

Classification of soils for engineering purposes

2.1 Soil classification principles

It is necessary to provide a conventional classification of types of soil for the purpose of describing the various materials encountered in site exploration. The system adopted needs to be sufficiently comprehensive to include all but the rarest of natural deposits; while still being reasonable, systematic and concise. Such a system is required if useful conclusions are to be drawn from the knowledge of the type of material. Without the use of a classification system, published information or recommendations on design and construction based on the type of material are likely to be misleading, and it will be difficult to apply experience gained to future design. Furthermore, unless a system of conventional nomenclature is adopted, conflicting interpretations of the terms used may lead to confusion, rendering the process of communication ineffective.

To be sufficiently adequate for this basic purpose, a classification system must satisfy a number of conditions:

- (a) It must incorporate as descriptions definitive terms that are brief and yet meaningful to the user.
- (b) Its classes and sub-classes must be defined by parameters that are reasonably easy to measure quantitatively.
- (c) Its classes and sub-classes must group together soils having characteristics that will imply similar engineering properties.

Most classification systems divide soils into three main groups: *coarse*, *fine* and *organic*. The main characteristic differences displayed by these groups are shown in Table 2.1.

In this country, guidelines and recommendations for both field identification and detailed classification are given in BS 5930 *Site Investigation* (1981). A comprehensive chart (Table 2.2) is given from which identification in the field is

Table 2.1 Major classes of engineering soils

Inclusive soil types	Coarse		Fine		Organic	
	Stone	Gravel	Silt	Clay	Peats	
Particle shape						
Particle or grain size						
Porosity or void ratio						
Permeability						
Interparticle cohesion						
Interparticle friction						
Plasticity						
Compressibility						
Rate of compression						

2.2 Field identification

This stage in the process of describing and classifying soils takes place during site exploration; the techniques of site exploration are described in Chapter 12, together with some *in-situ* testing procedures. It is important that adequate attempts are made during exploration to describe the nature and formation of all the sub-surface materials encountered. If at all possible, a preliminary classification should be carried out, so that the fullest possible information is passed on. A further and more detailed classification will usually follow a number of laboratory tests.

For the purpose of identification and classification in the field a series of simple tests may be carried out as follows:

Particle size. Identify the main groups by visual examination and 'feel'. Gravel particles (> 2 mm) are clearly recognisable; sands (0.06 mm $< d < 2$ mm) have a distinctive gritty feel between the fingers; silts (0.002 mm $< d < 0.06$ mm) feel slightly abrasive, but not gritty; clays (< 0.002 mm) feel greasy.

Grading. The *grading* of a soil refers to the distribution of sizes; a *well-graded* soil has a wide distribution of particle sizes, while a *poorly-graded* or *uniform* soil contains only a narrow range of sizes.

For a rapid estimate of particle sizes and grading a *field settling test* can be carried out in a tall jar or bottle. A sample of the soil is shaken with water in the jar and then allowed to stand for a few minutes. The coarsest particles settle to the bottom first, followed by progressively smaller sizes. Subsequent examination of the nature and thickness of the layers of sediment will yield approximate proportions of the size ranges.

Table 2.2 Field identification and description of soils

Basic soil type	Particle size (mm)	Visual identification	Particle nature and plasticity
BOULDERS		Only seen complete in pits or exposures	Particle shape:
COBBLES	200	Often difficult to recover from boreholes	angular
	60	Easily visible to naked eye; particle shape can be described; grading can be described	sub-angular
	20	Well graded: wide range of grain sizes, well distributed. Poorly graded: not well graded. (May be uniform: size of most particles lies between narrow limits; or gap graded: an intermediate size of particle is markedly under-represented)	sub-rounded
GRAVELS	medium		flat
	6		elongate
	fine		Texture: rough
	2	Visible to naked eye; very little or no cohesion when dry; grading can be described	smooth
SANDS	0.6	Well graded: wide range of grain sizes, well distributed. Poorly graded: not well graded. (May be uniform: size of most particles lies between narrow limits; or gap graded: an intermediate size of particle is markedly under-represented)	polished
	medium		
	0.2		
	fine		
SILTS	0.06	Only coarse silt barely visible to naked eye; exhibits little plasticity and marked dilatancy; slightly granular or silky to the touch	Non-plastic or low plasticity
	0.02	Disintegrates in water; lumps dry quickly; possess cohesion but can be powdered easily between fingers	
	medium		
	0.006		
	fine		
CLAYS	0.002	Dry lumps can be broken but not powdered between the fingers; they also disintegrate under water but more slowly than silt; smooth to the touch; exhibits plasticity but no dilatancy; sticks to the fingers and dries slowly; shrinks appreciably on drying usually showing cracks. Intermediate and high plasticity clays show these properties to a moderate and high degree, respectively	Intermediate plasticity (lean clay)
ORGANIC CLAY, SILT or SAND	Varies	Contains substantial amounts of organic vegetable matter	High plasticity (fat clay)

Fine soils
(over 35% silt and clay sizes)

Coarse soils
(over 65% sand and gravel sizes)

Very coarse
soils

Basic soil type	Composite soil types (mixtures of basic soil types)		Compactness / strength	
	Scale of secondary constituents with coarse soils	Term	Field test	
BOULDERS		Loose		By inspection of voids and particle packing
COBBLES		Dense		
	Term	% of clay or silt		
GRAVELS	slightly clayey	GRAVEL or SAND	under 5	
	slightly silty			
	clayey	GRAVEL or SAND	5 to 15	Can be excavated with a spade; 50 mm wooden peg can be easily driven
	very clayey			
	very silty	GRAVEL or SAND	15 to 35	Requires pick for excavation; 50 mm wooden peg hard to drive
SANDS	Sandy GRAVEL	Sand or gravel and important second constituent of the coarse fraction	Slightly cemented	Visual examination; pick removes soil in lumps which can be abraded
	Gravelly SAND			
	For composite types described as: clayey: fines are plastic, cohesive; silty: fines non-plastic or of low plasticity			
	Scale of secondary constituents with fine soils	Term	Soft or loose	Easily moulded or crushed in the fingers
SILTS		% of sand or gravel	Firm or dense	Can be moulded or crushed by strong pressure in the fingers
	sandy	CLAY or SILT	Very soft	Exudes between fingers when squeezed in hand
	gravelly			
	CLAY: SILT	under 35	Soft	Moulded by light finger pressure
CLAYS	Examples of composite types		Firm	Can be moulded by strong finger pressure
	(Indicating preferred order for description)		Stiff	Cannot be moulded by fingers. Can be indented by thumb
	Loose, brown, sub-angular, very sandy, fine to coarse GRAVEL with small pockets of soft grey clay		Very stiff	Can be indented by thumb nail
ORGANIC CLAY, SILT or SAND	Medium dense, light brown, clayey, fine and medium SAND		Firm	Fibres already compressed together
	Stiff, orange brown, fissured sandy CLAY		Spongy	Very compressible and open structure
	Firm, brown, thinly laminated SILT			

increase in compressibility. The degree of weathering evident in newly exposed soil should be reported. Chandler (1969) recommended a system for Keuper marl which may be generalised to describe the weathered state of originally stiff to hard soils:

Unweathered

Slightly weathered

Moderately weathered—fabric partly disrupted, with some parts at higher moisture contents than others

Highly weathered
—considerable fabric disruption and softening; original structure hardly apparent

Fully weathered
–structureless, softened matrix, considerably weaker than
original soil

2.3 Particle size analysis

The range of particle sizes encountered in soils is very wide: from around 200 mm down to the colloidal size of some clays of less than 0.001 mm. Although natural soils are mixtures of various-sized particles, it is common to find a predominance occurring within a relatively narrow band of sizes. When the width of this size band is very narrow the soil will be termed *poorly-graded*, if it is wide the soil is said to be *well graded* (see also Section 2.4). A number of engineering properties, e.g. permeability, frost susceptibility, compressibility, are related directly or indirectly to particle-size characteristics.

Figure 2.1 shows the British Standard range of particle sizes. The particle-size analysis of a soil is carried out by determining the weight percentages falling

Fine				Coarse						Very coarse	
Clay 	Silt			Sand			Gravel			Stone	
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	cobbles	boulders
	1	2	6	20	60	200	600	2	6	20	60
mm μm											

Fig. 2.1 British Standard range of particle sizes

within bands of size represented by these divisions and sub-divisions. In the case of a coarse soil, from which fine-grained particles have been removed or were absent, the usual process is a *sieve analysis*. A representative sample of the

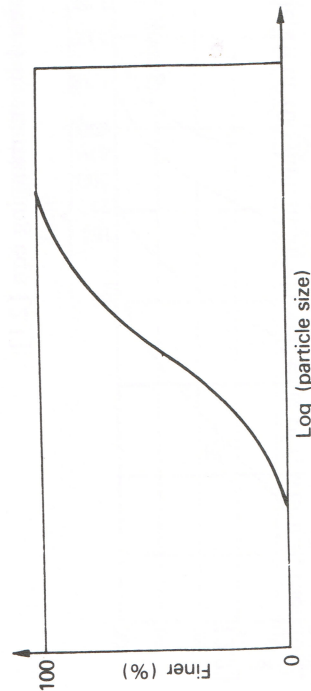


Fig. 2.2 Grading curve

oven-dried. This sample is then passed through a nest of standard test sieves arranged in descending order of mesh size. Following agitation of first the whole nest and then individual sieves, the weight of soil retained on each sieve is determined and the cumulative percentage of the sub-sample weight passing each sieve calculated. From these figures the particle-size distribution for the soil is plotted as a semi-logarithmic curve (Fig. 2.2) known as a *grading curve*.

Where the soil sample contains fine-grained particles, a *wet sieving* procedure is first carried out to remove these and to determine the combined clay/silt fraction percentage. A suitably-sized sub-sample is first oven-dried and then sieved to separate the coarsest particles (> 20 mm). The sub-sample is then immersed in water containing a dispersing agent (sodium hexametaphosphate: a 2 g/litre solution) and allowed to stand before being washed through a 63 μ m mesh sieve. The retained fraction is again oven-dried and passed through a nest of sieves. After weighing the fractions retained on each sieve and calculating the cumulative percentages passing each sieve, the grading curve is drawn. The combined clay/silt fraction is determined from the weight difference and expressed as a percentage of the total sub-sample weight. The coarsest fraction (> 20 mm) can also be sieved and the results used to complete the grading curve.

A further sub-division of particle-size distribution in the fine-grained fraction is not possible by the sieving method. A process of *sedimentation* is normally carried out for this purpose. A small sub-sample of soil is first treated with a dispersing agent and then washed through a 63 μm sieve. The soil/water suspension is then made up to 500 ml, agitated vigorously for a short while and then allowed to settle.

The procedure is based on Stokes' law, which states that the velocity at which a spherical particle will sink due to gravity in a suspension is given by:

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

where d = diameter of particle

time (t) may be obtained by rearranging eqn [2.1]:

$$d = \left[\frac{18\eta h}{(\gamma_s - \gamma_w)t} \right]^{1/2}$$

Usually $h = 100$ mm, giving:

$$d = \left[\frac{1800\eta}{(\gamma_s - \gamma_w)t} \right]^{1/2} \quad [2.2]$$

Samples taken at a depth of 100 mm, at an elapsed time of t , will not, therefore, include particles of greater size than the diameter d given by eqn [2.2]; but the proportions of particles smaller than d in the suspension will remain unchanged.

The procedure using a hydrometer consists of measuring the suspension density at a depth of 100 mm at a series of elapsed-time intervals. The percentage-finer values corresponding to particular diameters (i.e. particle sizes) are obtained from the density readings, and thus a grading curve for the fine-grained fraction may be drawn. An alternative method of obtaining suspension density values consists of drawing-off a small quantity from the prescribed depth using a special pipette (refer to BS 1377 for full details).

The sedimentation method is not particularly accurate in an absolute sense, since errors result from a number of factors: such as the flaky nature of fine-grained particles, the near molecular size of the very fine particles, incomplete dispersion, variations in viscosity due to temperature variations. However, the *equivalent spherical diameter* distribution obtained in this manner provides a sufficiently useful guide for engineering purposes.

2.4 Grading characteristics

The grading curve is a graphical representation of the particle-size distribution and is therefore useful in itself as a means of describing the soil. For this reason it is always a good idea to include copies of grading curves in laboratory and other similar reports. It should also be remembered that the primary object is to provide a descriptive term for the type of soil. This is easily done using the type of chart shown in Fig. 2.3 by estimating the range of sizes included in the most representative fraction of the soil. For example, curve A may be taken to represent a *poorly-graded medium SAND*; *poorly graded* because the curve is steep, indicating a narrow range of sizes, and *medium SAND*, since the largest proportion of the soil (approximately 65 per cent) lies in medium-sand sub-range. Curve B represents a *well-graded material* containing a wide range of particle sizes; from fine sand to medium gravel; this soil is properly described as a *well-graded GRAVEL SAND*, since about half the soil is gravel and the other half sand. Curve C also represents a well-graded material which is predominantly sand, but with a significant silt fraction (about 20 per cent); this soil should be described as a *very silty SAND*, the noun indicating the predominant fraction. Curve D indicates a *poorly-graded silty SAND*, the noun indicating the predominant fraction.

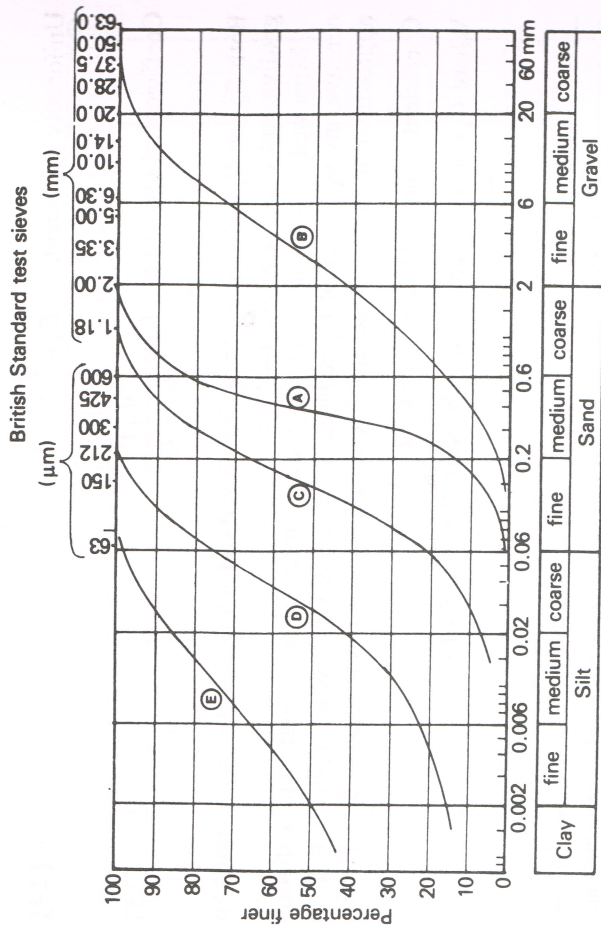


Fig. 2.3 Typical particle size distribution curves

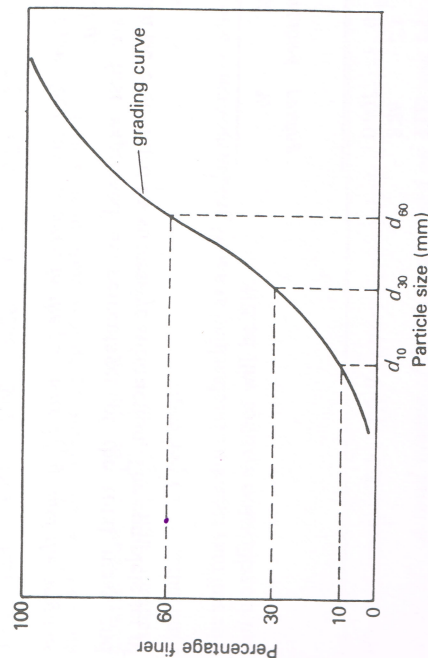


Fig. 2.4 Grading characteristics

certain geometric values known as *grading characteristics*. First of all, three points are located on the grading curve to give the following characteristic sizes (Fig. 2.4):

d_{10} = Maximum size of the smallest 10 per cent of the sample
 d_{30} = Maximum size of the smallest 30 per cent of the sample
 d_{60} = Maximum size of the smallest 60 per cent of the sample

Uniformity coefficient, $C_u = \frac{d_{60}}{d_{10}}$ [2.4]

Coefficient of gradation, $C_g = \frac{(d_{30})^2}{d_{60} \times d_{10}}$ [2.5]

Both C_u and C_g will be unity for a single-sized soil, while $C_u < 3$ indicates uniform grading and $C_u > 5$ a well-graded soil.

Most well-graded soils will have grading curves that are mainly flat or slightly concave, giving values of C_g between 0.5 and 2.0. One useful application is an approximation of the coefficient of permeability, which was suggested by Hazen.

Coefficient of permeability $(k) = C_k(d_{10})^2$ m/s

Where C_k = a coefficient varying between 0.01 and 0.015.

Worked example 2.1 The results of a dry-sieving test are given below: plot the particle-size distribution curve and give a classification for the soil.

Sieve size (mm or μm)	3.35	2.00	1.18	600	425	300	212	150	63
Mass retained (g)	0	2.5	12.5	57.7	62.0	34.2	18.7	12.7	13.1

The quantity passing the 63 μm sieve and collected in the pan was 3.9 g, and the original weighed quantity was 217.2 g.

The retained masses are first expressed as percentages of the total mass and the percentage passing each sieve obtained by successive subtraction. The complete set of results is tabulated below:

Sieve size	Mass retained (g)	% retained	% passing
mm	3.35	0	100.0
	2.0	2.6	98.8
	1.18	12.5	93.1
μm	600	57.7	66.5
	425	62.0	37.9
	300	34.2	22.2
	212	18.7	13.6
	150	12.7	7.8
	63	13.1	1.8
Pan		3.9	1.8

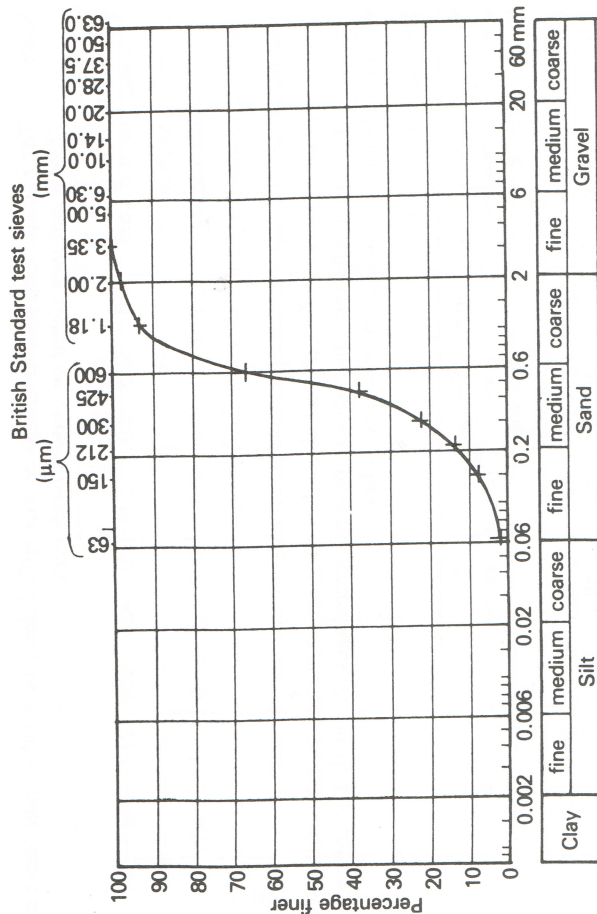


Fig. 2.5 Particle size distribution WE 2.1

curves shows the following approximate proportions:

- Coarse sand 33 per cent
- Medium sand 54 per cent
- Fine sand 13 per cent

The soil may therefore be classified as a well-graded medium coarse SAND and the sub-group soil classification symbol will be SW.

Worked example 2.2 A full wet/dry sieve analysis was carried out with the following results:

Stage 1. A total sample of 3274 g was sieved on a 20 mm test sieve:

Mass retained = 104.8 g Mass passing = 3169 g

Stage 2. The mass retained on the 20 mm sieve was sieved on larger mesh sizes:

Sieve size (mm)	50	37.5	28	20
Mass retained (g)	0	45.9	26.2	32.7

Stage 3. The mass passing the 20 mm sieve was riffled down to a sub-sample mass of 2044 g and then sieved on a 6.3 mm test sieve:

Stage 5. The mass passing the 6.3 mm sieve was riffled down to a sub-sample mass of 212.4 g and then sieved on smaller mesh sizes:

Sieve size (mm or μm)	5.0	3.35	2.0	1.18	600	425	300	212	150	63
Mass retained (g)	22.5	69.4	58.4	43.4	20.9	10.3	9.1	5.6	4.7	7.2

The mass passing the 63 μm sieve was 21.2 g.

Plot the particle-size distribution curve and give a classification for the soil.

The retained masses are first corrected so that they are expressed as proportions of the total sample mass, and the retained- and passing-percentages obtained. The complete set of results and calculations is tabulated below.

Total sample: 3274 g

Sieve size (mm)	Mass retained (μm) (g)	Correction	Corrected mass retained	% retained	% passing
50.0	0.0		0.0	0.0	100.0
37.5	45.9		45.9	1.4	98.6
28.0	26.2	None	26.2	0.8	97.8
20.0	32.7		32.7	1.0	96.8
Pan	3169	Riffled down to: 2044 g			
14.0	40.2	$3169 \times \frac{2044}{3274}$	62.3	1.9	94.9
10.0	48.8		75.6	2.3	92.6
6.3	112.0	$= 1.55$	173.6	5.3	87.3
Pan	1843	Riffled down to: 272.4 g			
5.00	22.5		236.0	7.2	80.1
3.35	69.4	$3169 \times \frac{2044}{3274}$	728.0	22.2	57.9
2.00	58.4		612.6	18.7	39.2
1.18	43.4		455.3	13.9	25.3
600	20.9	$1843 \times \frac{272.4}{3274}$	219.2	6.7	18.6
425	10.3		108.0	3.3	15.3
300	9.1	$= 10.49$	95.5	2.9	12.4
212	5.6		58.7	1.8	10.6
150	4.7		49.3	1.5	9.1
63	7.2		75.5	2.3	6.8
Pan	21.2		222.4	6.8	

The plot of the particle-size distribution curve is shown in Fig. 2.6: an inspection of which shows the following approximate proportions:

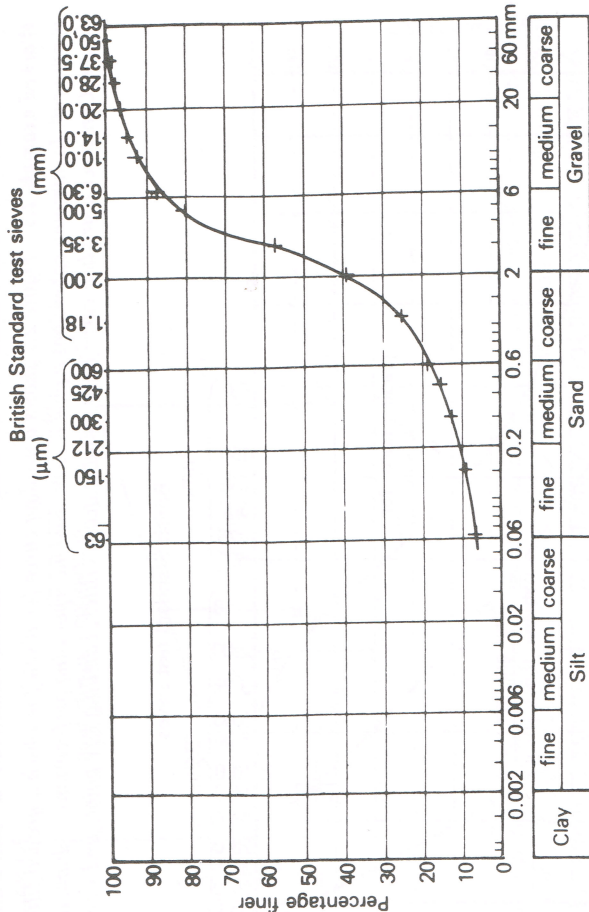


Fig. 2.6 Particle size distribution WE 2.2

The soil may therefore be classified as a well-graded silty sandy GRAVEL; the Soil Classification symbol will be GW M (a dual symbol being used since the percentage fines is between 5 and 15 per cent).

2.5 Design of filters

In water-pumping operations and in the construction of earth dams, it is often necessary to provide a layer (or layers) of filter material to prevent fine particles being carried into pipes, through mesh screens or into the void space of coarser materials. An effective filter material may be designed using a few simple rules and the grading characteristics of the soil to be protected:

- (a) The soil content exceeding a grain size 19 mm should be discounted.
- (b) The filter should not contain material of particle size greater than 80 mm.
- (c) The filter should have a fines content (particle size $<75 \mu\text{m}$) of not more than 5 per cent.
- (d) The grading curve of the filter should have the same approximate shape as that of the soil.
- (e) The $d_{1.5}$ size of the filter should lie between four times $d_{1.5}$ for the soil and