CHAPTER 3

SOIL CLASSIFICATION

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CLASSIFICATIONS USED IN THIS CHAPTER

As stated at the beginning of Chapter 1, in civil engineering a soil may be taken to include any loose sedimentary deposit. This could include sand, clay, gravel, marl, etc. In order to be able to discuss the properties of different types of soil it is first necessary to have some way of classifying them. There are several ways in which a soil may be classified: by geological origin, by mineral content, by grain size or by plasticity. The last two are most widely used by engineers, and will be dealt with in this chapter.

FIELD IDENTIFICATION

For field identification of soils the Building Research Station has adopted a simple series of tests and this table is reproduced here (*see* Table 2).

Table 2. general basis for field identification and classification of soils

	Size and nature of particles		*Composite types 3*
	Principal soil types 1 2		
	Types	*Field identification*	
Coarse grained, non-cohesive	Boulders Cobbles	Larger than 200 mm in diameter Mostly between 200 mm and 80 mm	Boulder gravels Hoggin Sandy gravels
	Gravels	Mostly between 80 mm and 2 mm sieve	
	Uniform Graded	Composed of particles mostly between 2 mm and 63 pm sieves, and visible to the naked eye. Very little or no cohesion when dry Sands Sands may be classified as uniform or well graded according to the distribution of particle size Uniform sands may be divided into coarse sands between 2 mm and 0-5 mm sieves, medium sands between 0*5 mm and 0-25 mm sieves and fine sands between 0-25 and 63 pm sieves	Silty sands Micaceous sands Lateritic sands Clayey sands
Fine grained, cohesive	Low Plasticity	Particles mostly passing 63 pm sieve Particles mostly invisible or barely visible to the naked eye. Some plasticity Silts and exhibits marked dilatancy. Dries moderately quickly and can be dusted off the fingers. Dry lumps possess cohesion, but can be powdered easily in the fingers	Loams Clayey silts Organic silts Micaceous silts

	Medium Plasticity High Plasticity	Dry lumps can be broken but not powdered. They also disintegrate under water Smooth touch and plastic, no dilatancy. Clays Sticks to the fingers and dries slowly Shrinks appreciably on drying, usually showing cracks Lean and fat clays show those properties to a moderate and high degree respectively	Boulder clays Sandy clays Silty clays Marls Organic clays Lateritic clays
Organic	Peats	Fibrous organic material, usually brown or black in colour	Sandy, silty or clayey peats
	Strength and structural characteristics		
	Strength 4		Strength 5
Term	*Field test*	*Term*	*Field identification*
Loose	Can be excavated with spade. 50 mm wooden peg can be easily driven	Homogeneous	Deposit consisting essentially of one type
Compact	Requires pick for excavation. 50 mm wooden peg hard to drive more than a few inches		
Slightly cemented	Visual examination Pick removes soil in lumps which can be abraded with thumb	Stratified	Alternating layers of varying types
Soft	Easily moulded in the fingers	Homogeneous	Deposit consisting essentially of one type
Firm	Can be moulded by strong pressure in the fingers	Stratified	Alternating layers of varying types
Very soft Soft Firm Stiff	Exudes between fingers when squeezed in fist Easily moulded in fingers Can be moulded by strong pressure in the fingers Cannot be moulded in fingers	Fissured Intact Homogeneous Stratified	Breaks into polyhedral fragments along fissure planes No fissures Deposits consisting essentially of one type Alternating layers of varying types. If layers are thin the soil may be described as laminated
Hard	Brittle or very tough	Weathered	Usually exhibits crumb or columnar structure
Firm Spongy	Fibres compressed together Very compressible and open structure		

If you were responsible for carrying out preliminary site investigations you could prepare a scheme of simple tests for examining and identifying any soil you might encounter. The tests should require no special apparatus, and their purpose should be:

(*a*) To distinguish between the main soil types.
(*b*) To assess the strength and structure of the soil.

Grain size. In this system, soils are split into coarse-grained noncohesive, fine-grained cohesive and organic soils. They are then further subdivided into gravels, sands, silts, etc. The division of the coarse-grained non-cohesive soils into gravels and sands is according to grain size, which is readily determined by sieving.

Plasticity. The fine-gramed cohesive soils are divided into silts and clays according to their plasticity. In the field, plasticity is determined by touch. Clays cannot be powdered when dry and are sticky when wet. Silts, on the other hand, are readily powdered when dry, and exhibit marked dilatancy when wet, that is, the moisture at the surface will recede if pressure is applied. Most students will have observed this phenomenon if they have stepped on damp fine sand on the beach and noticed the "dry" patch which forms around the foot. Most soils are a mixture of the various types, and a few examples of composite types are given in column 3.

The tests to assess the strength of the soil give in column 4 are very easy to apply, and the structure in column 5 is determined by simple visual examination.

It should be remembered that this classification is merely for use in the field. More elaborate tests are required for complete classification and for determining the strength of a soil.

PARTICLE SIZE DISTRIBUTION

Most systems of soil classification depend to some extent upon the distribution of various-sized particles in the soil. For coarse-grained material this distribution may be determined by sieving, and for finer particles a method of measuring the rate of settlement in water is used. The determination of particle-sized distribution by these methods is known as *mechanical* analysis.

Several systems of particle-size classification are in use, but the British Standards Institution had adopted that evolved by the Massachusetts Institute of Technology, since the boundaries of the main divisions correspond, approximately, to important changes in the engineering properties of the soil. These boundaries, together with a detailed description of the tests, are given in B.S. 1377: 1975, and therefore only a brief description is given here (see Table 1).

Table 1. particle size limits

Type	*Range of particle size, mm*
Cobbles	200-60
Coarse gravel	60-20
Medium gravel	20-6

Fine gravel	6-2
Coarse sand	2-0.6
Medium sand	0.6-0.2
Fine sand	0.2-0.06
Coarse silt	0.06-0.02
Medium silt	0.02-0.006
Fine silt	0.006-0.002
Clay	Less than 0-002

Coarse analysis (sieve test)

For coarse analysis either wet or dry sieving may be used. In either case an oven-dried sample of soil is weighed and passed through a batch of sieves.

The weight of dry soil retained on each sieve is recorded, and the percentage of the total sample passing each of the sieves is calculated. This percentage passing is plotted on the sand and gravel fractions of a semi-logarithmic chart as shown in Fig. 9. The silt and clay fractions of the chart are completed after fine analysis of the soil.

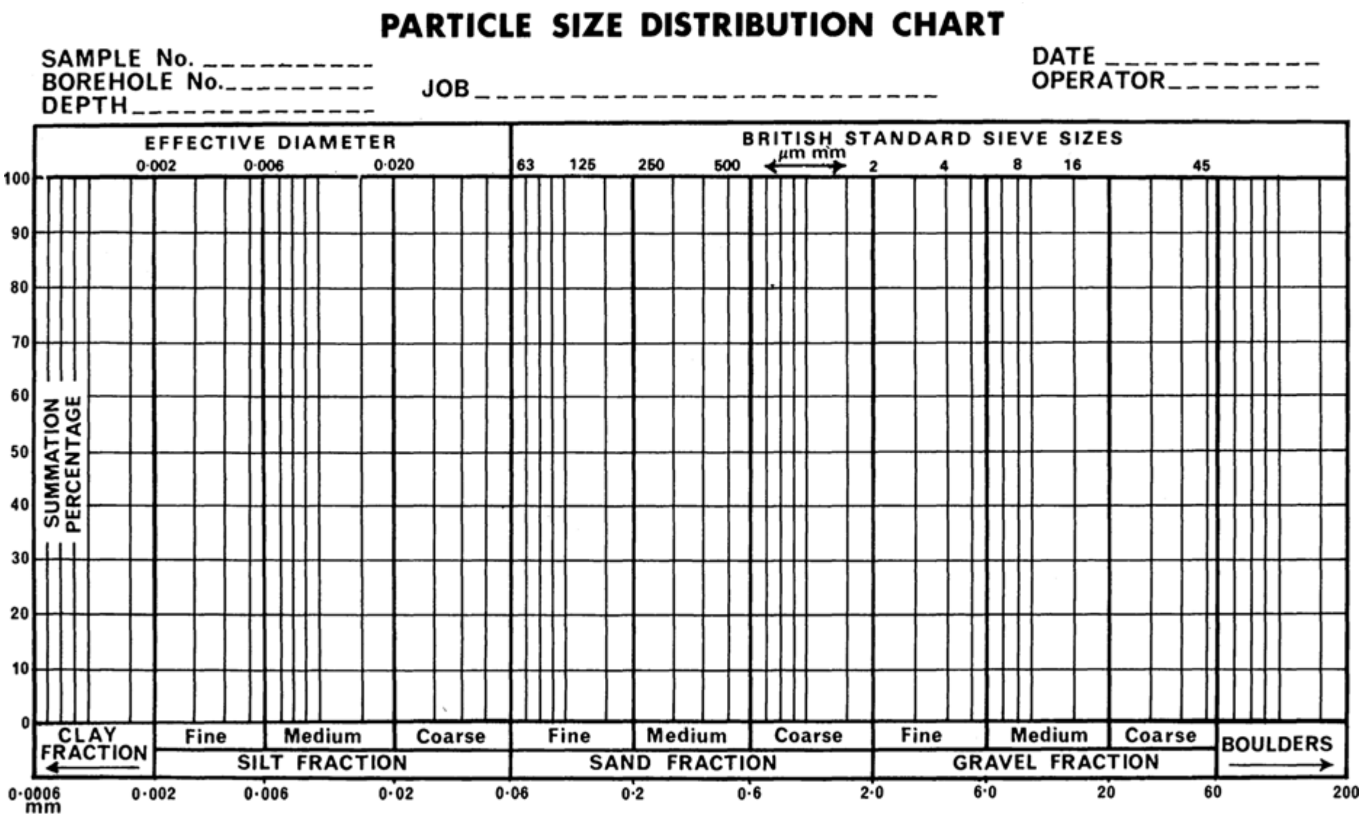


Fig. 9. Particle-size distribution chart

Fine analysis

The theory of fine analysis is based on Stokes s law of settlement, i.e. small spheres in a liquid settle at different rates according to the size of the sphere.

The terminal velocity of a spherical soil particle settling in water is expressed by Stokes's law as:

$$v = \frac{\gamma_s - \gamma_w}{18\mu_w} D^2$$

where: γ_s = Density of soil particle;

γ_w = Density of water;

μ_w = Viscosity or water;

D Diameter of the spherical particle.

For soil an average figure for γ_s is 2670 kg/m^3. The density of water γ_w is 1000 kg/m^3 and the viscosity of water at varying temperatures μ_w can be found from tables. At 20° C the viscosity is 0-001009 Ns/m^2, which gives:

$$V = \frac{(2670 - 1000) \times 9 \cdot 81}{18 \times 0 \cdot 001} D^2 \text{ m/s}$$

with D in metre units.

or $$V \simeq \underline{\underline{900\ D^2 \text{mm/s}}}$$

with D m mm units.

In practice, soil particles are never truly spherical. To overcome this, particle size is defined in terms of *equivalent diameter*, where the equivalent diameter of a particle is the diameter of an imaginary sphere of the same material which would sink in water with the same velocity as the irregular particle in question. It is this equivalent diameter, therefore, which is finally determined.

Stokes's law should only be applied to spheres between about 0-2 and 0-0002 mm in diameter. This, however, is within the limits required for classification of silt particles.

Experimental procedure for fine analysis

The soil must first be pre-treated to remove organic matter, the weight of which should be recorded. This is a lengthy and pains

taking process, described in detail in B.S. 1377. A dispersing agent is now added to prevent flocculation, and coarse particles are removed by washing through a 63 µm sieve. The material retained on the sieve is dried and treated as for sands and gravels. The washing water is then subjected to sedimentation.

There are two methods of sedimentation analysis: (*a*) the pipette method, and (*b*) the hydrometer method.

(*a*) *Pipette method*. The washing water containing the fine particles (weight W_b) is made up to 500 ml with distilled water and placed in a constant-temperature bath (*see* Fig. 10). When the suspension has reached the temperature of the bath it is taken out, shaken to disperse the particles and replaced in the bath. A stop watch is started immediately the suspension is replaced.

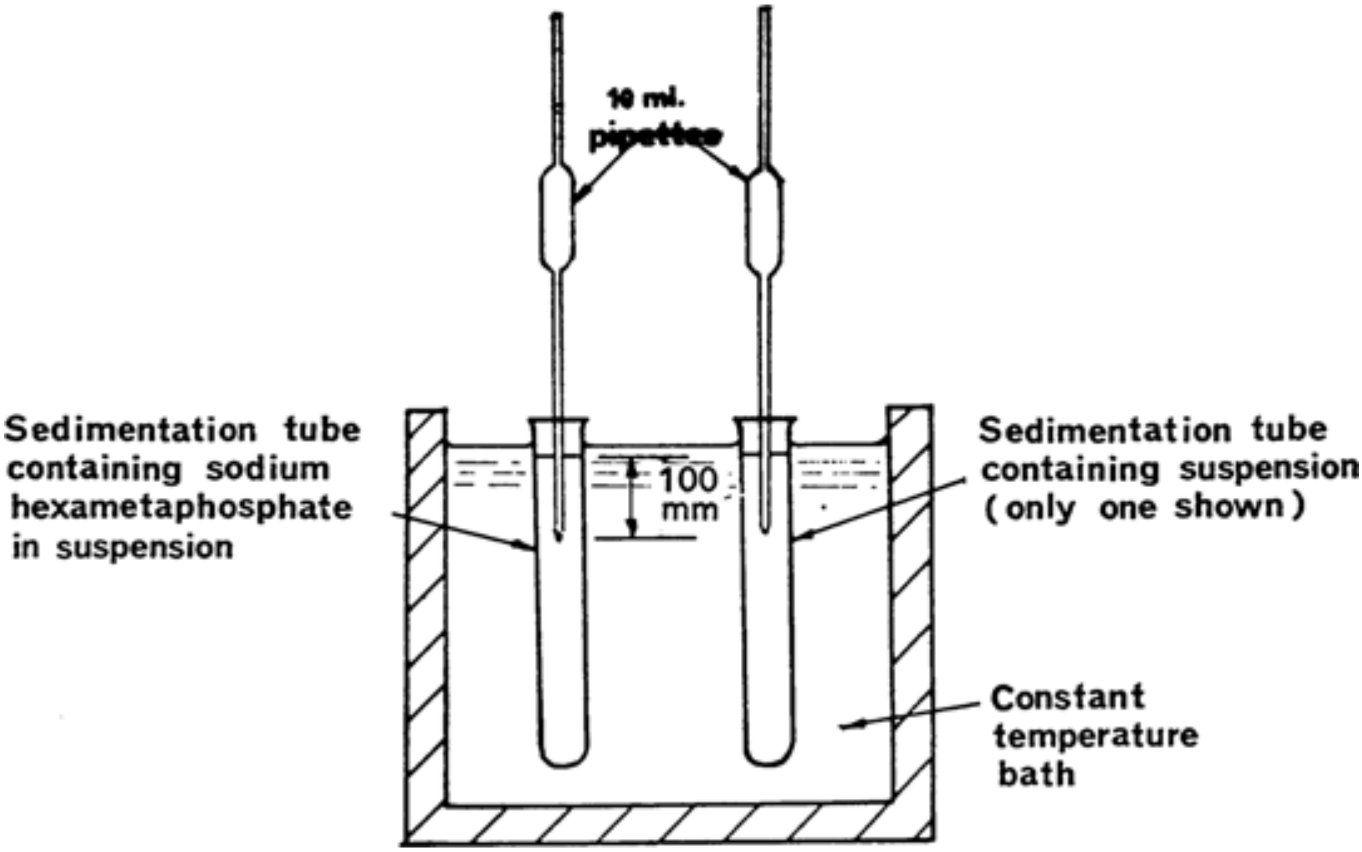


Fig. 10. Pipette method of settlement analysis

After a given time t (3-4 minutes depending on the specific gravity of the sample) a 10-ml sample of suspension is taken by pipette from a depth of 100 mm and the weight of solids in this sample found (W_D).

A correction must be made for the weight of dispersing agent (sodium hexametaphosphate) in the suspension. To do this a separate solution of the dispersing agent is tested at the same time in the same manner.

The whole procedure is repeated alter 40-50 minutes and again after a further 6-7 hours.

From Stokes's law the velocity of the particles $v = KD^2$, where K is a constant equal to

$$\frac{\gamma_s - \gamma_w}{18_{\mu w}}.$$

After time t_1 all the particles of a certain size D_1 will have settled from the surface to a depth of 100 mm. Any particles larger than size D_1 will have sunk below the 100 mm mark in the suspension. The velocity of particles size D_1 can therefore be calculated since they have moved a distance of 100 mm in known time t_1,i.e.:

$$v = \frac{h}{t_1}$$
$$KD_1 2 = \frac{h}{t_1}$$
$$D_1 2 = \frac{h}{Kt_1}$$

As h, t_1 and K are known, the maximum grain size D_1, at depth 100 mm after time t_1, can be calculated.

Since all sizes smaller than D_1 at this depth will be present in the same concentration as they were in the original suspension (*see* Fig. 11), percentage of particles less than size D_1 in original solution

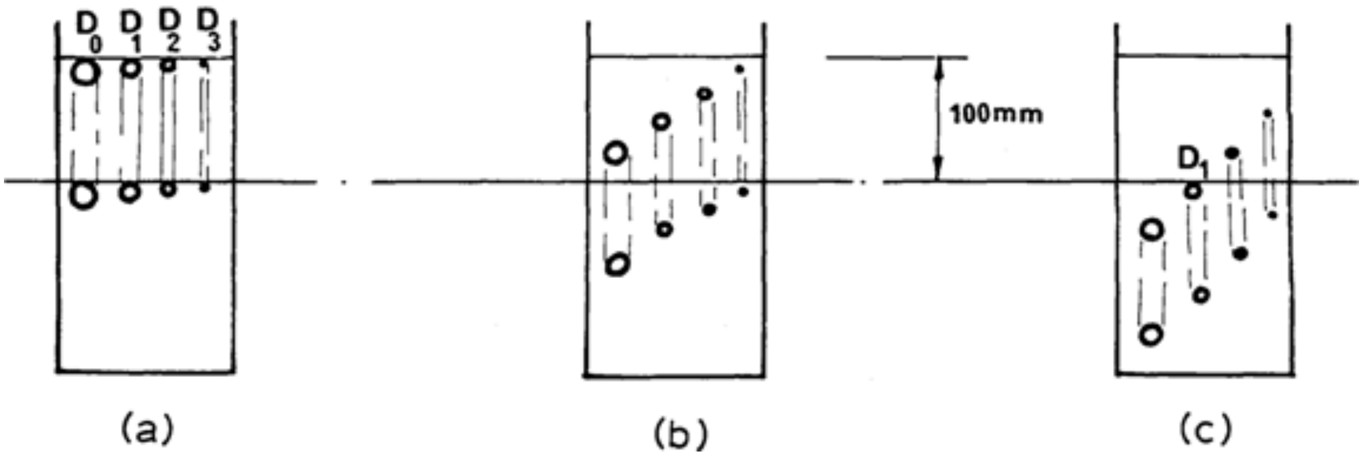


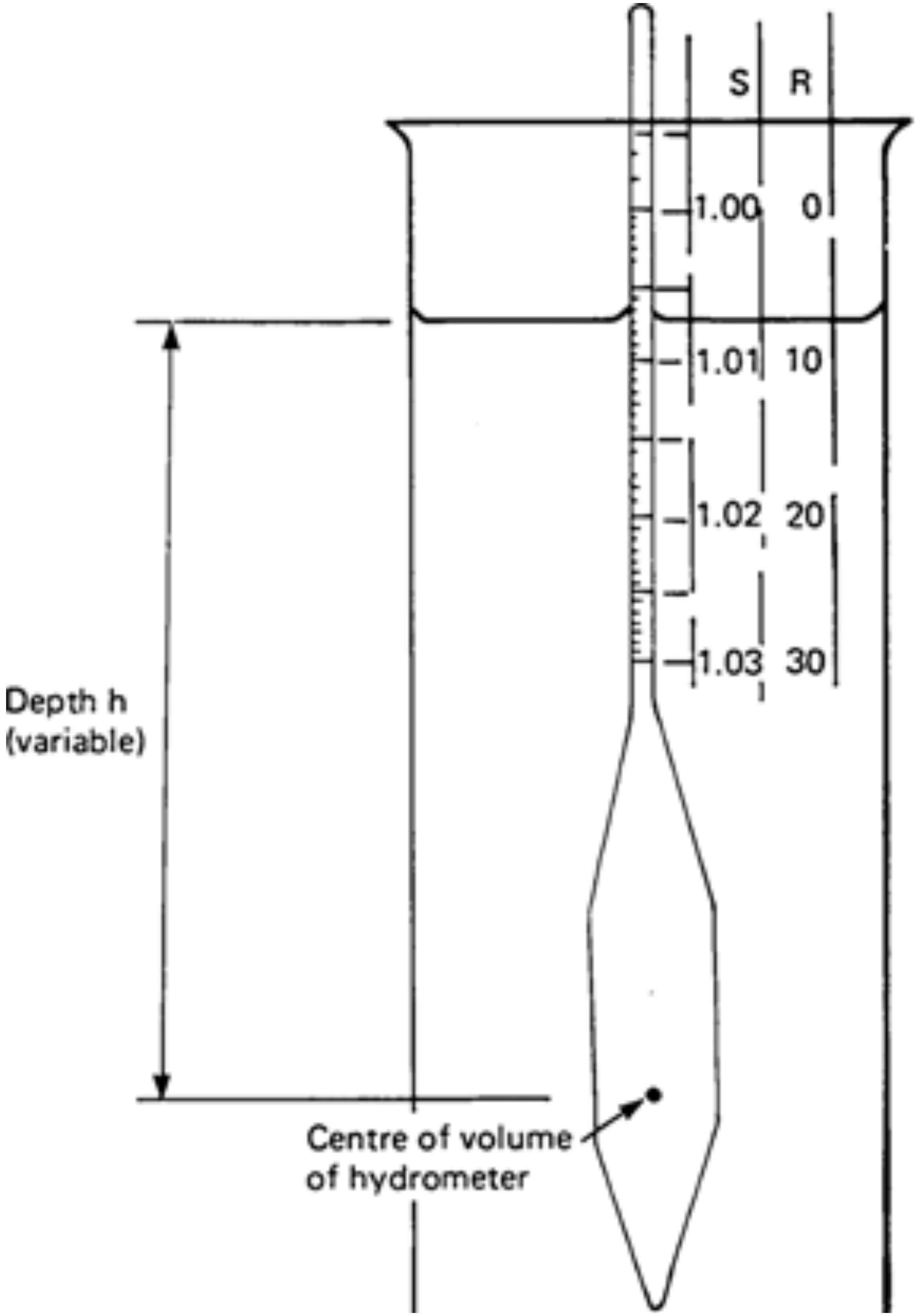
Fig. 11. Particle concentration on settlement, (a) Original suspension. Particles are completely dispersed and hence all particles sizes will be present at any horizontal section, (b) Intermediate suspension. Larger particles settle faster, (c) Suspension after time t_1. All particles larger than size D_1 have sunk below the 100 mm mark. Smaller particles are in the same concentration. Note that for convenience it is assumed that particles of the same size lie above each other.

$$N_1 = \frac{\text{Weight of solids per ml at depth 100 mm after time } t}{\text{Weight of solids per ml in original suspension}} \times 100$$

$$= \frac{W_{D1}/10}{W_b/500} \times 100$$

Values for D_2 and D_3 can be found in time t_2 and t_3. These values can be plotted in the silt and clay fraction of the particle-size distribution chart.

(*b*) *Hydrometer method*. A 1000 ml suspension of fine particles is prepared in a similar manner to that in the pipette method, and the specific gravity of the suspension at depth h is measured at given intervals of time, using a hydrometer (*see* Fig. 12).


S
R
1.00
0
1.01
10
1.02
20
1.03
30
Depth h
(variable)
Centre of volume
of hydrometer

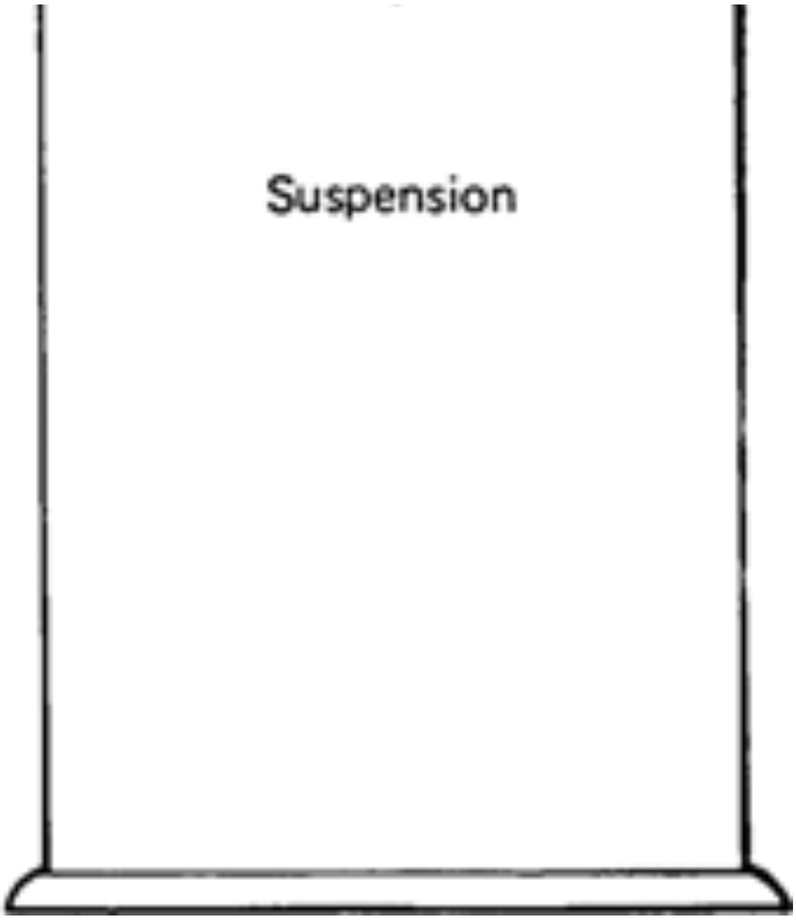


Fig. 12. Hydrometer method of settlement analysis. S = specific gravity of suspension. R = reading on hydrometer. R = (S — 1)1000.

The hydrometer gives a direct reading for the specific gravity of the suspension. For convenience, the 1 is often omitted from the specific gravity reading on hydrometers and the decimal point moved three places to the right, i.e., a reading of 12 on the hydrometer means the specific gravity of the suspension is 1-012.

Assuming units are grammes and millilitres, then $\mu_w = 1$.

In original suspension of 1000 ml:

$$\text{Weight of solids} = W_b$$

$$\therefore \quad \text{Volume of solids} V_b = \frac{W_b}{G_s \gamma_w}$$

$$\therefore \quad \text{Volume of water} = 1000 - \frac{W_b}{G_s \gamma_w}$$

$$\therefore \quad \text{Weight of water} = 1000\gamma_w - \frac{W_b}{G_s}$$

$$\text{Initial density of suspension} \gamma_i = \frac{W_b + 1000\gamma_w - W_b/G_s}{1000}$$

$$\gamma_i = \gamma_w + \frac{W_b}{1000}\left(\frac{G_s - 1}{G_s}\right)$$

and density of suspension at depth h after time t_1

$$= \gamma_t = \gamma_w + \frac{W_D}{1000}\left(\frac{G_s - 1}{G_s}\right).$$

Percentage of particles less than size D_1 in original suspension = N_1

$$N_1 = \frac{W_D}{W_b} \times 100$$
$$\therefore \quad \gamma_t = \gamma_w + \frac{N_1 W_b}{100000}\left(\frac{G_s-1}{G_s}\right)$$
$$N_1 = \left(\gamma_t - \gamma_w\right)\frac{1000000 G_s}{W_b(G_s-1)}$$
$$N_1 = \frac{100000 G_s \gamma_w}{W_b(G_s-1)}(S-1)$$
$$= \frac{100000 G_s \gamma_w}{W_b(G_s-1)} \frac{R}{1000}$$
but $\gamma_w = 1$
$$\therefore \quad N_1 = \frac{100 G_s R}{W_b(G_s-1)}$$

Readings of the hydrometer should be taken after ½ 1, 2, 4, 8, 15 and 30 minutes, 1, 2 and 4 hours, and then once or twice daily.

Corrections must be made for temperature variations and the addition of dispersing agent. It should also be noticed that as the hydrometer sinks, h will increase slightly. It is therefore normal to calibrate the hydrometer before use.

Example 6

In a sedimentation test 20 g of soil of specific gravity 2-69 and passing a 63 μ sieve were dispersed in 1000 ml of water having a viscosity of 0-001 SI units. One hour after the commencement of sedimentation, 20 ml of the suspension were taken by means of a pipette from a depth of 100 mm. The amount of solid particles (in the sample of 20 ml taken by pipette) obtained on drying was 0-07 g. Compute the following:

(a) The largest size of particle remaining in suspension at a depth of 100 mm, 1 hour after the commencement of sedimentation.

(b) The percentage of particles finer than this size in the original sample,

(c) The time interval from the commencement, after which the largest particle remaining in suspension at 100 mm depth is one-quarter of this size.

Solution

$$(a)\; v = \frac{\gamma_s - \gamma_w}{18\mu_w} D^2 = \frac{(2690-1000)\times 9\cdot 81}{18 \times 0\cdot 001}\; D^2 \text{m}/\text{s}$$
$$v = \frac{h}{t} = \frac{100}{60\times 60}\,\text{mm}/\text{s}$$
$$D = \sqrt{\frac{100\times 18\times 0-001}{60\times 60\times 1000\times 1690\times 981}}\;\text{m}$$
also $= 0-0055\text{mm}$

$$W_b = 20\text{g}$$
$$\text{at commencement volume of solids} = \frac{20}{2\cdot 69} = 7.4\text{ml}$$
$$\therefore \quad \text{volume of solution } V_{sol} = 1007.5\text{ml}$$
$$\text{after 1 hour } W_D = 0.07\text{g}$$
$$\text{percentage particles less than } 0.0055\text{mm} = \frac{W_D/20}{W_b/V_{sol}} \times 100$$
(b)
$$= \frac{0.07/20}{20/1007.5} \times 100 = 17.6\%$$

$$(c)\; v = KD^2 = \frac{h}{t}$$

if D is multiplied by ¼, then D^2 must be multiplied by 1/16 and t must be multiplied by 16, i.e. 16 hours

Example 7

(*a*) A sample ot soil weighing 50 g is dispersed in 1000 mi oi water. How long after the commencement of sedimentation should the hydrometer reading be taken in order to estimate the percentage of particles less than 0-002 mm effective diameter, if the centre of the hydrometer is 150 mm below the surface of the water?

G_s = 2.7 Viscosity of water μ = 0.001 SI units

Solution

From Stokes's law

$$v = \frac{(2700-1000)\times 9.81}{18\times 0.001}\left(\frac{0.002}{1000}\right)^2 \times 1000$$
$$= 0.0037 \text{mm/s}$$

Time of reading $= \dfrac{150}{0.0037\times 60\times 60} = 11.26\text{hr}$

Particle-size distribution curve

Coarse and fine analysis having been carried out, the particle-size distribution curve may be plotted. The soil can be described according to the shape of the curve and where it fits on to the chart.

A uniform soil, where all the particles are approximately the same size, will have an almost vertical curve. A well-graded soil, containing a wide range of particle size, will have a curve spread evenly across the chart. A poorly graded soil will stretch across the chart but be deficient in intermediate sizes. Some examples are shown in Fig. 13.

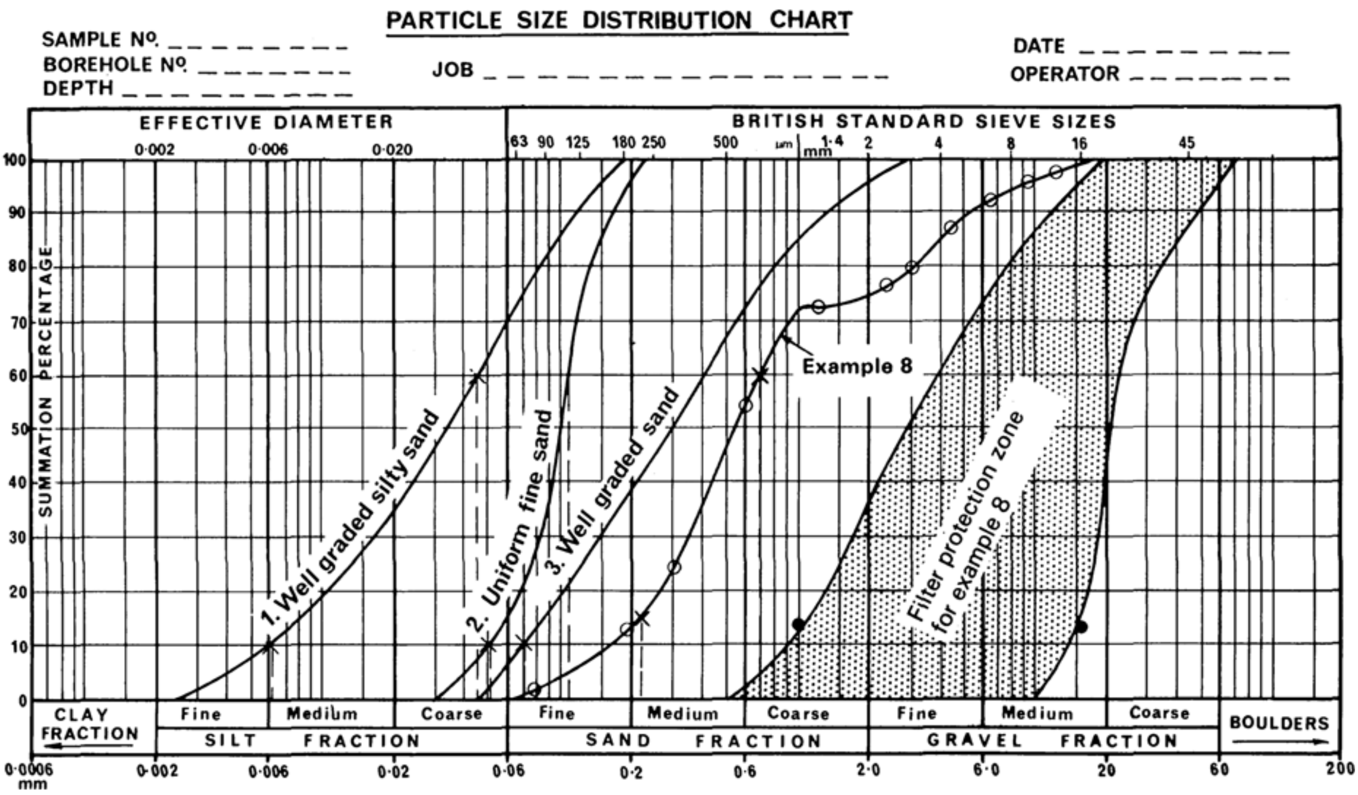


Fig. 13. Particle-size distribution chart

Effective size

This is defined as the maximum particle size of the smallest 10 per cent and is denoted as D_{10}, i.e. for curves shown in Fig. 13:

Curve 1, D_{10} = 0.006 mm

Curve 2, D_{10} = 0.052 mm

Curve 3, D_{10} = 0.07 mm

Allen Hazen's uniformity coefficient

This is the ratio of the maximum particle size of the smallest 60 per cent to the effective size, and is denoted as *U*.

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

A uniform soil will have a coefficient approaching 1, whereas a well graded soil will have a high uniformity coefficient, i.e. for curves in Fig. 13:

Curver 1, $U = \frac{0.044}{0.006} = 7.33$

Curver 2, $U = \frac{0{\cdot}11}{0{\cdot}052} = 2 \cdot 12$

Curver 3, $U = \frac{0.4}{0.07} = 5.71$

Thus uniformity coefficient and effective size give two points on the curve, which is often sufficient to define the curve.

Example 8

The results of a sieving analysis of a soil were as follows:

Retained on sieve size (mm)	*Weight retained (g)*	*Retained on sieve size (mm)*	*Weight retained (g)*
20	0	2	3.5
12.5	1.7	1.4	1.1
10	2.3	0.5	30.5
6.3	8.4	0.355	45.3
5.6	5.7	0.180	25.4
2.8	12.9	0.063	7.4

The total weight of the sample was 147.2 g.

(*a*) Plot the particle-size distribution curve and describe the soil. Comment on the "flat" part of the curve.

(***b***) State the effective grain size.
(**c**) Find Allen Hazen's uniformity coefficient.
(***d***) Design a filter suitable for protecting this soil.

Solution

Sieve Size (mm)	20	12.5	10	6.3	5.6	2.8	2.0	1.4
Weight passing (g)	147.2	145.5	143.2	134.8	129.1	116.2	112.7	111.6
Percentage passing	100	98.8	97.2	91.5	87.8	79.0	76.5	75.8

Sieve size (μm)	500	355	180	6.3
Weight passing (g)	811	35.8	10.4	3.0
Percentage passing	55.0	24.3	7.0	2.0

For curve plotted from these results *see* Fig. 13.

From Fig. 13:

(*a*) Description: poorly graded gravelly sand. The "flat" portion of the curve indicates an absence of particles around 2 mm diameter.

(*b*) D_{10} = Effective size = <u>0-21 mm</u>

(*c*) D_{60} = 0-69 mm Allen Hazen's uniformity coefficient = $\frac{D_{60}}{D_{10}}$ = 3.3

(*d*) For filter design *see* Chapter 4, p. 52.

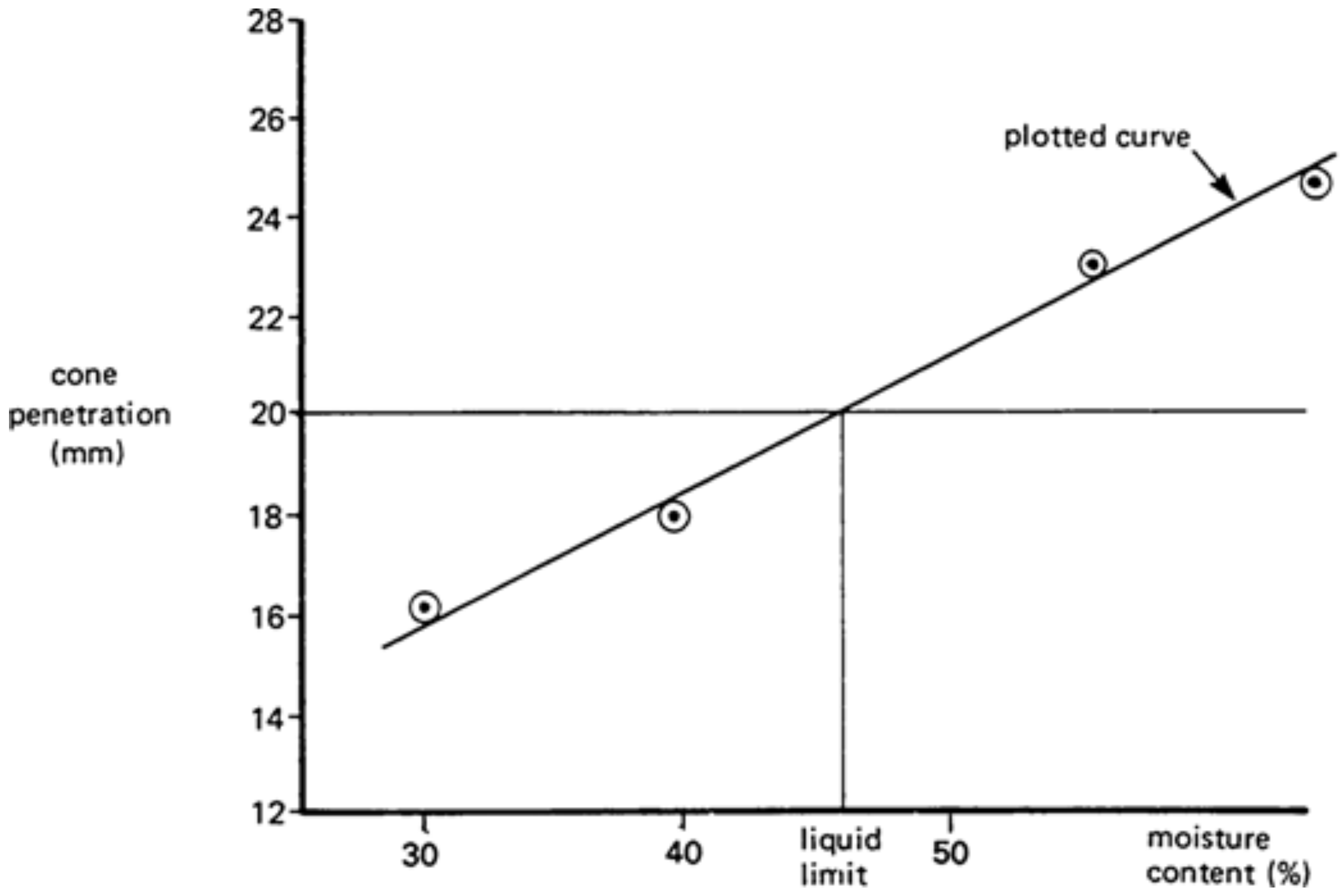


Fig. 16. Plot of penetrometer test results

PLASTICITY

Consistency limits

As moisture is removed from a fine-grained soil it passes through a series of states, i.e. liquid, plastic, semi-solid and solid. The moisture contents of a soil at the points where it passes from one stage to the next are known as *consistency limits*. These limits are defined as:

Liquid limit (*LL*). The minimum moisture content at which the soil will flow under its own weight.

Plastic limit (*P.L*). The minimum moisture content at which the soil can be rolled into a thread 3 mm diameter without breaking up.

Shrinkage limit (*S.L*). The maximum moisture content at which further loss of moisture does not cause a decrease in the volume of the soil.

The range of moisture content over which a soil is plastic is known as the *plasticity index* and is denoted as I_p.

These definitions may be shown diagrammatically (*see* Fig. 14).

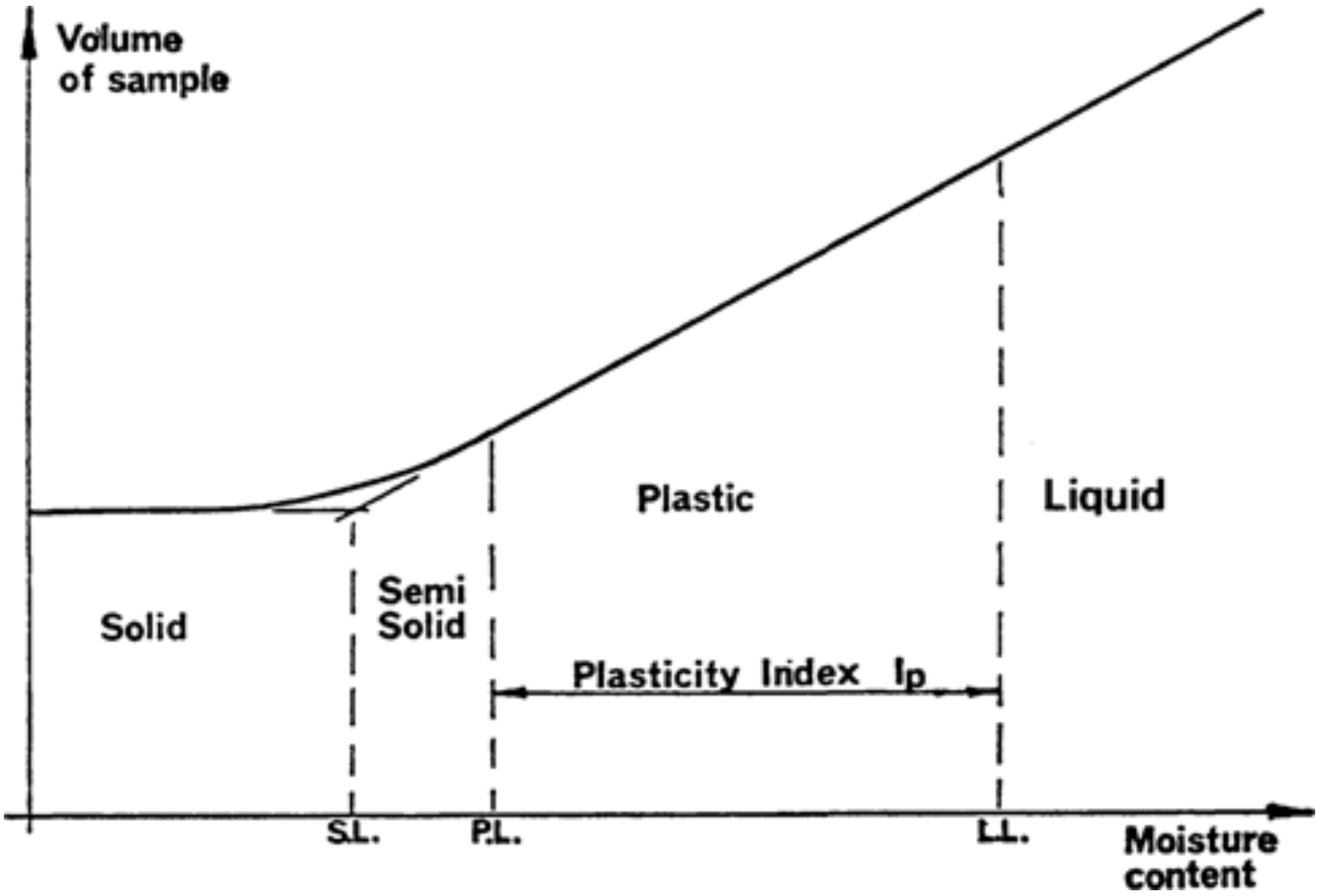


Fig. 14 Consistency-limits graph

Determination of liquid limit

A sample of oven-dried soil, all passing the 0.425 mm sieve, is mixed with distilled water to a stiff consistency, a portion of it placed in

the penetrometer cup, (*see* Fig. 15) the soil being struck off level with the top of the cup. The penetrometer cone is then clamped with its tip just touching the soil. The clamp is released and the cone allowed to penetrate the soil for 5 seconds, when the clamp is reapplied. The amount of penetration is read on the dial gauge. This is repeated until two consecutive tests give the same penetration, and this reading is recorded. At this stage the moisture content of the soil in the cup is determined.

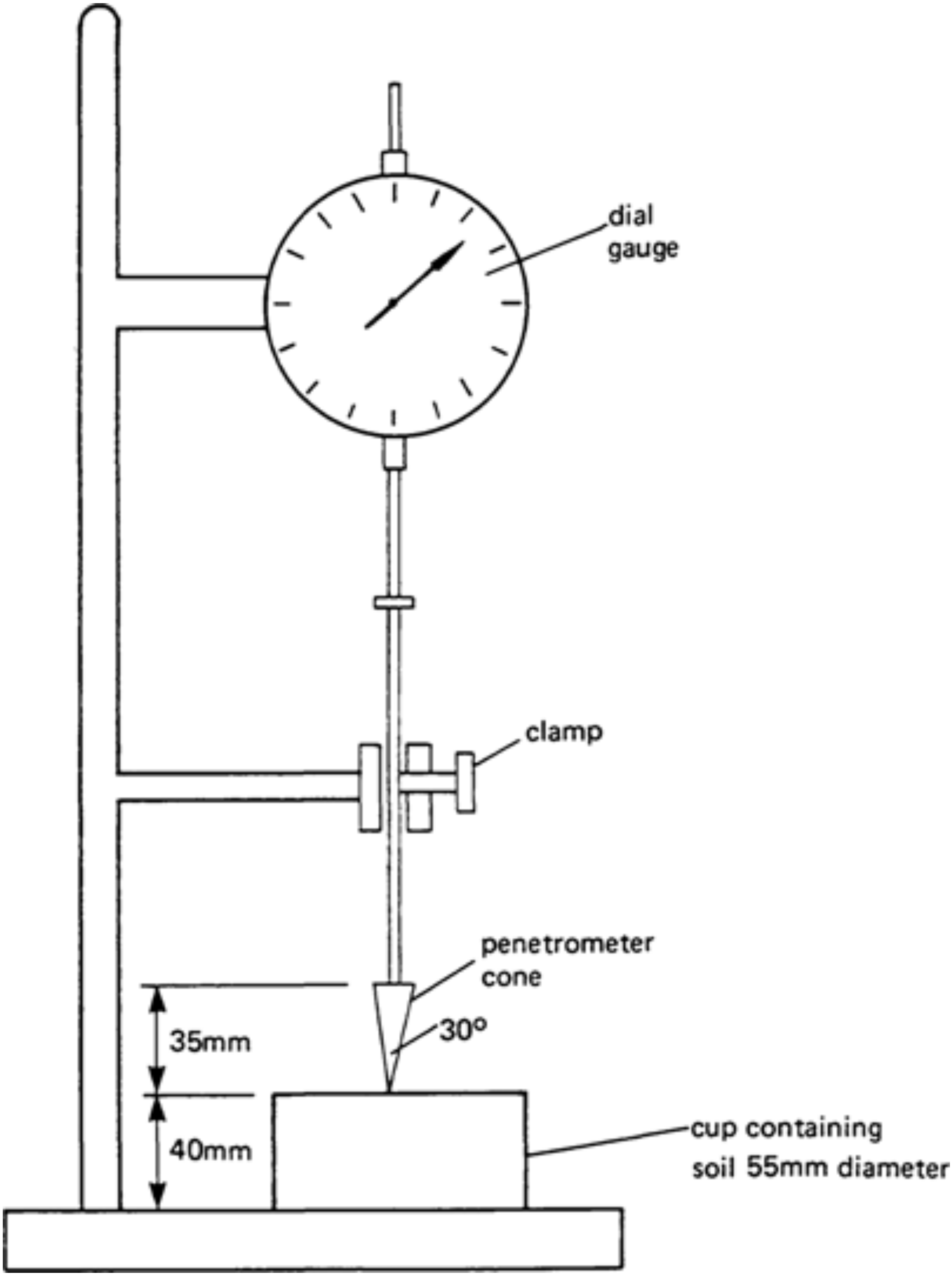


Fig. 15. Standard penetrometer apparatus

The whole procedure is repeated with successive additions of distilled water to the sample, and the relationship between moisture content and penetration plotted on a graph (***see*** Fig. 16). The best straight line between these points is drawn and the moisture content corresponding to 20 mm penetration is taken as the liquid limit. This test is described in detail in B.S. 1377 (1975).

Determination of plastic limit

About 20 g of the dried soil, all passing the 0.425 mm sieve, are mixed with distilled water and moulded into a ball. The ball of soil should be rolled by hand on a glass plate with sufficient pressure to form a thread. When the diameter of the resulting thread becomes 3 mm the soil is kneaded together and then rolled out again. The process is continued until the thread crumbles when it is 3 mm diameter, and at this stage the moisture content of the soil is determined. This whole procedure should be carried out twice and the average value of moisture content taken as the plastic limit of the soil. This test is described in detail in B.S. 1377 (1975).

Plasticity chart

The plasticity index of a soil and its liquid limit give one point on a plasticity chart (Fig. 17). Fine-grained soils are subdivided into soils of low. medium and high elasticity as shown, i.e.:

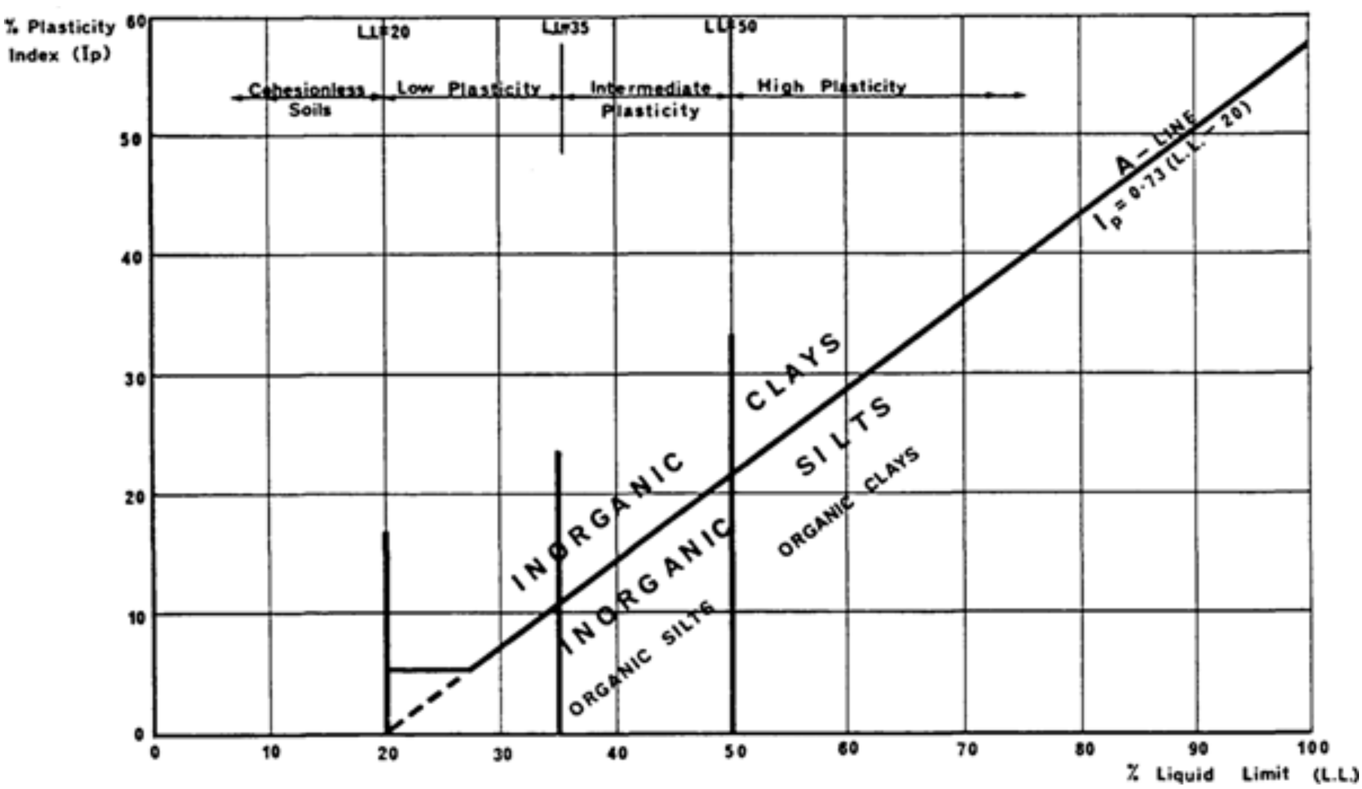


Fig. 17. Casagrande's plasticity chart

Low plasticity (L) L.L. < 35%
Intermediate plasticity (I) L.L. 35%-50%
High plasticity (H) L.L. > 50%

The division between inorganic clays and inorganic silts (or organic soils) is by an empirical line (*A* line) the equation of which is I_p 0.73 (L.L. —20). Clays fall above the line and silts below it.

CASAGRANDE'S SYSTEM OF SOIL CLASSIFICATION

This system has been developed for roads and airfields. The soil type is designated by two capital letters. (*See* tables 3 and 4)

Table 3. casagrande's system

Main soil type	*Prefix*		
Coarse-grained soils			
Gravel	G }	Well graded	W
Sand	S }	Poorly graded	P
	}	Uniform	U
	}	Clay binder	C
	}	Excess fines	F
Fine-grained soils			
Silt	M }	Low plasticity	L
Clay	C }	Medium plasticity	I
Organic soils	O }	High plasticity	H
Peat	Pt }		

Table 4. examples of casagrande's classification for roads and airfields

1		2	3	4	5
Major divisions		*Description and identification*	*Sub-groups*	*Casagrande group-symbol*	*Applicable classification tests (carried out on disturbed samples)*
Coarse-grained soils	Gravel and gravelly soils	Soils with an appreciable fraction between the 80 mm and 2 mm sieves. Generally easily identifiable by visual inspection. A medium to high dry strength indicates that some clay is present. A negligible dry strength indicates the absence of clay	Well-graded gravelsands with small clay content	GC	Mechanical analysis. Liquid and plastic limits on binder
			Uniform gravel with little or no fines	GU	Mechanical analysis

			Poorly-graded gravel -sand mixtures, little or no fines	GP	Mechanical analysis
			Gravel-sand mixtures with excess of fines	GF	Mechanical analysis, liquid and plastic limits on binder of applicable
	Sands and sandy soils	Soils with an appreciable fraction between the 2 mm sieve and the 63 pm sieve. Majority of the particles can be distinguished by eye. Feel gritty when rubbed between the fingers. A medium to high dry strength indicates that some clay is present. A negligible dry strength indicates absence of clay	Well-graded sands and gravelly sands, little or no fines	sw	Mechanical analysis
			Well-graded sand with small clay content	SC	Mechanical analysis, liquid and plastic limits on binder
			Uniform sands, with little or no fines	SU	Mechanical analysis
			Poorly-graded sands, little or no fines	SP	Mechanical analysis
			Sands with excess of fines	SF	Mechanical analysis, liquid and plastic limits on binder if applicable
Finegrained soils Containing little or no coarse-grained material	Finegrained soils having low plasticity (silts)	Soils with liquid limits less than 35% and generally with less than 20% of clay. Not gritty between the fingers. Cannot be readily rolled into threads when moist. Exhibit dilatancy	Silts (inorganic), rock flour, silty fine sands with slight plasticity	ML	Mechanical analysis, liquid and plastic limits if applicable
			Clayey silts (inorganic)	CL	Liquid and plastic limits
			Organic silts of low plasticity	OL	Liquid and plastic limits from natural conditions after oven drying

	Finegrained soils having medium plasticity	Soils with liquid limits between 35 and 50% and generally containing between 20 and 40% clay. Can be readily rolled into threads when moist. Do not exhibit dilatancy. Show some shrinkage on drying	Silty clays (inorganic) and sandy clays	MI	Mechanical analysis, liquid and plastic limits if applicable
			Clays (inorganic) of medium plasticity	CI	Liquids and plastic limits
			Organic clays of medium plasticity	OI	Liquid and plastic limits from natural conditions and after oven drying
	Finegrained soils having high plasticity	Soils with liquid limits greater than 50% and generally with a clay content greater than 40%. Can be readily rolled into threads when moist. Greasy to the touch. Show considerable shrinkage on drying. All highly compressible soils	Highly compressible micaceous or diatomaceous soils	MH	Mechanical analysis, liquid and plastic limits if applicable
			Clays (inorganic) of high plasticity	CH	Liquid and plastic limits
			Organic clays of high plasticity	OH	Liquid and plastic limits from natural conditions and after oven drying

Some examples of these designations can be seen in column 4 of Table 4. This table is based on Casagrande's classification for roads and airfields.

Example 9

A liquid limit test carried out on a sample of inorganic soil taken from below the water table gave the following results:

Penetration (mm)	15.5	18.2	21.4	23.6
Moisture content (%)	34.6	40.8	48.2	53.4

A plastic limit test gave a value of 33 per cent.

Determine the liquid limit and plasticity index of this soil and give its classification.

Solution

From graph (*see* Fig. 18(*a*) L.L. = 45

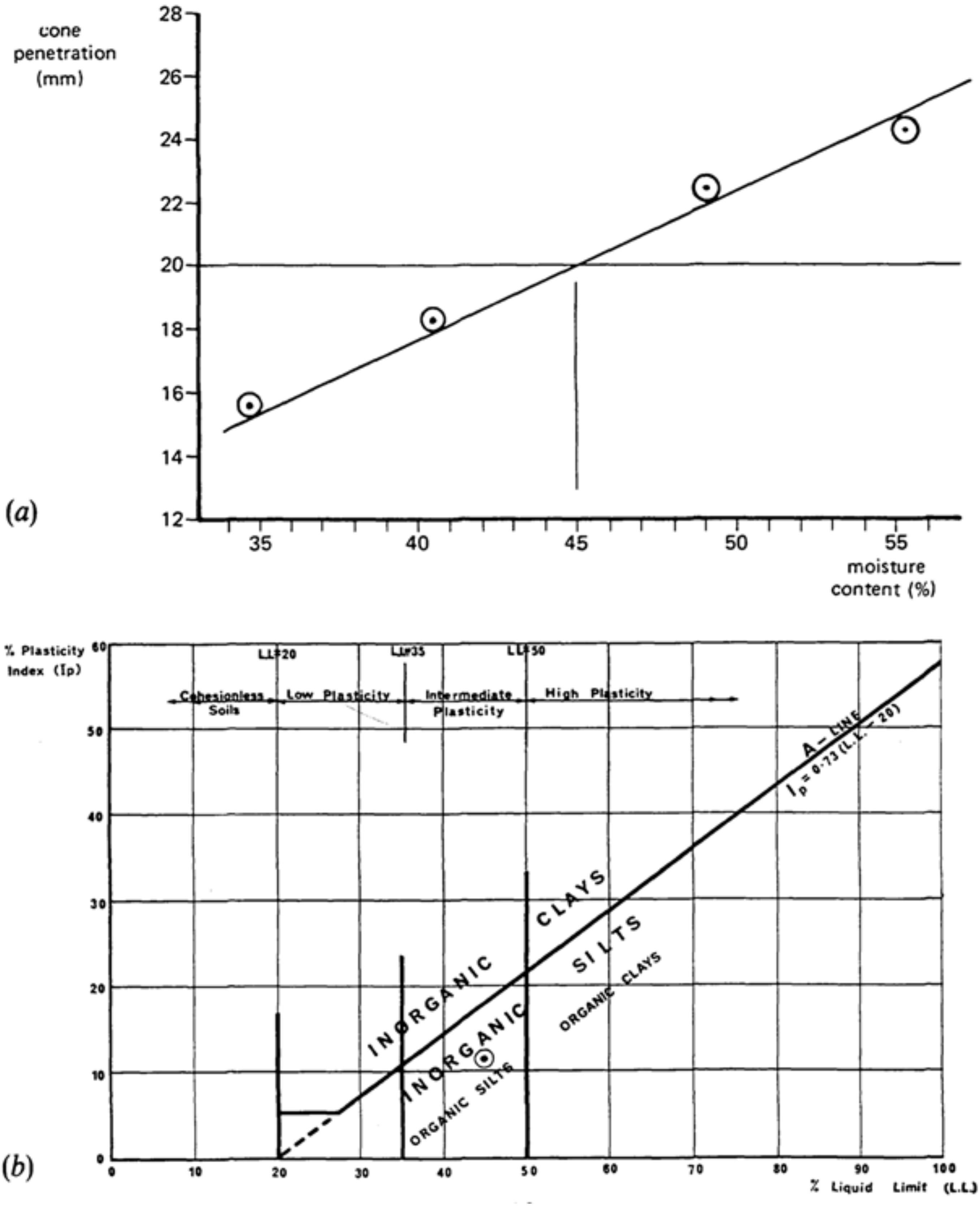


Fig. 18.

P.L. = 33

$I_p = 12$

referring to Fig. 18(*b*), the soil will be classified as an inorganic silt of intermediate plasticity (MI).

QUESTIONS

1. The results of a sieving analysis of a soil were as follows:

Retained on sieve size (mrn)	50	37.5	19	12.5	8	5.9	4.75	2.8
Wt. retained (g)	0	15.5	17	10	11	33	33.5	81

Retained on sieve size (μm)	2360	1300	400	212	150	100	75
Wt retained (g)	18	31	32.5	9	8	5.5	5

The total weight of the sample was 31lg.

Plot the particle-size distribution curve and give a description of the soil from this curve. Also find Allan Hazen's effective size and uniformity coefficient.

2. Figure 19 shows a grain-size classification curve for a soil sample. Describe the test carried out to obtain this curve. Describe the soil.

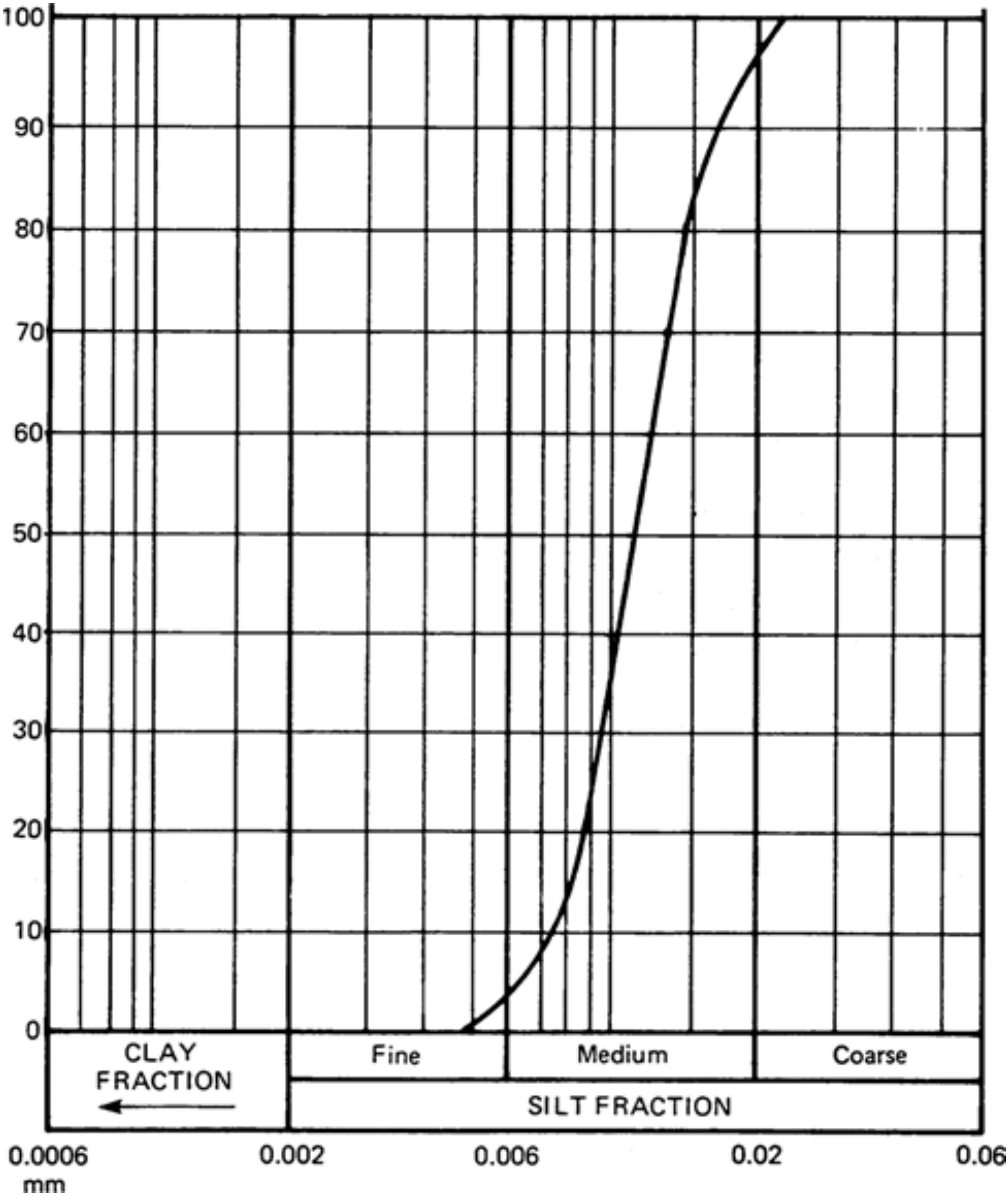


Fig. 19.

If a suitably prepared sample of this soil was dispersed in a cylinder of water 500 mm deep, estimate how long it would take for all the particles to settle to the bottom of the cylinder.

3. The following results were obtained from a liquid limit test on a fine-grained soil:

Penetration (mm)	15.6	18.2	21.4	23.6
Moisture content (%)	48.6	54.8	62.2	67.4

A plastic limit test gave a value of 22 per cent.

What is the Casagrande classification of this soil**?**