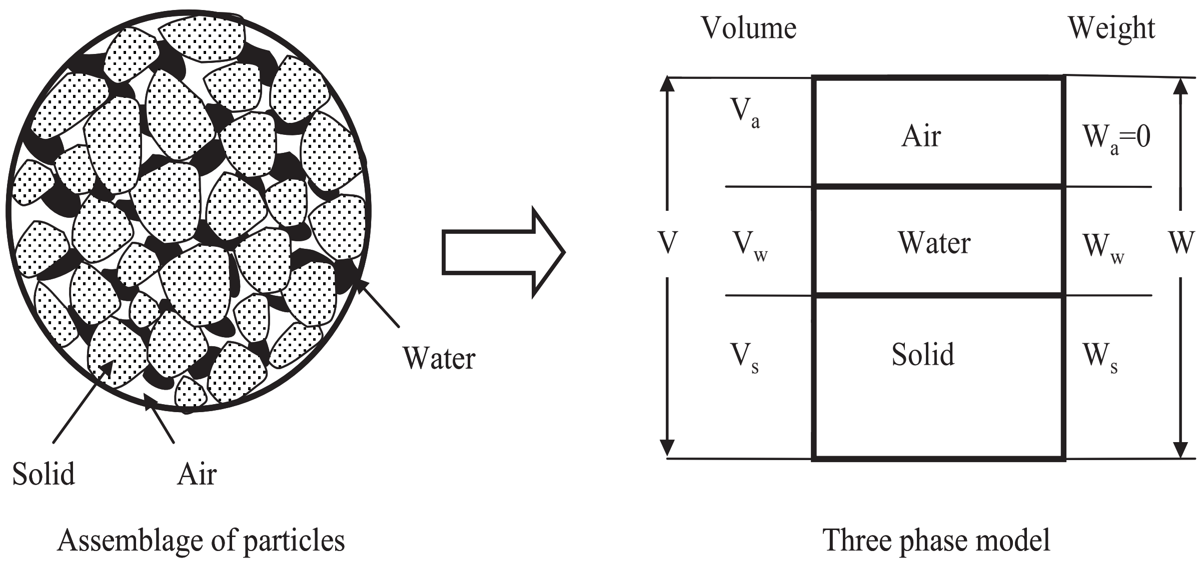
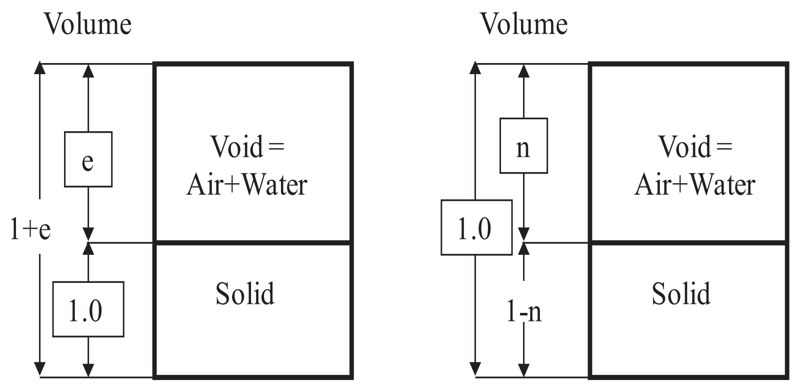


Fig. 2.4 Three phase diagram of soil

Porosity: $$n = \frac{\text{volume of void}}{\text{total volume}} = \frac{V_v}{V} = \frac{V_a + V_w}{V} \qquad (2.1)$$

Void ratio: $$e = \frac{\text{volume of void}}{\text{volume of solid}} = \frac{V_v}{V_s} \qquad (2.2)$$



(a) Definition of void ratio, e (b). Definition of porosity, n

Fig. 2.5 Relationship between porosity, n and void ratio, e

$$n = \frac{e}{1+e} \qquad \text{or} \qquad e = \frac{n}{1-n} \tag{2.3}$$

Water content: $$w = \frac{\text{weight of water}}{\text{weight of solid}} = \frac{W_w}{W_s} \quad (\text{x}100\ \%) \tag{2.4}$$

Degree of saturation:

$$S = \frac{\text{volumeof water}}{\text{volumeof volid}} = \frac{V_w}{V_v} \quad (\text{x}100\ \%) \tag{2.5}$$

Specific gravity:

$$G_S = \frac{\text{unit weight of solid}}{\text{unit weight of water}} = \frac{W_s / V_s}{\gamma_w} \tag{2.6}$$

Total unit weight:

$$\gamma_t = \frac{\text{total weight}}{\text{total volume}} = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a} \tag{2.7}$$

Dry unit weight: $$\gamma_d = \frac{\text{weight of solid}}{\text{total volume}} = \frac{W_s}{V} \tag{2.8}$$

$$\gamma_t = \frac{(1 + w)G_s}{1 + e}\gamma_w = \frac{G_s + Se}{1 + e}\gamma_w \tag{2.9}$$

$$\gamma_t = (1 + w)\frac{G_s \gamma_w}{1 + e} = (1 + w)\gamma_d \quad \text{or} \quad \gamma_d = \frac{G_s \gamma_w}{1 + e} = \frac{\gamma_t}{1 + w} \tag{2.10}$$

submerged unit weight or **buoyant unit weight**

$$\gamma' = \gamma_t - \gamma_w = \frac{G_s + Se}{1+e}\gamma_w - \gamma_w = \frac{G_s - 1 - e(1-S)}{1+e}\gamma_w$$

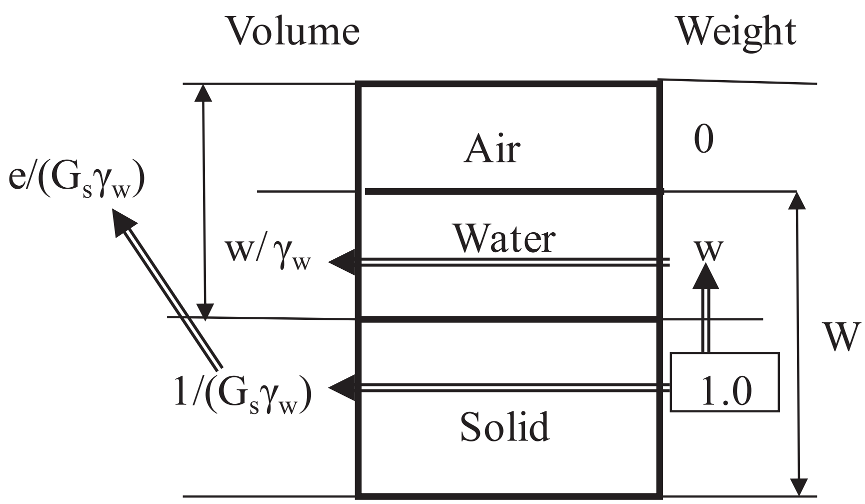
(for **partially saturated**) (2.11)

$$\gamma' = \gamma_t - \gamma_w = \frac{G_s + e}{1+e}\gamma_w - \gamma_w = \frac{G_s - 1}{1+e}\gamma_w$$

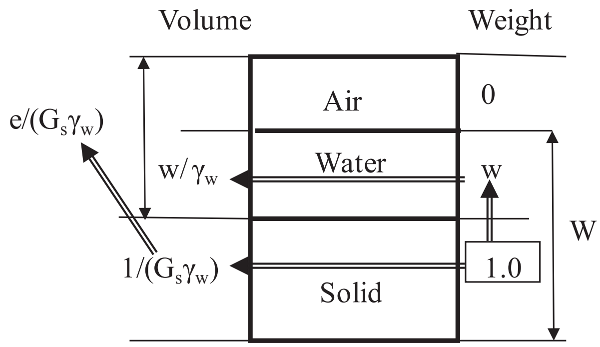
(for **fully saturated**) (2.12)

Exercise 2.1

Using three phase diagram for a general soil, derive a formula to determine γ_t from known values of S, e, w, and G_s.



first assume that W_s=1, then W_w=w



$$G_s = \frac{W_s}{V_s} / \gamma_w \ , \quad \text{thus } V_s = \frac{W_s}{G_s \gamma_w} = \frac{1}{G_s \gamma_w}$$

$$\gamma_w = \frac{W_w}{V_w} \ , \quad \text{thus } V_w = \frac{W_w}{\gamma_w} = \frac{w}{\gamma_w}$$

$$S = \frac{V_w}{V_a + V_w} \text{, thus } V_a = \frac{(1-S)V_w}{S} = \frac{(1-S)w}{S\gamma_w}$$

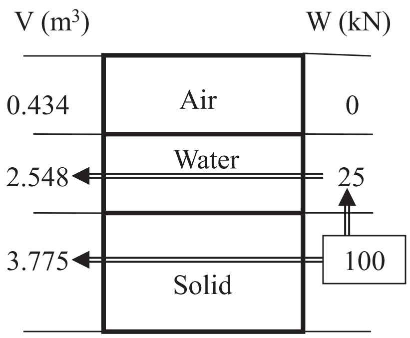
$$e = \frac{V_a + V_w}{V_s} = \frac{V_a + V_w}{1/G_s \gamma_w} \ , \ \text{thus } V_a + V_w = \frac{e}{G_s \gamma_w}$$

$$S = \frac{V_w}{V_a + V_w} = \frac{w/\gamma_w}{e/G_s \gamma_w} = \frac{wG_s}{e} \ , \quad \text{then} \quad Se = wG_s$$

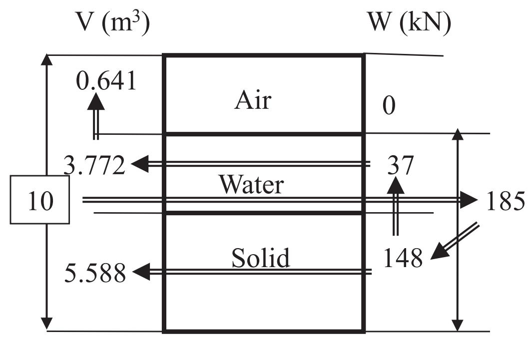
$$\gamma_t = \frac{W_s + W_w}{V_a + V_w + V_s} = \frac{1 + w}{e/G_s \gamma_w + 1/G_s \gamma_w} = \frac{(1 + w)G_s}{1 + e} \gamma_w = \frac{G_s + wG_s}{1 + e} \gamma_w = \frac{G_s + Se}{1 + e} \gamma_w$$

Exercise 2.2

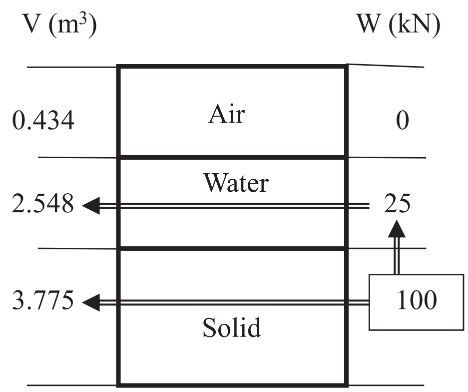
For a given soil, w=25 % and γ_t = 18.5 kN/m^3 are measured. Determine void ratio e and degree of saturation S. Assume that G_s is 2.70.



Solution (a)



Solution (b)



Solution (a)

Solution (a):

First assume W_s = 100 kN as seen in Fig. 2.6(a). Then W_w = 100 x 0.25 = 25 kN.

Calculate $V_s = W_s/G_s\gamma_w$ = 100/(2.7 x 9.81) = 3.775 m^3.

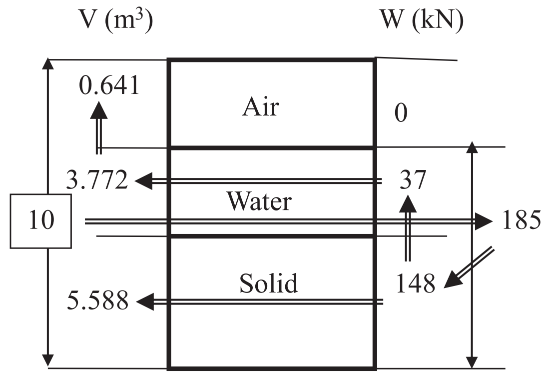
Calculate $V_w = W_w/\gamma_w$ = 25/9.81 = 2.548 m^3.

Since γ_t = 18.5 kN/m^3 = $(W_s+W_a)/(V_s+V_w+V_a)$ = (100+25)/(3.775+2.548+V_a), thus, V_a=0.434m^3.

Now, all components in the three phase are obtained as shown in Fig. 2.6(a) and,

e = $(V_w+V_a)/V_s$ = (2.548+0.434)/3.775=**0.790** ←

S = $V_w/(V_w+V_a)$ = 2.548/(2.548+0.434)=0.854=**85.4 %**. ←



Solution (b)

Solution (b):

First assume V=10 m^3 as seen in Fig. 2.6(b).

From $W_s + W_w = W_s + wW_s = (1+w)W_s = V\gamma_t = 10x18.5=185$ kN,

$W_s = 185/(1+0.25)=148$ kN, and $W_w = 185-148=37$ kN.

Using Gs as a bridge value, $V_s=W_s/G_s\gamma_w = 148/(2.7 \text{ x } 9.81) = 5.588$ m^3.

Using γ_w as abridge value, $V_w = W_w/\gamma_w = 37/9.81 = 3.772$ m^3.

Thus $V_a = V-(V_s+V_w) = 10-(5.588-3.772) = 0.641$ m^3.

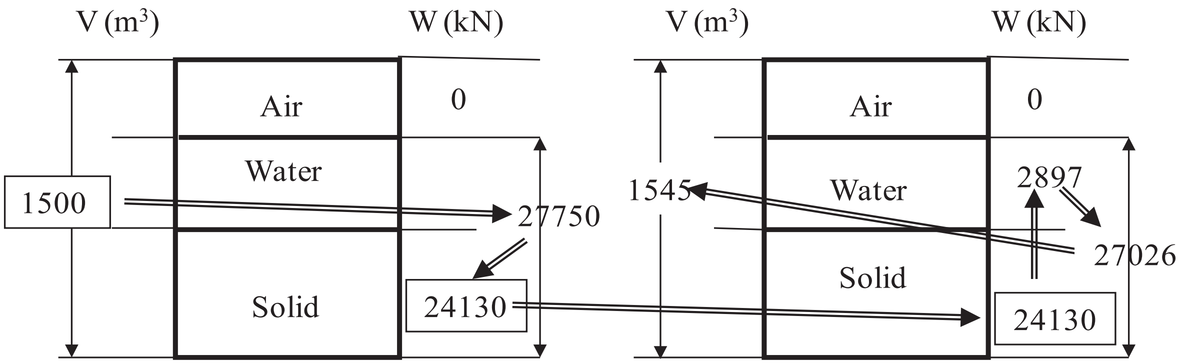
Now, all components in the three phase are obtained as shown in Fig. 2.6(b) and,

$e = (V_w+V_a)/V_s = (3.772+0.641)/5.588=$**0.789.** ←

$S = V_w/(V_w+V_a) = 3.772/(3.772+0.641)=0.855=$**85.5 %**. ←

Exercise 2.3

In a fill section of a construction site, 1500 m^3 of moist compacted soils is required. The design water content of the fill is 15 % and the design density of the compacted soil is 18.5 kN/m^3. Necessary soil is brought from a borrow site with a soil having 12 % natural water content, 17.5 kN/m^3 wet density, and G_s=2.65. How much (in cubic meters) of the borrow material is required to fill the construction fill section? And how heavy is it?



(a) Fill site (b) Borrow site

Solution:

Draw three phase diagrams of the fill site and the borrow site in Fig. 2.8(a) and 2.8(b), respectively.

First for the fill site in Fig. 2.8(a), V=1500 m^3 so that $W_s+W_w = V\gamma_t$ =1500 x 18.5 = 27750 kN.

W_s+W_w =(1+w)W_s=27750 kN, so that W_s = 27750/(1+0.15) = 24130 kN.

This much solid weight of the soil is required at the fill site.

At the borrow site, the same solid weight 24130 kN is needed as shown in Fig. 2.8(b).

Thus W_w=wW_s=0.12 x 24130 = 2897 kN, and W_s+W_w=24130+2897=**27026 kN**. ←

Since γ_t = (W_s+W_w)/V=17.5 kN/m^3, V= 27026/17.5 =**1545 m^3**. ←

Thus, 1545 m^3 of the borrow material is needed for the project carrying a total weight of 27026 kN.

2.5 Particle Size and Gradation

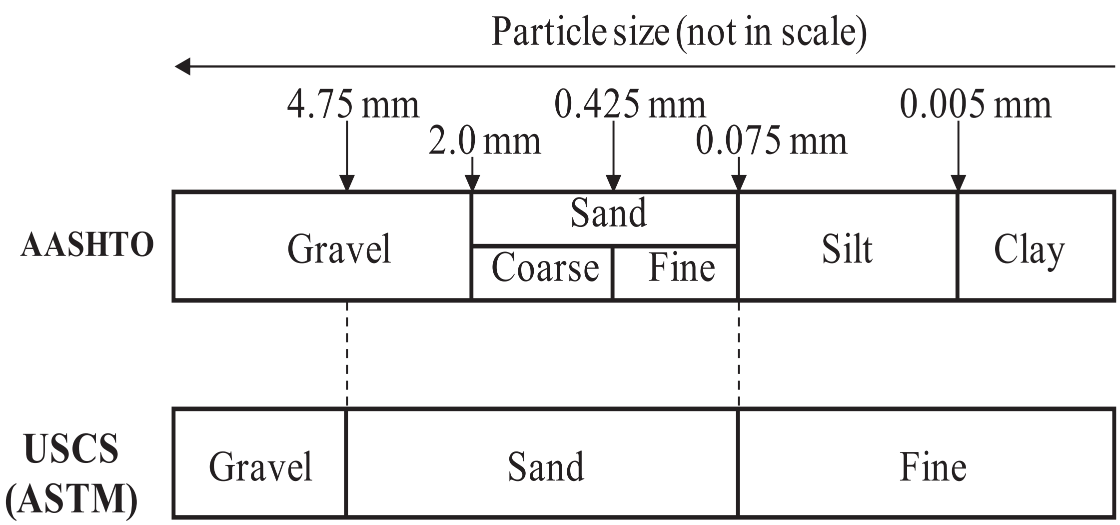


Fig. 2.9 Soil's names with grain sizes

Note: British soil classification (**BS8004, 1986**), **2 μm** is used as the boundary between **silt** and **clay**

Table 2.1 U.S. Standard Sieve Numbers and openings

U.S. Standard Sieve No.	Opening in mm
4	4.75
10	2.00
20	0.85
40	0.425
60	0.25
100	0.15
140	0.106
200	0.075

Table 2.2 Example computation of sieve analysis

	A	B	C	D	E	F
i	U.S. Standard Sieve No	Opening mm	Weight Retained gf	% Weight Retained	% Cumulative Retained	% Finer
1	4	4.75	0	0.0	0.0	100
2	10	2.00	16.8	3.1	3.1	96.9
3	20	0.85	37.8	7.0	10.1	89.9
4	40	0.425	45.9	8.5	18.5	81.5
5	60	0.25	44.4	8.2	26.7	73.3
6	100	0.15	52.5	9.7	36.4	63.6
7	140	0.106	50.7	9.3	45.7	54.3
8	200	0.075	39.0	7.2	52.9	47.1
9	Pan		255.6	47.1	100	0
10		summation	542.7	100		

Column D(i)=C(i)/C(10) x 100
Column E(1)=D(1) and E(i)=E(i-1)+D(i)
Column F(i)=100 - E(i)

Hydrometer analysis

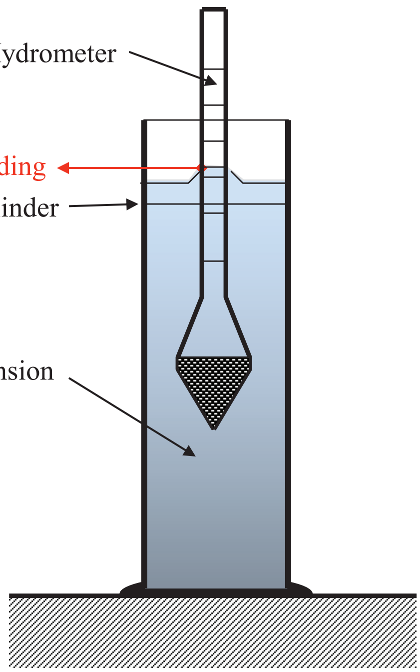


Fig. 2.10 Hydrometer test setup
(click to start the test)

Table 2.3 Example of hydrometer test result

A Particle Dia. D, mm	B % finer	C Modified % finer
0.066	84.5	45.7
0.045	74.3	40.2
0.036	68.3	37.0
0.025	58.2	31.5
0.015	48.4	26.2
0.011	42.3	22.9
0.007	34.6	18.7
0.005	28.1	15.2
0.004	24.3	13.2
0.003	20.1	10.9
0.0018	16.2	8.8
0.0012	12.3	6.7

Column C = Column B x $F_{200\ (Curve\ 1)}/F_{200(Curve\ 2)}$

Combined grain size analysis

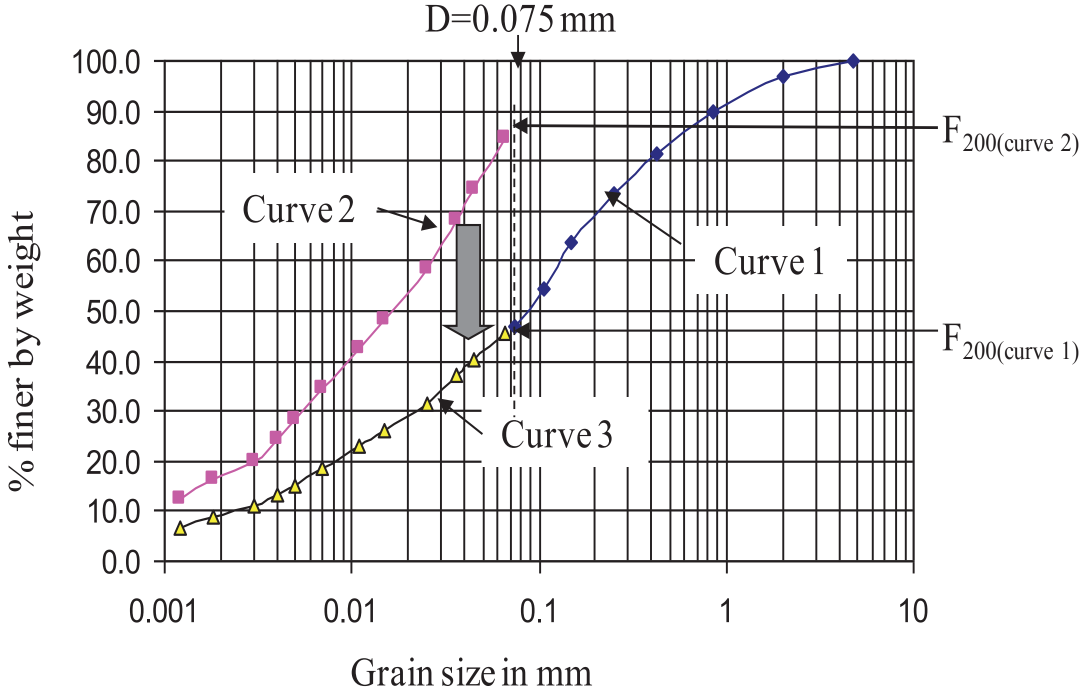


Fig. 2.11 Combined grain size analysis

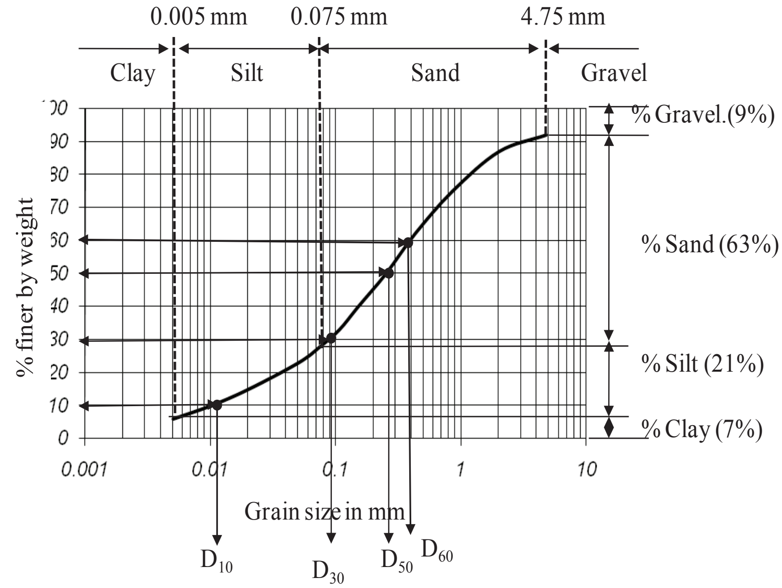


Fig. 2.12 Grain size distribution curve

D_{50}: Mean grain size

D_{10}: Effective grain size

Coefficient of uniformity $$C_u = D_{60} / D_{10} \quad (2.19)$$

Coefficient of gradation $$C_c = \frac{D_{30} / D_{10}}{D_{60} / D_{30}} = \frac{(D_{30})^2}{D_{60}\, D_{10}} \quad (2.20)$$

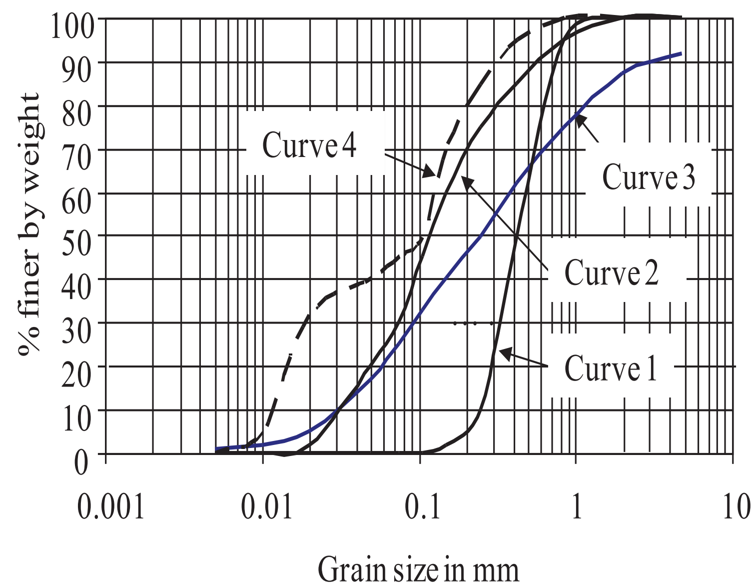


Fig. 2.13 Various grain size distribution curves

uniformly graded (or **poorly graded**) **soil**

well graded soil

gap graded soils