Sub-Sieve Particle Size Analysis by Different Methods

by

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Introduction

Particle size analysis signifies separation of soil grains into two or more fractions, each containing particles only of one size. This analysis furnishes information about the textural character of the soils and its grading for the purpose of classification and identification of the soils. It also helps in separating soils into different groups in respect of in-situ properties like maximum density, compression etc. In recent years, some geotechnical engineers have started using activity co-efficient as an additional index property for fine grained soils. Activity co-efficient is defined as the ratio of plasticity index to the clay fraction, where the clay fràction is finer than 0.002 mm size (ASCE Committee (1969).) Such a test is also useful in selection of the material for the construction of earth dams, roads and embankment filters.

Particle size distribution of coarse materials is done by passing the sample through a set of sieves and weighing the fraction retained on each sieve. Fractions finer than 0.075 mm are analysed by mechanical methods. The existing two methods in common use for wet analysis are hydrometer and pipette methods. Though these methods give fairly accurate results yet these are time consuming and cumbersome to determine the percentage of fractions finer than 0.075 mm.

A device called 'Plummet Balance' has been designed to give quick results for particle size distribution. Before this device is accepted as one of the standard methods for determining the particle size distribution of finer fractions, results obtained by the Plummet Balance have to be compared with those obtained by hydrometer and pipette methods. So this study is purported to evaluate the reliability of results for different types of soils as obtained by plummet balance by comparing them with the test results obtained by hydrometer and pipette methods. Plummet balance is essentially a specific gravity balance and works on the principle that depth of immersion of the plummet to a fixed depth is balanced by a beam moving on the graduated scale and the reading of the beam on the scale gives directly the percentage of fraction of a particular size at a given time (Marshall, 1956).

Methods of Analysis

Hydrometer Method

In the hydrometer method, devised by Bouyocos, 50 g. of soil passing

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0.075mm sieve is taken and a soil-water suspension of 1000cc is prepared. The solution is agitated and allowed to settle on a levelled platform. A hydrometer is suspended gently in the solution and readings are taken at regular intervals of time. Based on Stoke's law which states that

$$V = \frac{(\gamma_s - \gamma_w)}{18\mu} D^2$$

where V is the terminal velocity in cm./sec., D is the diameter of the soil particle in cm., γ_s is unit weight of the soil particle in g/cc., γ_w is unit weight of water in gm./cc. and μ is the viscosity of water in g./s./cm^2. The diameter of the falling particle is given by $D = \sqrt{\frac{18\mu}{\gamma_s - \gamma_w} \frac{Z}{t}}$ where Z is the depth of immersion in cm. and the percentage of particles smaller than the equivalent diameter D is given by

$$N = \frac{G}{G-1} \cdot (\gamma_s - \gamma_w) . \frac{V}{W} \times 100.$$

Pipette Method

This is another method used commonly in determining particle size distribution of finer fractions. It is essentially a sampling technique in which soil solution from a soil-water suspension is taken and allowed to dry. The initial procedure of preparing soil solution is similar to that for hydrometer method. From 1000cc. of soil water and suspension, 50 cc. of solution is taken by the pipette and allowed to dry. In order to ensure authenticity of results, soil suspension should be sufficiently dense such that pipette sample has sufficient solids to give accurate weighings. Calculations are again based on Stoke's law. According to this law, particles of a given size settle at the same rate wherever they exist and have the same concentration at any depth. Thus the sample collected at any time contains particles of one size which can be seen in the standard tables. The percentage by weight smaller than that diameter size D is given by

$$N = \frac{W_p}{W_s} \frac{V}{V_p} \times 100$$

where

W_s = the weight of the soil used in suspension of volume V

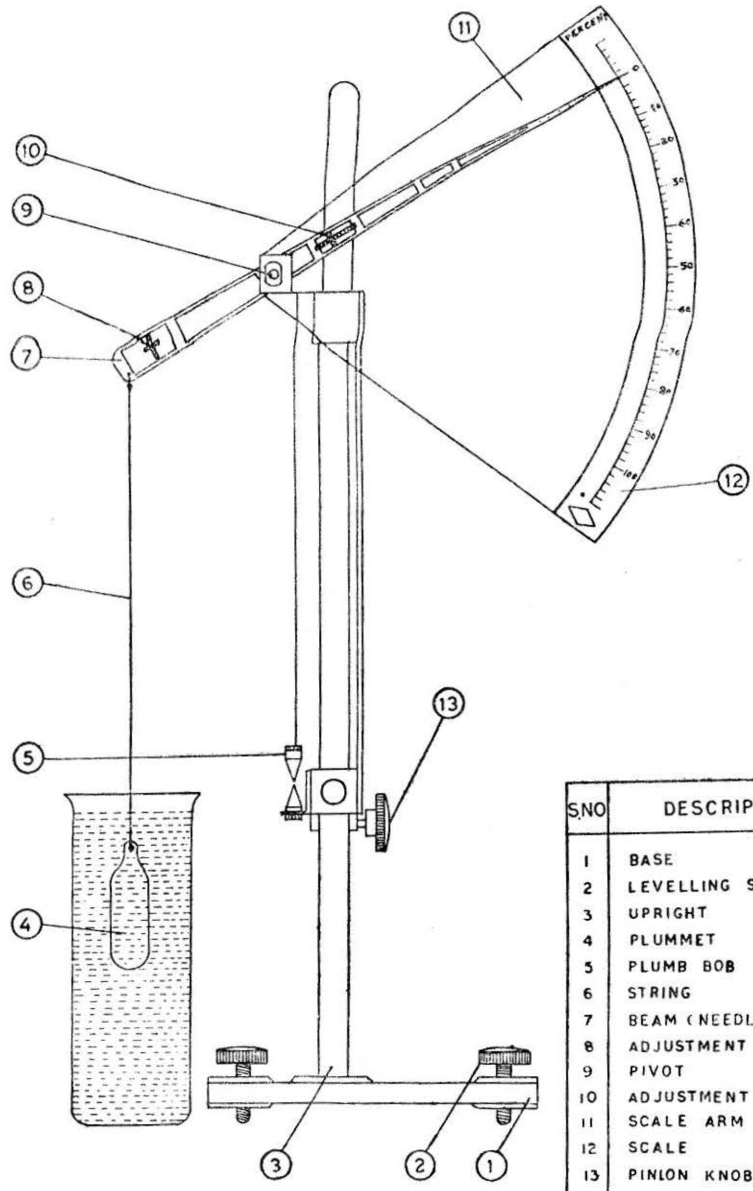
V = total volume of the suspension

W_p = weight of solids in the pipette sample

V_p = volume of the sample taken in the pipette

Plummet Balance

The plummet balance which is essentially a specific gravity balance, consists of a base with three levelling screws and an upright pillar. An arm is mounted on the pillar and this moves on a scale graduated from zero to hundred as shown in Figure 1*a*. A plummet made of perspex and



S.NO	DESCRIPTION
1	BASE
2	LEVELLING SCREW
3	UPRIGHT
4	PLUMMET
5	PLUMB BOB
6	STRING
7	BEAM (NEEDLE SHAPED)
8	ADJUSTMENT SCREW
9	PIVOT
10	ADJUSTMENT SCREW
11	SCALE ARM
12	SCALE
13	PINION KNOB

FIGURE 1*a* Plummet Balance

weighing 3g. in water, is hooked to one end of the pointer and is suspended in water to a fixed depth level. The desired depth level can be achieved by moving the pointer beam on the pillar by a rock and pinion arrangement. The pointer has two screws to adjust its position on the scale. There are two weights marked hundred and zero. With the weight marked 100 hooked to the pointer, it should read hundred. When the weight marked 0 is attached to the hook, the pointer should read zero. After these adjustments, the plummet is suspended by the pointer and dipped in water to a depth where readings are to be taken. In this position, the pointer should read zero on the scale.

A 2.0 per cent soil solution is prepared and the plummet is made to dip in the suspension to a predetermined mark. The percentage of soil particles of a given size in suspension is directly read by the pointer. The plummet is kept immersed in suspension and readings of the pointer on the scale against time are taken.

The diameter of particle in mm. is given by the following relationship.

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

where

Z = effective depth of immersion in cm

t = time in minutes when the pointer readings are taken.

K = constant to be calculated from the chart. (Fig. 1*b*)

Percentage finer is plotted against diameter in the log scale to obtain the particle size distribution curve.

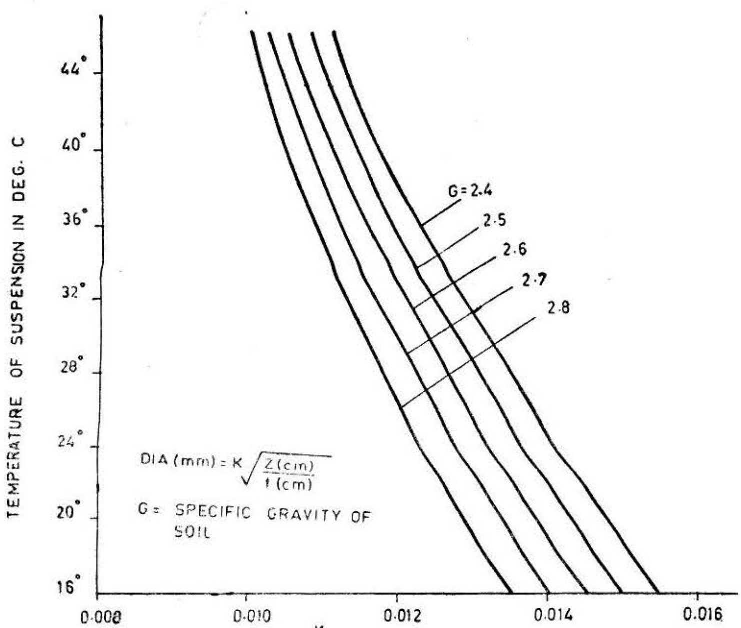


FIGURE 1*b* Chart for aid in solving Stoke's equation

Laboratory Tests

In order to examine the reliability of results obtained with plummet balance, grain size analysis curves were plotted for six soils ranging from very clayey ones to sandy soils. Soils selected for investigation had the following physical characteristics

TABLE 1

Soil Type	Physical Characteristics LL %	PI %	Clay Content %	Specific Gravity %
Black Cotton Soil	72.3	45.0	40.0	2.57
Bentonite Clay	126.3	50.3	93.0	2.59
Clayey Soil	45.0	22.0	43.5	2.66
Alluvial Soil	28.0	10.0	18.0	2.61
Silty Soil	18.5	6.2	17.2	2.57
Sandy Soil	12.8	3.0	11.0	2.62

In the case of test analysis by plummet balance, the quantity of soil taken was 20g. as directed in the guidelines while in other two methods, the quantity of soil taken for each was 50g. As a substantial amount of divergence was discerned between the percent values obtained by plummet balance and those obtained by hydrometer and pipette methods, so thirty gram of soil was taken to get 0.03 per cent solution for the plummet balance tests to get more proximate values.

Grain size distribution curves as obtained by these three methods for all the soils are given in Figure 2 and are also tabulated in Table 2.

Discussion

For a detailed comprehension of results, a comparison of percentages passing various sizes as obtained by three methods for different soils has been made and is discussed below.

Plummet Balance Versus Hydrometer Method

In the case of clayey soil, percentage values passing various fractions as obtained by hydrometer method are significantly more than those obtained by plummet balance. The magnitude of difference is quite consistent for all fractions and is of the order of about 30 per cent or more for finer fractions. In view of the large gap between the percentage values as obtained by these two methods, the concentration of soil solution taken for analysis with plummet balance was increased to 0.03 per cent. Percentage values for various fractions obtained with 0.03 per cent solution are appreciably more than the values obtained with 0.02 per cent soil solution and are comparable to those obtained with hydrometer method.

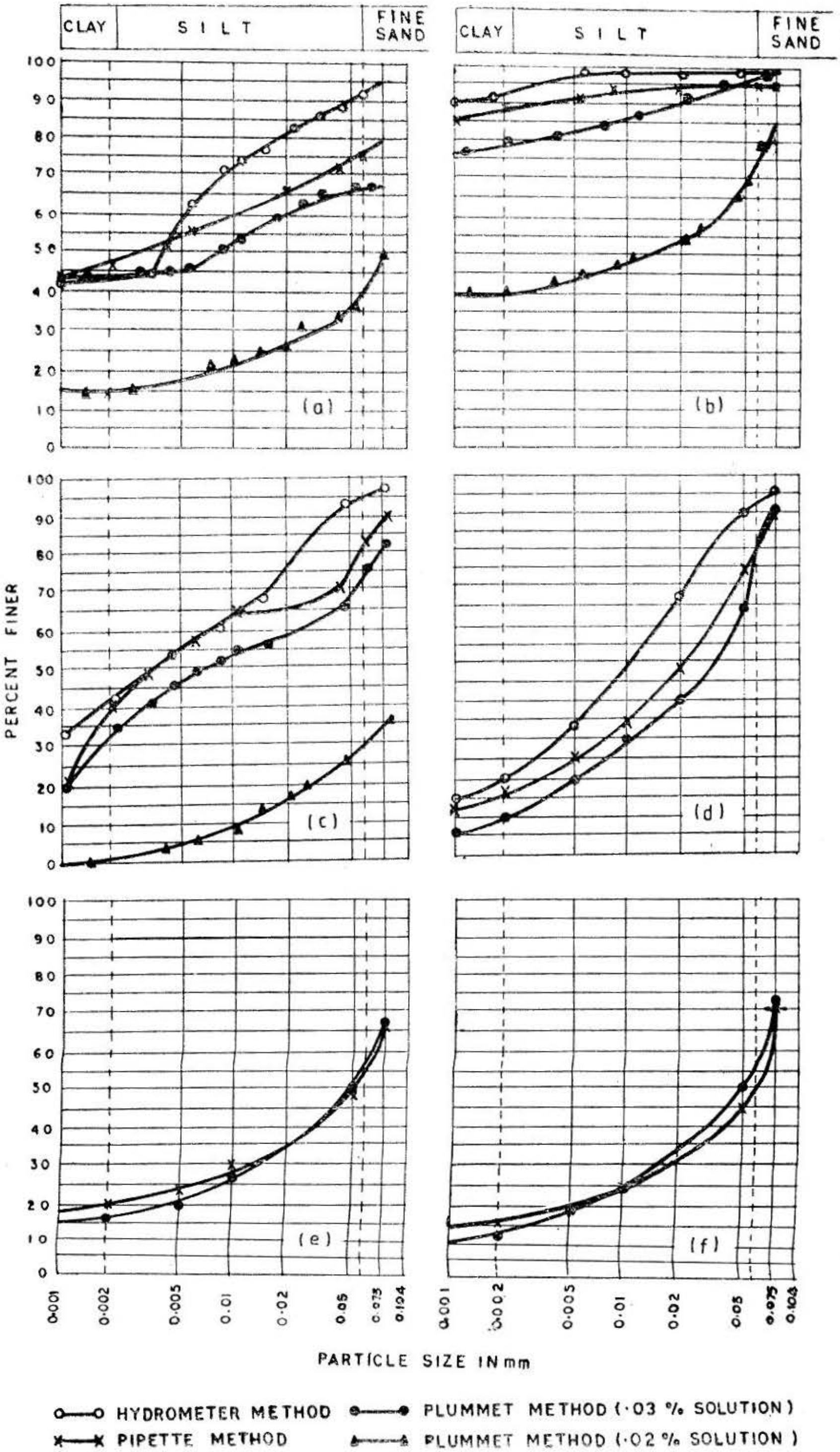


FIGURE 2 Particle Size Distribution

(*a*) Black Cotton Soil; (*b*) Bentonite Clay; (*c*) Clayey Soil; (*d*) Alluvial Soil; (*e*) Silty Soil; (*f*) Sandy Soil.

TABLE 2

Particle Size Analysis By Various Methods

Soil Type	Particle Size (mm)	Percentage values passing various particle sizes			
		Hydrometer method (%)	Pipette method (%)	Plummet Balance (.02%)	Plummet Balance (.03%)
B.C. Soil	0.075	88.0	72.0	45.0	63.0
	0.050	85.0	69.0	33.0	62.0
	0.020	75.0	62.0	22.0	56.0
	0.005	53.0	47.0	14.0	40.0
	0.001	39.0	36.0	10.0	37.0
Bentonite Clay	0.075	98.0	96.0	86.0	97.0
	0.050	98.0	96.0	72.0	97.0
	0.020	97.0	94.0	52.5	90.0
	0.005	97.0	92.0	46.0	83.0
	0.001	90.0	85.0	40.0	77.0
Clayey Soil	0.075	97.0	91.0	35.0	83.0
	0.050	94.5	78.0	30.0	70.0
	0.020	78.0	67.0	16.0	58.0
	0.005	55.0	55.0	5.0	46.5
	0.001	33.0	19.5	1.0	19.5
Alluvial Soil	0.075	96.0	90.0	The pointer read beyond zero mark.	91.0
	0.050	90.0	74.0		63.0
	0.020	67.0	47.0		40.0
	0.005	32.0	25.0		19.0
	0.001	14.0	13.0		6.5
Silty Soil	0.075	67.1	67.1	—do—	The pointer crossed the hundred mark.
	0.050	49.1	46.2		
	0.010	28.3	29.2		
	0.005	18.9	23.6		
	0.002	16.0	20.1		
Sandy Soil	0.075	72.5	70.5	—do—	—do—
	0.050	50.0	44.8		
	0.010	23.0	24.0		
	0.005	18.8	18.9		
	0.002	12.6	16.8		

Looking at the percent values for various fractions as obtained by plummet balance with 0.03 per cent solution for clayey soils, percentages as obtained with hydrometer method are still higher than those obtained with plummet balance. To have a quantitative estimation, percentage value for fraction passing 0.075 mm for Black Cotton Soil as given by hydrometer method is

80.0 while the percentage value obtained by plummet balance is only 63.0 percent. Similar trend of results is discernible for other clayey soils. Examining the values for finer fractions, value obtained for fraction passing 0.001 mm in the case of bentonite clay is 90.0 per cent while the percentage obtained with plummet balance is only 77.0 per cent. So a disparity in percentage values for various fractions is existing in general for clayey soils. In the case of silty soil, also, the plummet balance gave values which were at large variance with the percentage values obtained by hydrometer. For sandy soils, the plummet balance gave the value less than zero mark for 0.02 per cent soil solution and crossed hundred mark when the concentration of soil solution was increased to 0.03 per cent. So the utility of the plummet balance for sub-sieve particle size analysis lies more for clayey soils.

Pipette Method Versus Plummet Balance

Percentage values passing different fractions as obtained by these two methods differ appreciably though the amount of divergence in percentage values is less than in the case of hydrometer and plummet balance methods. This is quite evident from the data given in Table 2. To narrow down the difference in values, concentration of soil solution was increased to 0.03 per cent for plummet balance tests as stated earlier. The percentage values for various fractions increased tangibly. Even with 0.03 per cent soil solution, the percentage values passing various fractions as obtained by plummet balance were slightly less than those obtained by pipette method. For silty soils also, the trend continues to be same since percentage values passing different fractions as obtained by plummet balance are slightly short of those obtained by pipette method.

Hydrometer Versus Pipette Method

Though both hydrometer and pipette methods are presently used as standard methods IS (1975) for grain size distribution yet a perceptible difference in the percent values passing different fractions as obtained by these two methods exists for clayey soils. Percentage values passing different fractions as obtained by hydrometer method are slightly more than the corresponding values obtained by pipette method. This holds good for fractions of all sizes. In the case of silty and sandy soils, the percentage values for various fractions appear to be more or less the same.

Though these two methods are widely used yet they suffer from an inherent defect. The movement of the particles is restricted by the frictional resistance offered by the walls of the soil and this allows a slight inaccuracy to creep in the results Bauer (1959), Berg (1959), Sullivan and Jacollsen (1959). It has been also reported that the length of the bulb and height of the stem of the hydrometer also affect the results, Misra (1970). Besides, the values obtained for those particles which settle soon after the stirring stops, are not taken into account in both these methods. Despite these minor shortcomings, these two methods are used universally for sub-sieve grain size analysis.

Conclusions

1. In the case of clayey soils, percentage values passing various particle sizes as obtained by hydrometer method are slightly more than the corresponding values as obtained by pipette method. For silty and sandy soils, the percentage values for different particle sizes are more or less the same.

2. Percentage values passing different fractions as obtained by hydrometer and pipette methods are tangibly more than the corresponding percentage values as obtained by plummet balance. This is true both for clayey and silty soils.

3. However, if the concentration of soil solution is increased from 0.02 to 0.03 per cent in the case of plummet balance, percentage values for different fractions increase appreciably and become fairly proximate to those obtained by hydrometer and pipette methods.

4. Plummet balance is a handy tool for quick determination of particle size distribution if the soil solution taken is 0.03 per cent and is useful in situations where a general idea along the textural composition of a soil is required and where a large number of soil samples are to be analysed in a short period. In case a high order of accuracy is desired, the hydrometer and pipette methods stand out to be the better methods.

5. Plummet balance has more utility for clayey soil than for sandy soils.

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References

ASCE Committee on Soil Properties, (1969), 'Standardisation of Particle Size Ranges', Jour of SMFE, Vol, 98, SM 5.

BAUER, E.E. (1959), 'Recent Developments in the Hydrometer Method Applied to Soils', *Symposium on Particle Size Measurements*. ASTM, STP 234, pp. 89-96.

BERG, S., (1959), "Determination of Particle Size Distribution by Examining Gravitational and Centrifugal Sedimentation According to the Pipette Method and with Divers". *Symposium on Particle Size Analysis and Measurement*. ASTM, STP 234, pp. 143-14.

IS (1975), 'Methods of Test for Soils. Grain Size Analysis,' IS 2720, Part IV, Indian Standards Institute, New Delhi.

MARSHALL, T.J,, (1956), "A Plummet Balance for Measuring the Size Distribution of Soil Particles". *CSIRO Publication*. pp. 142-147.

MISRA, A.P-, (1970), "Influence of Hydrometer Bulb on Grain Size Analysis". Journal of Indian National Society of Soil Mechanics and Foundation Engineering. Vol. 9, 1970 pp. 445-450.

SULLIVAN, W.P. and JACOLESEN, A.E. (1959)., "Sedimentation Procedures for Determining Particle Size Distribution". *Symposium on Particle Size Analysis and Measurement*. ASTM, STP 234, pp. 78-116.