GEOTECHNICAL ENGG. – I (VI sem)

UNIT-1

(Part-2 Index properties of soil)

(Part-2 (iv) Particle size distribution)

Index Properties of Soil:

4. Particle Size Distribution:

This classification test determines the range of sizes of particles in the soil and the percentage of particles in each of these size ranges. This is also called 'grain-size distribution'; 'Mechanical analysis' means the separation of a soil into its different size fractions.

The particle-size distribution is found in two stages:

(i) Sieve analysis- for the coarse fraction.

(ii) Sedimentation analysis or wet analysis- for the fine fraction.

Nomenclature of Grain Sizes

Natural soils are mixtures of particles of various sizes and it is necessary to have a nomenclature for the various fractions comprising particles lying between certain specified size limits.

The Indian standard nomenclature is as follows:

Gravel- 80 mm to 4.75 mm

Sand- 4.75 mm to 0.075 mm

Silt- 0.075 mm to 0.002 mm

Clay- Less than 0.002 mm

Sieve Analysis

'Sieving' is the most direct method for determining particle sizes. Sieving is a screening process in which coarser fractions of soil are separated by means of a series of graded mesh. Mechanical analysis is one of the oldest test methods for soils.

Sieve designation is specified by the number of openings per inch in the B.S. and A.S.T.M. standards, while it is specified by the size of the aperture in mm or microns in the I.S. standard. (IS: 460–1978 Revised).

The test procedure for sieve analysis has been standardised by ISI as given in IS:2720 (Part IV)–1985.

The complete sieve analysis can be divided into two parts:

1. Coarse Analysis

2. Fine Analysis

An oven-dried sample of soil is separated into fractions by sieving it through a 4.75 mm IS sieve. The portion retained on (+ 4.75 mm size) is termed as the Gravel fraction and is kept for the coarse analysis, while the portion passing through (- 4.75 mm size) is subjected to fine sieve analysis.

The following set of sieves are used for coarse sieve analysis are:

IS: 80, 60, 40, 20, 10 and 4.75 mm

The following set of sieves are used for fine sieve analysis are:

IS: 2 mm, 1 mm, 600 μ, 425 μ, 300 μ, 212 μ,150 μ and 75 μ.

The general procedure may be summarised as follows:

A series of sieves having different-size openings are stacked with the larger sizes over the smaller. A pan is kept at the bottom and a cover is kept at the top of the assembly. The soil sample to be tested is dried, clumps are broken if necessary, and the sample is passed through the series of sieves by shaking. The fractions retained on and passing 2 mm IS Sieve are tested separately. An automatic sieve-shaker, run by an electric motor, may be used. About 10 to 15 minutes of shaking is considered adequate. Larger particles are caught on the upper sieves, while the smaller ones filter through to be caught on one of the smaller underlying sieves.

The material retained on any particular sieve should naturally include that retained on the sieves on top of it, since the sieves are arranged with the aperture size decreasing from top to bottom. The weight of material retained on each sieve is converted to a percentage of the total sample. The percentage material finer than a sieve size may be got by subtracting this from 100. The material passing the bottom-most sieve, which is usually the 75–μ sieve, is used for conducting sedimentation analysis for the fine fraction.

$$\% \text{ Retained on particular sieve } = \frac{\text{Weight of soil retained on that sieve}}{\text{Total weight of soil taken}} \times 100$$

Cumulative % retained = Sum of % retained on all sieves of larger sizes and the % retained

on that particular sieve

Percentage finer than sieve under reference = 100% - cumulative % retained

If the soil is clayey in nature the fine fraction cannot be easily passed through the 75–μ sieve in the dry condition. In such a case, the material is to be washed through it with water, until the wash water is fairly clean. The material which passes through the sieve is obtained by evaporation. This is called 'Wet sieve analysis, and may be required in the case of cohesive granular soils.

Soil grains are not of an equal dimension in all directions. Hence, the size of a sieve opening will not represent the largest or the smallest dimension of a particle, but some intermediate dimension, if the particle is aligned so that the greatest dimension is perpendicular to the sieve opening.

The resulting data are conventionally presented as a "Particle-size distribution curve" (or "Grain-size distribution curve"–the two terms being used synonymously hereafter) plotted on semi-log co-ordinates, where the sieve size is on a horizontal 'logarithmic' scale, and the percentage by weight of the size smaller than a particular sieve-size is on a vertical 'arithmetic' scale. The "reversed" logarithmic scale is only for convenience in presenting coarser to finer particles from left to right.

Logarithmic scales for the particle diameter give a very convenient representation of the sizes because a wide range of particle diameter can be shown in a single plot; also, a different scale need not be chosen for representing the fine fraction with the same degree of precision as the coarse fraction.

Sedimentation Analysis (Wet Analysis)

If the soil contains a substantial (say, more than 5%) of fine particles, a wet sieve analysis is required. The soil particles less than 75–μ size can be further analysed for the distribution of the various grain-sizes of the order of silt and clay be 'sedimentation analysis' or 'wet analysis'.

Sedimentation Analysis Theory

The soil fraction is kept in suspension in a liquid medium, usually water. The particles descend at velocities, related to their sizes, among other things. The analysis is based on *'Stokes Law'*.

Stokes Law

According to the law, gives the terminal velocity of a small sphere settling in a fluid of infinite extent. When a small sphere settles in a fluid, its velocity first increases under the action of gravity, but the drag force comes into action, and retards the velocity. After an initial adjustment period, steady conditions are attained and the velocity becomes constant. The velocity attained is known as terminal velocity.

'Terminal velocity' of a sphere falling through an infinite liquid medium. If a single sphere is allowed to fall in an infinite liquid medium without interference, its velocity first increases under the influence of gravity, but soon attains a constant value. This constant velocity, which

is maintained indefinitely unless the boundary conditions change, is known as the terminal velocity.

The velocity at which grains settle out of suspension, all factors being equal, is dependent upon the shape, weight and size of the grain. It is assumed that the soil particles are spherical and have the same specific gravity (average specific gravity). The principle is obvious, coarser particles tend to settle faster than finer ones.

By Stokes' law, the terminal velocity of the spherical particle is given by:

$$\mathbf{v} = \left(\frac{1}{18}\right) D^2 \left(\frac{\gamma_s - \gamma_w}{\eta}\right)$$

Where, D = diameter of spherical particles (m)

v = terminal velocity (m)

γ_s = unit weight of particles (kN/m^3)

γ_w = unit weight of water (kN/m^3) = 9.81 kN/m^3

η = viscosity of water/liquid (kN-s/m^2) = μ /g

μ = viscosity in absolute unit of poise

(1 poise = 0.1 N-s/m^2) or (1 poise = 10^{-4} kN-s/m^2)

g = acceleration due to gravity

If the water is used as the medium for suspension, γ_w is equal to 9.81 kN/m^3. Also substituting (γ_s = G γ_w), we get:

$$\mathbf{v} = \left(\frac{1}{18}\right) D^2 \left(\frac{(G - 1)\gamma_w}{\eta}\right)$$

If the above formula is expressed in the units of meters, seconds and kilo-newton. If the diameter (D) of the particles is in mm, we have:

$$\mathbf{v} = \left(\frac{1}{18}\right) \left(\frac{D}{1000}\right)^2 \left(\frac{(G - 1)\gamma_w}{\eta}\right)$$

$$\mathbf{v} = \frac{D^2 \gamma_w (G - 1)}{18 \times 10^6 \eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Putting, γ_w = 9.81 kN/m^3

$$v = \frac{D^2 (G - 1)}{1.835 \times 10^6 \, \eta}$$

Therefore,

$$D = \sqrt{\frac{18 \times 10^6 \, \eta \, v}{(G - 1) \, \gamma_w}} \quad mm \quad \text{………………..... (2)}$$

or

$$D = 1355 \sqrt{\frac{\eta \, v}{G - 1}} \quad mm$$

(1 poise = 0.1 N-s/m^2) or (1 poise = 10^{-4} kN-s/m^2)

If a particle of diameter D mm falls through a height H_e cm in t minutes,

$$v = \frac{H_e}{60 \, t} \quad cm/sec = \frac{H_e}{6000t} \quad m/sec$$

Substituting the value in eq. (2); we get

$$D = \sqrt{\frac{18 \times 10^6 \, \eta}{(G - 1) \, \gamma_w} \times \frac{H_e}{6000 \, t}} = \sqrt{\frac{3000 \, \eta}{(G - 1) \, \gamma_w}} \cdot \sqrt{\frac{H_e}{t}}$$

or

$$D = 10^{-5} \, F \sqrt{\frac{H_e}{t}}$$

Where, $F = \sqrt{\frac{3000 \, \eta}{(G - 1) \, \gamma_w}}$ is a constant factor for given values of η and G.

However, η depends upon the temperature and the factor F varies with the temperature which changes during the total time of testing.

At 27°C, the viscosity μ of distilled water is approximately 0.00855 poise.

Since 1 poise = 10^{-4} kN-s/m^2; we have

$$\eta = 0.00855 \times 10^{-4} \text{ kN-s/m}^2$$

Taking G = 2.68 in eq. (1); we get

$$v = \frac{D^2 \, (9.81) \, (2.68 - 1)}{18 \times 10^6 \times 0.00855 \times 10^{-4}}$$

$$\approx 1.077 \, D^2 \quad \text{(m/sec)}$$

The Sedimentation analysis is done either with the help of a *'Pipette method'* or a *'Hydrometer method'*.

The greater the time interval 't' allowed for suspension to settle, the finer are the particle sizes retained at the depth 'H_e'. Hence sampling at different time intervals, at this sampling depth H_e, would give the content of particles of different sizes.

If at any time interval t, M_D is the mass, per ml, of all particles smaller than the diameter D still in suspension at the depth H_e the percentage finer than D is given by:

$$N = \frac{M_D}{M_d \, / \, V} \times 1000$$

Where,   N = percentage finer than the diameter D

M_d = total dry mass of all particles put in the suspension

V = volume of suspension

Limitations of Sedimentation Analysis based on Stokes' law, or the assumptions are as follows:

(i) The finer soil particles are never perfectly spherical. Their shape is flake-like or needle-like. However, the particles are assumed to be spheres, with equivalent diameters, the basis of equivalence being the attainment of the same terminal velocity as that in the case of a perfect sphere. Thus, the sedimentation analysis gives the particles size *equivalent diameter*.

Stokes' Law is considered valid for particle diameters ranging from 0.2 to 0.0002 mm.

For particle sizes greater than 0.2 mm, turbulent motion is set up and for particle sizes smaller than 0.002 mm, Brownian motion is set up. In both these cases Stokes' law is not valid.

(ii) Stokes' law is applicable to a sphere falling freely without any interference, in an infinite liquid medium. The sedimentation analysis is conducted in a one-litre jar, the depth being finite; the walls of the jar could provide a source of interference to the free fall of particles near it. The settlement of the particles is influenced by the surrounding particles as the liquid is not of infinite extent. However, it is assumed that the effect of these sources of interference is insignificant if suspension is prepared with about 50 g of soil per litre of water.

 (iii) All the soil grains may not have the same specific gravity. Different particles may have different specific gravity, depending upon their mineral constituents. However, an average value is considered all right, since the variation may be insignificant in the case of particles constituting the fine fraction.

(iv) Particles constituting to fine soil fraction may carry surface electric charges, which have a tendency to create 'flocs. Unless these flocs are broken, the sizes calculated may be those of the flocs. Flocs can be a source of erroneous results.

A deflocculating agent, such as sodium silicate, sodium oxalate, or sodium hexametaphosphate, is used to get over this difficulty.

Pipette Method:

It is the standard sedimentation method used in the laboratory. The equipment consists of a Pipette, a jar, number of sampling bottles. Generally, a boiling tube of 500 ml capacity is used in place of a jar. A pipette for extracting samples from the jar or tube from the desired depth (H_e).

The pipette consists of:

(i) 125 ml bulb with stop cock, for keeping distilled water.

(ii) A three-way stopcock

(iii) Suction and wastewater outlets, and

(iv) Sampling pipette of 10 ml capacity.

The method consists in drawing off samples of soil suspension, 10 ml in volume, by means of this pipette from a depth of 10 cm (H_e) at various time intervals after the commencement of the sedimentation. The recommended time intervals are: 1/2, 1, 2, 4, 8 ,15 and 30 minutes, and 1, 2, 4, 8, 16 and 24 hours, reckoned from the commencement of the test. The pipette should be inserted in the boiling tube about 25 seconds before the selected time interval and the time taken for sucking the sample should not be more than 10 to 20 seconds. Each sample so taken, is transferred into suitable sampling bottles and dried in an oven. The mass M_D of solids per ml of suspension is the thus found by taking the dry mass and dividing it by 10.
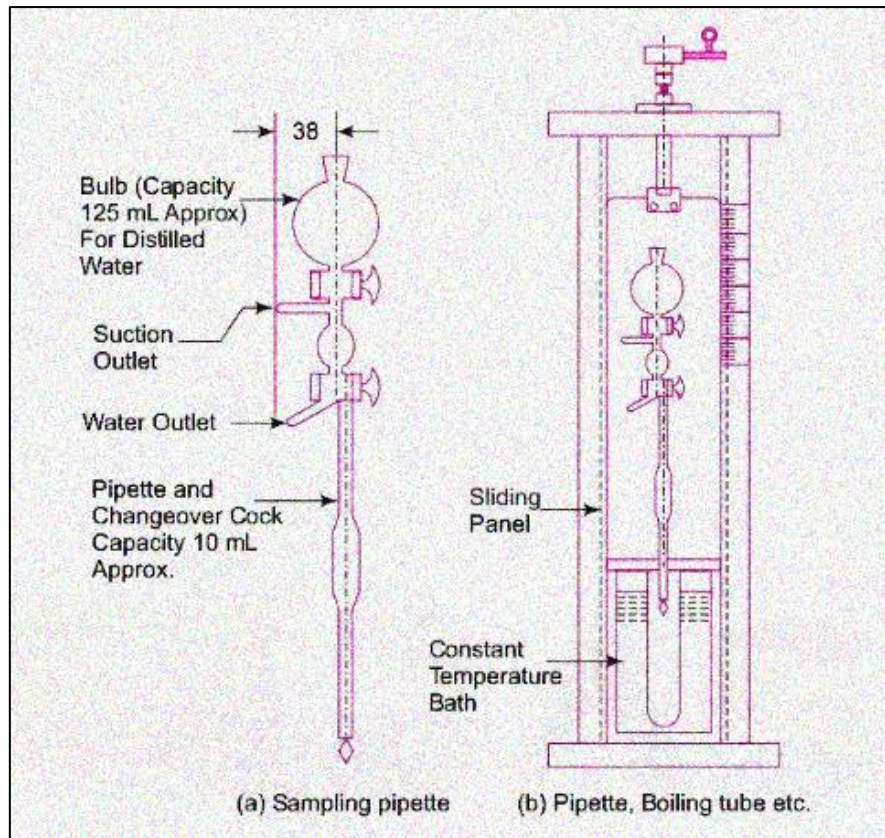
Fig 1. Pipette Analysis Apparatus

Method of preparing soil suspension

In the sedimentation analysis, only those particles which are finer than 75 micron size are included. The soil sample is washed through a 75 Micron sieve. About 12 to 30 gram of oven dried sample is accurately weighed and mixed with distilled water in a dish to form a thin smooth paste. To have proper dispersion of soil, a dispersing agent (de-flocculating agent) is added to the soil.

Some of the common dispersing agents are:

Sodium oxalate, sodium silicate and sodium polyphosphate compounds as such as tetrasodium pyrophosphate, sodium hexametaphosphate (Calgon), and sodium tripolyphosphate.

IS: 2720 (Part IV)- 1965 recommends the use of dispersing solution consisting 33 gm of the sodium hexametaphosphate and 7 gm of sodium carbonate in distilled water to make 1 litre of solution. 25 ml of this solution is added to the dish (containing the soil and distilled water) and the mixture is warmed gently for about 10 minutes. The contents are then transferred to the cup of a mechanical mixer, using a jet of distilled water to wash all traces of the soil out of the evaporating dish. The soil suspension is then stirred well for 15 minutes or longer clayey soils.

The suspension is then washed through 75 micron sieve, using the jet of distilled water and the suspension, which has passed through the sieve, is transferred to the 500ml capacity boiling tube (sedimentation tube). Care should be taken that all the particles finer than 75 micron size are transferred to the tube. The tube is then filled to the 500 ml mark, by adding distilled water. The tube is then put in a constant temperature water bath. When the temperature in the tube has been stabilized to the temperature of the bath, the soil suspension is thoroughly shaken by inverting the tube several times, and then replaced in the bath. The stopwatch, is then started, and the soil samples are collected at various time intervals, with the help of the pipette.

Those soils which contains organic matter and calcium compound, are pre-treated before the dispersing agent is mixed since these contents act as cementing agents and cause the particles to settle as aggregations of particles instead of as individuals. The process of removal of organic matter and calcium compound is known as *Pre-treatment*.

The soil is first treated with hydrogen peroxide solution to remove organic matter by oxidation.

Calculation of D and N

10 ml are collected from the soil suspension (sedimentation tube) from a depth of 10 cm, with the help of the pipette, at various time intervals. The samples are collected into the weighing bottles (sampling bottles), and kept in the oven for drying.

The mass M_D, per ml of suspension so collected is calculated as:

$$M_D = \frac{\textbf{Dry mass of sample in the weighing bottle}}{V_p}$$

Where, V_p = volume of the pipette

= volume of sample collected in the weighing bottle = 10 ml

The percentage finer calculated from the following expression:

$$N' = \frac{M_D - \frac{m}{V}}{M_d / V} \text{ x } 100$$

Where,   m = mass of dispersing agent present in the total suspension of volume V

V = Volume of suspension = 500 ml

N' = percentage finer, based on M_d

If 25 ml of dispersing agent solution, containing 33 gm of sodium hexametaphosphate and 7 gm of sodium carbonate per litre is used, we get:

$$m = \frac{33 + 7}{1000} \, x \, 25 \; = \; 1 \, gm$$

The corresponding diameter D of the particle, to which the above percentage of the soil is finer, is calculated by

$$\mathbf{D} \; = \; \sqrt{\frac{\mathbf{3000 \, \eta}}{(\mathbf{G} \, - \, 1) \, \gamma_\mathbf{w}}} \; \cdot \sqrt{\frac{\mathbf{H_e}}{\mathbf{t}}}$$

The apparatus is very sensitive, very accurate weighing are required and also takes more time. Due to these reasons, Hydrometer method of sedimentation analysis is preferred.

Hydrometer Method:

Hydrometer method of sedimentation analysis differs from the pipette analysis in the method of taking observations- the principles of the test being the same in both the cases. In the pipette analysis, the mass M_D per ml of the suspension is found directly by collecting 10 ml sample of soil suspension from the sampling depth H_e. However, in the hydrometer analysis, M_D is computed indirectly by reading the density of the soil suspension at a depth H_e, at various time intervals. In the pipette test, the sampling depth H_e is kept constant (=10 cm), while in the hydrometer test, the sampling depth (also known as effective depth) goes on increasing the particles settle with the increase in the time intervals. It is therefore necessary calibrate the hydrometer and the sedimentation jar before the start of the sedimentation test, to find a relation between H_e and the density readings of hydrometer.

Calibration of Hydrometer

The readings on the hydrometer stem give the density of the soil suspension situated at the centre of the bulb at any time. For convenience, the hydrometer readings are recorded after subtracting 1 and multiplying the remaining digits by 1000. Such a *reduced reading* is designated as R_h.

For example, if the density reading at the intersection of horizontal surface of soil suspension with the stem, is 0.010, it is recorded as 10 (i.e., $R_h = 10$). Similarly, a density reading of 0.995 is recorded as $R_h = -5$.

The hydrometer reading R_h (and also the density reading) increase in the downward direction towards the hydrometer bulb. Let H be the height, in cm, between any hydrometer reading R_h and the neck, and h the height of the bulb.

Figure shows the jar, containing the soil suspension. when the hydrometer is immersed in the jar, the water level aa rises to a1a1 the rise being equal to the volume V_h of the hydrometer divided by the internal area of cross-section A of the jar. Similarly, the level bb rises to b1b1, where bb is the level, situated at a depth H_e below the top level aa, at which is the density measurements of the soil suspension are being taken. The rise between bb and b1b1 will be approximately equal to $V_h/2\,A$. The level b1b1 is now corresponding to the centre of the bulb, but the soil particles at b1b1 are of the same concentration as they were at bb.

Therefore, we have

$$H_e = \left(H + \frac{h}{2} + \frac{V_h}{2A} \right) - \frac{V_h}{A} = H + \frac{1}{2} \left(1 - \frac{V_h}{A} \right)$$

where, H_e = effective depth

         H = the depth

which depends upon the hydrometer which depends upon the hydrometer reading R_h.
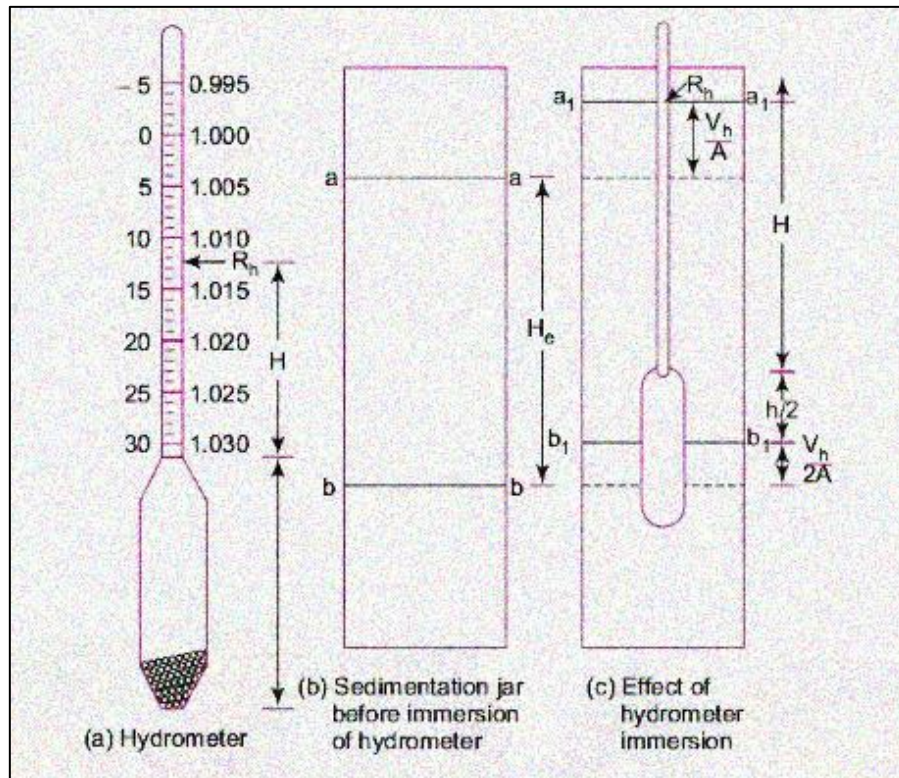

Fig 2. Hydrometer Analysis

Test Procedure

The method of preparation of the method of preparation of soil suspension is same as in the pipette method. The volume of suspension is 1000 ml in this case and hence, double the quantity of dry soil and dispersing agent is taken. The sedimentation jar (cylindrical) is shaken vigorously and is then kept vertical over a solid base. The stop watch is simultaneously started. The hydrometer is slowly inserted in the jar and reading are taken at 1/2, 1 and 2 minutes time intervals. The hydrometer is taken out. More readings are taken at the following time intervals: 4, 8, 15, 30 minutes and 1, 2, 4 hours etc. To take the reading, the hydrometer is inserted about 30 seconds before the given time interval, so that it is stable at the time when the reading is to be taken. Since, the soil suspension is opaque, the reading is taken corresponding to the upper level of the meniscus. A suitable meniscus correction is then applied to the hydrometer reading.

Corrections to the Hydrometer Readings

The following three corrections are necessary:

1. Meniscus correction

2. Temperature correction

3. Dispersing agent correction.

1. Meniscus Correction

The reading should be taken at the lower level of the meniscus. Since, the soil suspension is opaque, the reading is taken at the top of the meniscus. Actual reading, to be taken at the water level, will be more. Therefore, a correction is required to be applied to the observed reading. Since the hydrometer readings increase downward on the stem, the meniscus correction (Cm) is obviously positive.

The magnitude can be found by immersing hydrometer in a jar containing distilled water and finding the difference between the reading corresponding to the top and bottom levels of the meniscus.

2. Temperature Correction

Hydrometers are usually calibrated at a temperature of 27°C. If the temperature at the time of the soil suspension is not 27°C, a temperature correction (Ct) should be applied to the observed hydrometer reading. If the temperature at the time of test is more than 27°C, the hydrometer reading will naturally be less than what is should be and hence the temperature correction (Ct) would be positive and vice versa.

3. Dispersing Agent Correction

The addition of the deflocculating agent increases the density of the suspension and thus necessitates a correction (Cd) which is always negative. This is obtained by immersing the hydrometer, alternately in clean distilled water and a solution of the deflocculating agent in water (with the same concentration as is to be used in the test), and noting the difference in the reading.

Thus, the corrected hydrometer reading R is given by:

$$R = R_h' + Cm \pm Ct - Cd$$

where, R_h' = observed hydrometer reading at the top of the meniscus.

The three corrections can be combined into one correction, known as the Composite correction $\pm C$ and can be represented as:

$$R_h = R_h' \pm C$$

The corrected hydrometer reading (R_h)

Where, $C = Cm - Cd \pm Ct$

Calculation of D and N

The particle size D is calculated from

$$D = 10^{-5} \, F \sqrt{\frac{H_e}{t}}$$

Where, $F = \sqrt{\dfrac{3000 \, \eta}{(G - 1)\gamma_w}}$ is a constant factor.

For various time intervals, R_h is found corresponding values of H_e. Substituting the values of H_e (cm) and t (minutes), the diameter D (mm) is computed. To calculate the percentage of the soil finer than this diameter, the mass M_D per ml of suspension at effective depth H_e is first calculated as under. Since, the hydrometer readings have been recorded by subtracting 1 from the (ρ) readings and multiplying them by 1000, we have

$$R = (\rho - 1) \, 1000 \quad \text{or} \quad \rho = 1 + \frac{R}{1000} \quad \text{................ (1)}$$

where, ρ is the density reading actually marked on the hydrometer, R is the hydrometer reading corrected for the composite correction.

Now, let us consider 1 ml of soil suspension, at a time interval t, at the effective depth H_e. If M_D is the mass of solids in this 1 ml suspension, the mass of water in it will be $= 1 - \dfrac{M_D}{G}$

Total mass of 1 ml suspension $= 1 - \dfrac{M_D}{G} + M_D$

Hence density of the suspension $= 1 - \dfrac{M_D}{G} + M_D \quad \text{..................... (2)}$

Equating eq. (1) and (2), we get;

$$1 + \frac{R}{1000} = 1 - \frac{M_D}{G} + M_D$$

or

$$M_D = \frac{R}{1000} \left(\frac{G}{G - 1} \right)$$

Where G = specific gravity of soil solids (average)

Substituting the value of M_D in eq.

$$N = \frac{M_D}{M_d / V} \; x \; 1000$$

we get;

$$N' = \frac{\dfrac{R}{1000}\left(\dfrac{G}{G-1}\right)}{M_d / V} \; x \; 100$$

taking V = 1000 ml, we get;

$$\mathbf{N' = \frac{100\,G}{M_d\,(G-1)}\,R}$$

where, N' = percentage finer with respect to M_d

For various values of R, N' can be computed. For combined sieve and sedimentation analysis, if M is the total dry mass of the soil originally taken (before sieving it over 2 mm sieve), the overall percentage finer N is given by

$$\mathbf{N = N'\;x\;\frac{M'}{M}}$$

where, M' = cumulative mass passing 2 mm sieve (out of which the soil having mass M_d was

taken for the wet analysis)

M = total dry mass of soil sample

If the soil sample does not contain particles coarser than 2 mm sieve, N and N' will be equal.

Particle Size Distribution Curve

Particle size distribution curve also known as *Gradation curve*, represents the distribution of particles of different sizes in the soil mass. The grading of soil can be determined from the particle size distribution curve.

The results of the mechanical analysis are plotted to get a particle size distribution curve with the percentage finer N as the ordinate and the particle diameter as the abscissa, with the diameter plotted on a logarithmic scale. The curve gives us the idea about the type and gradation of the soil.

A soil is said to be **"*Well-graded*"**, if it contains a good representation of various grain-sizes.

If the soil contains grains of mostly one size, excess of certain particles and deficiency of the other, it is said to be *or "Poorly graded"*.

If the soil has most of the particles of the same size it is known as *"Uniformly graded"*

A curve with a flat portion represents a soil in which the intermediate size particles are missing or if it is deficient in a particular range of particle sizes. Such a soil is known as *"Gap-graded" or "Skip graded".*

The more uniform a soil is, the steeper is its grain-size distribution curve.

For coarse grained soil, certain particle sizes such as D_{10}, D_{30} and D_{60} are important. The size D_{10} represents the size, in mm such that 10% of the particles are finer than this size. The size D_{10} is sometimes called the *effective size* **or** *effective diameter*.
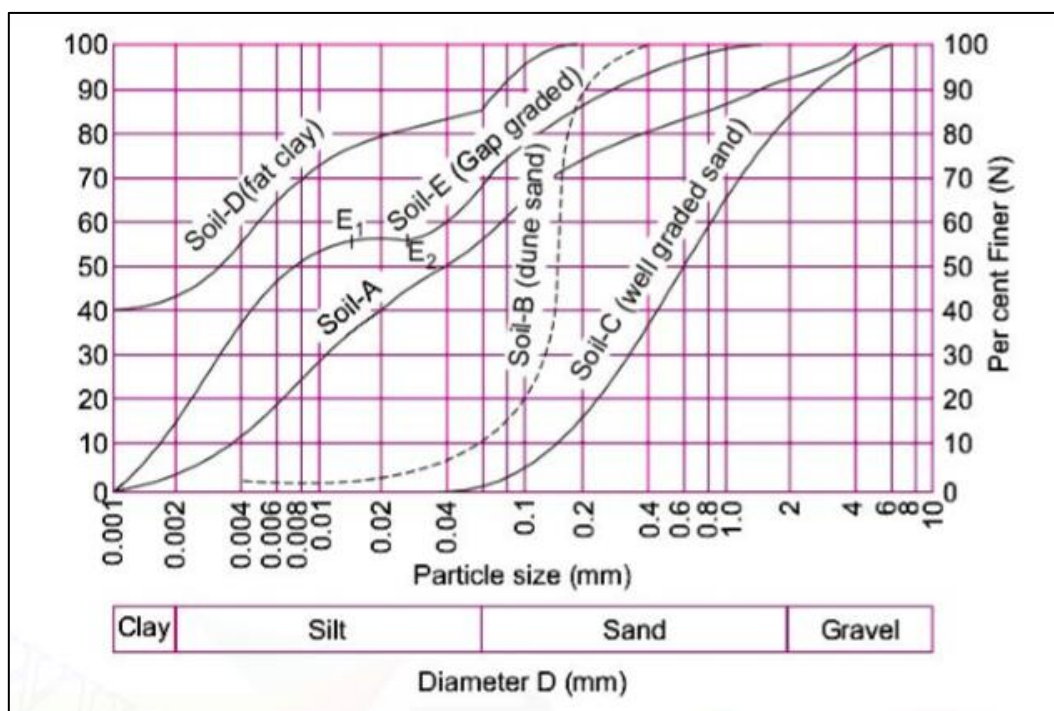

Fig 3. Particle Size Distribution Curve

Uniformity Co-efficient or (Co-efficient of Uniformity) (C_U) - It is the measure of particle-size range and is given by the ration of D_{60} and D_{10} sizes.

$$C_U = \frac{D_{60}}{D_{10}}$$

where, D_{60} = particle size such that 60% of the soil is finer than this soil.

and, D_{10} = particle size such that 10% of the soil is finer than this soil.

Larger the numerical value of C_U, more is the range of particles. For a uniformly graded soil, C_U is nearly 1, C_U must be greater than 4 for gravels and 6 for sands.

Co-efficient of Curvature (C_C)- The shape of the particle is represented by this.

$$C_C = \frac{(D_{30})^2}{D_{10} \; x \; D_{60}}$$

Where, D_{60} = particle size such that 60% of the soil is finer than this soil.

D_{30} = particle size such that 30% of the soil is finer than this soil.

D_{10} = particle size such that 10% of the soil is finer than this soil.

For a well graded soil, C_C must be between 1 and 3.