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Definitions and Soil Classification

Rock. Rock is natural aggregate of mineral grains connected by strong or permanent cohesive forces which cannot be separated by simple mechanical means.

Boulder. These are coarse grained material of size more than 300 mm.

Cobble. These are coarse grained material ranging in between 75 mm and 300 mm size.

Gravel. It consists of coarse-grained particles larger than 4.75 mm and lesser than 75 mm.

Soil. To an engineer, soil is the natural aggregate of mineral grains, with or without organic constituents that can be separated by gentle mechanical means such as agitation in water. It covers large portion of the earth's crust.

Coarse Grained Soil. Coarse grained soil consists of mineral fragments visible with the naked eye and/or having a gritty feel when rubbed between the fingers.

Fine Grained Soil. This soil consists of mineral particles of microscopic or sub-microscopic size which have a smooth or floury feel when moistened with water.

Poorly Graded Soils. These soils are composed of particles having excess or deficiency of certain sizes.

Well graded Soils. These soils contain a fairly well representation of particles of several sizes ranging continuously from coarse to fine.

Sand. Sand consists of coarse-grained particles finer than 4.75 mm but coarser than 0.075 mm.

Silt. It constitutes the fine grained soil material ranging the size between 0.075 to 0.002 mm.

Clay. It is the finest and most active portion of the soil material and is generally characterized by high to very high dry strength. The grains have size less than 0.002 mm.

Black Cotton Soils. Black cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. They are predominantly montmorillonitic in structure and black or blackish grey in colour. They are characterized by high shrinkage and swelling properties.

Organic Clay. It is a combination of finely divided organic matter with a significant amount of clay size particles. It is black or dark grey in colour and is generally characterized by very high dry strength.

Unit Weight of Soil Mass (γ_t). The density or unit weight (also called Bulk density) of a soil mass is defined as its weight per unit volume.

Dry Density (γ_d). The dry density is the weight of soil solids per unit of total volume of the soil mass.

Saturated Density (γ_{sat}). The saturated density is the ratio of weight of soil mass in saturated condition to its volume.

Submerged Density (γ_{sub}). It is defined as unit weight of saturated soil mass minus unit weight of water

i.e. $$\gamma_{sub} = \gamma_{sat} - \gamma_\omega.$$

Void Ratio (e). The void ratio of a soil mass is defined as the ratio of volume of voids to the volume of solids.

i.e. $$e = \frac{V_v}{V_s} = \frac{V_a + V_w}{V_s}$$

where V_v = Total volume of voids

V_a = Volume of air in voids

V_w = Volume of water in voids

and V_s = Volume of solids.

Porosity (n). The porosity is expressed as the ratio of the volume of voids V_v to the total volume (V) of soil mass

i.e. $$n = \frac{V_v}{V} = \frac{V_a + V_w}{V_a + V_w + V_s}$$

It is usually expressed in percentage.

Water Content (w). The water content of a soil is defined as the ratio of weight of water to the weight of solid mass

$$w = \frac{W_w}{W_s}$$

The weight W_w is the weight of water lost when the wet soil is heated at a temperature of 105^oC to 110^oC for such a time that its weight becomes constant and W_s is the weight of solid mass. In routine laboratory tests, twenty four hours heating in an oven is considered adequate.

Dry Strength. It is measured by the effort required to break an intact fragment of dry soil about 3 mm in size between the thumb and fore-finger.

Terms Relating to Bearing Capacity

Net Loading Intensity—The net loading intensity on the foundation is the gross intensity of loading minus the weight of displaced soil above the foundation base.

Ultimate Bearing Capacity—The intensity of loading at the base of the foundation which would cause shear failure of the soil support.

Safe Bearing Capacity—Maximum intensity of loading that the foundation will safely carry without the risk of shear failure of soil irrespective of any settlement that may occur.

Safe Bearing Pressure or Net Soil Pressure for Specified Settlement—The intensity of loading that will cause a permissible settlement (Appendix II) or specified settlement of the structure.

Allowable Bearing Capacity—The net intensity of loading which the foundation will carry without undergoing settlement in excess of the permissible value for the structure under consideration but not exceeding net safe bearning capacity.

General Terms. *Density Index (Relative Density)*—The ratio of the difference between the void ratios of cohesionless soil in the loosest state and any given state to the difference between its void ratios at the loosest and densest states.

Effective Surcharge at the Base Level of Foundation—The intensity of vertical pressure at the base level of foundation, computed assuming total unit weight for the portion of soil above the water table and submerged unit weight for the portion below the water table.

Footing—A structure constructed in brickwork, masonary or concrete under the base of a wall or column for the purpose of distributing the load over a larger area.

Foundation—That part of a structure which is in direct contact with soil and transmits loads into it.

Shallow Foundation—A foundation whose width is greater than its depth. The shearing resistance of the soil in the sides of the foundation is generally neglected.

SOIL CLASSIFICATION. Soil classification is a medium of communication among soil engineers for geotechnical practices. This differentiates the coarse grained and fine grained soils. This also provides the basis for detailed geotechnical investigations. As per I.S. 1498-1970, the soils are classified as below according to their sizes.

Boulder	—	above 300 mm
Cobble	—	300-75 mm
Coarse Gravel	—	75-20 mm
Fine Gravel	—	20-4.75 mm
Coarse Sand	—	4.75-2 mm
Medium Sand	—	2.0-0.425 mm
Fine Sand	—	0.425-0.075 mm
Silt	—	0.075-0.002 mm
Clay	—	below 0.002 mm.

Classification Methodology

Take dry soil sample - run sieve analysis

- If 50% or less pass 75 micron IS sieve, it is Coarse grained soil
- If more than 50% pass 75 micron IS sieve, it is fine grained soil
- For gravel (G) - greater percentage (> 50%) of coarse fraction retains on 4.75 mm sieve. It is represented as GW, GP, GM or GC
- For sand(S)-greater percentage (> 50%) of coarse fraction passes 4.75 mm sieve, it is termed as SW, SP, SM or SC
- For clay(C)-greater percentage (> 50%) of soil passes 75 micron sieve. It is termed as CL, CI or CH
- For fine grained soils-determine LL and PL on (-) 425 micron sieve
- For low plasticity (L), LL should be < 35%
- For intermediate or medium plasticity (l), LL should be 35–50%
- For high plasticity (H), LL should be > 50%

The major soil groups and sub-groups alongwith corresponding prefix and suffix that are used in Indian system are shown in following table.

Soil Type	*Symbol & Prefix*	*Sub-group*	*Suffix*
Gravel	G	Well graded	W
Sand	S	Poorly graded	P
Silt	M	Silty	M
Clay	C	Clayey	C
Organic	O	$W_L < 35\%$	L
		$35 < W_L < 50$	I
Peat	P_t	$50 < W_L$	H

Note : W_L denotes for liquid limit, W_p denotes for plastic limit

Charts for Coarse Grained Soils

Note: The A-line or hatched zone on plasticity chart can be referred in Fig. 1.1

Note : *L* denotes Low plasticity

I denotes medium (or intermediate) plasticity

H denotes for High plasticity

FINE GRAINED SOIL

- If > 50% soil passes 75 μ sieve, soil may be generally silt (ML), silty clay of low plasticity (CL), medium plasticity (CI) or high plasticity (CH) or it may be ML-CL (clayey silts).
- Atterberg limits should be performed on (-) 425 μ soil. Soil with LL 35% and Pl above A-line or hatched zone, the soil is called CL. The soil possessing *LL* < 35% and PI in hatched zone between 4-7, it is ML-CL. Soil with *LL* < 35% and PI below A-line or hatched zone (PI < 4) is known as ML. For soil having LL between 35-50 and PI above A-line, soil is termed as CI. When LL is > 50 and PI above A-line, soil is CH.

Grain size analysis and Atterberg limits values are also used to classify the soil. In broad sense the soil is first classified as "coarse grained" or "fine grained" soil. The fraction of soil smaller than 75-micron (0.075 mm) size *i.e.* passing through 75 micron sieve is known as fines and those retained on 75 micron sieve *i.e.* gravel and sand are termed as coarse.

According to IS : 1498-1970 (Amended in 1987) coarse grained soils are those whose 50 per cent or less pass through 75 micron sieve. If the greater percentage (> 50%) of the coarser fraction is retained on 4.75 mm IS : sieve, the soil is termed as gravelly soil and is represented by GW, GP, GM or GC. Where greater percentage of the coarser soil passes 4.75 mm IS : sieve, the soil is called, sandy soil and may be represented by SW, SP, SM or SC.

For better understanding, following classification methods and flow charts may be referred. It is worth mentioning here that when the soil sample is brought from field into laboratory, the particles larger than 75 mm size should be removed from sample and fraction of sample smaller than 75 mm size should be used for classification purpose.

COARSE GRAINED SOILS

Coarse grained Soil when Half or more than half of total Soil is retained on 75 micron IS sieve. Further, if half or more than half of material, retained on 75 micron sieve, is retained on 4.75 mm sieve, then the soil is gravel dominated. Therefore, symbol 'G' shall be prefixed in classificaton.

If the percentage of soil passing 75 micron IS sieve is less than 5 percent, the whole soil is GW or GP. For soil to be GW, the uniformity coefficient $\left(C_u = \dfrac{D_{60}}{D_{10}}\right)$ should be greater than 4 and coefficient of curvature $\left(C_c = \dfrac{(D_{30})^2}{D_{10} \times D_{60}}\right)$ should be between 1 and 3. The soil not meeting both the requirements is designated as GP.

If a fraction of the soil passing 75 micron IS sieve is between 5-12 per cent, the soil is given a boundary line classification *e.g.* GW-GM or GP-GM whatever the case may be.

Where the portion of the soil passing 75 micron IS : sieve is more than 12 per cent, the Atterberg limits (details in Chap. 5) values on minus 425 micron IS sieve shall be determined. Where the plasticity index is above the A-line or hatched zone of plasticity chart (Fig. 1.1) the whole soil is classified as GC. For plastic index to be in hatched zone, the soil is known as GM-GC.

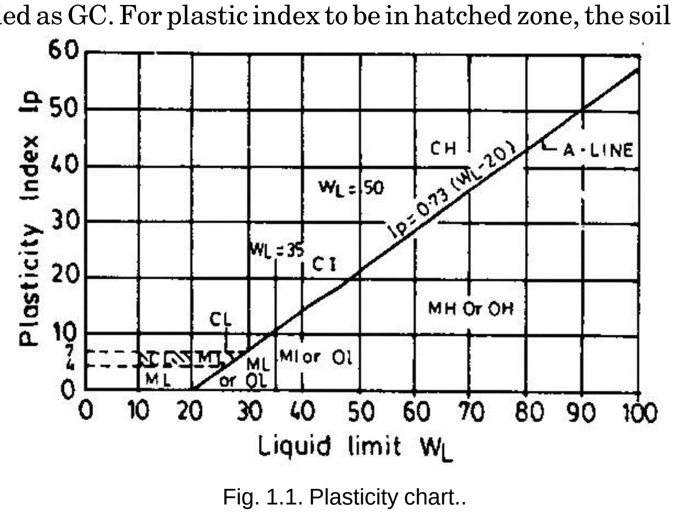


Fig. 1.1. Plasticity chart..

If the plasticity index of the soil is below hatched zone or non-plastic the soil is silty gravels (GM).

For greater percentage of Coarser fraction passing 4.75 mm IS sieve and less than 5 per cent passing .075 mm IS sieve, the soil may be called well graded or poorly graded sands (SW or SP). If C_u of the soil is greater than 6 and C_c between 1 and 3, the soil is SW otherwise SP. Where the percentage of soil passing 75 micron IS sieve is between 5-12 per cent, the soil is given a dual symbol *e.g.* SW-SM or SP-SM.

Where the soil passing 75 micron IS sieve is more than 12 percent, atterberg limits test, shall be conducted on minus 425 micron IS sieve soil and plasticity index shall be noted. For plasticity index above A-line or hatched zone the soil is termed as SC. If the plasticity index value lie in the hatched zone the soil is termed as SM-SC. In case the plasticity index of the soil is below hatched zone or non-plastic the soil is termed as silty sands (SM).

FINE GRAINED SOILS

If more than 50 per cent of the soil passes 75 micron IS sieve, the soil may be generally silts (ML), silty clay of low plasticity (CL), medium plasticity (CI) or high plasticity (CH) or may be clayey silts (ML-CL).

For proper identification, Atterberg limits tests shall be performed on minus 425 micron IS sieve soil. Having liquid limit less than 35 and plasticity index above A-line or hatched zone the soil is called as CL. The soil possessing liquid limits less than 35 and plasticity index in hatched zone *i.e.* between 4-7, is classified as ML-CL. The soil having liquid limit less than 35 and plasticity index below A-line or hatched zone (*i.e.* plasticity index less than 4) or the soil is n on-plastic, NP is termed as ML. For soil having liquid limit between 35-50 and plasticity index above A-line, the soil is termed as CI. Where the liquid limit is greater than 50 and plasticity index above A-line the soil is designated CH.

VISUAL IDENTIFICATION OF SOIL

- Coarse grained soil particle can be seen by naked eyes but particles of silt and clay are not visible by naked eyes. Visual classification is done by taking a representative sample of soil and spreading it on a flat surface or palm of hand. The visual classification is carried out with respect to size, angularity, touch and grading.
- For fine grained soils, following tests are carried out for fraction passing through 425 micron sieve.

(*a*) **DILATANCY (Response to Shaking).** About 5 gm of soil sample is taken and enough water is added to nearly saturate it. The pat of soil is placed at palm and shaken horizontally by striking vigorously against other hand several times. The pat is then squeezed between the figures. The appearance and disappearance of water with shaking and squeezing is referred to as a possible reaction. This reaction is called 'quick condition', if water appears and disappears rapidly. If water appears and disappears slowly. It is called "slow".

It is called 'No reaction' if the water condition does not appear to change. The type of reaction is observed and recorded. Fine sands and silts exhibit a quick reaction whereas clays show slow to none.

(*b*) **Toughness (Consistency near plastic limit).** The soil sample used in the dilatancy test is dried by working and moulding until it reaches the consistency of putty. The time required to dry the sample is indicative of its plasticity. Further, the moisture content is reduced by rolling and re-rolling into 3mm diameter thread till it reaches plastic limit. The resistance to moulding at the plastic limit is called toughness. After the thread crumbles, the pieces are lumped together and slight kneading action is continued until the lump also crumbles. If the lump can still be moulded slightly drier than the plastic limit and if high pressure is required to roll the thread between the palms of hand, the soil is said to have high toughness. The medium toughness is indicated by a medium thread and a lump formed of the threads slightly below the plastic limit crumbles, while the low toughness is indicated by a weak thread and breaks easily and can not be lumped together when drier than plastic limit.

Non-plastic soil cannot be rolled into threads of 3mm dia at any moisture content.

(*c*) **Crushing Strength (dry strength).** The prepared soil sample is completely dried in sun or by air. Its strength is tested by breaking a lump between fingures. Resistance to breaking termed as crushing strength or dry strength is a measure of plasticity and is considerably influenced by colloidal fraction content of soil. If dry sample can be powdered easily, it is said to have a low dry strength, whereas if considerable finger pressure is required to break the lump, it is said to have a medium dry strength and if it can not be powdered at all, it is said to have a high dry strength.

The hatching representation of some of the important type of soil has been shown [IS : 1498-1970 (amended in 1987)] in Fig. 1.2.

(*a*) Well graded gravels (GW)

(*b*) Poorly graded gravels (GP)

(*c*) Silty gravels (GM)

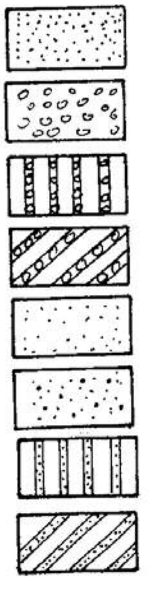
(*d*) Clayey gravels (GC)

(*e*) Well graded sands (SW)

(*f*) Poorly graded sands (SP)

(*g*) Silty sands (SM)

(*h*) Clayey sands (SC)



Fine grained soil (More than half of soil passes through 75 micron IS sieve size).

(*a*) Inorganic silts and Fine Sands (ML)

(*b*) Inorganic clays (CL) silty clays with low compressibility and liquid limit less than 35

(*c*) Inorganic clays (CI) silty clays with medium compressibility and liquid limit greater than 35 and less than 50.

(*d*) Inorganic clays (CH) silty Clays with high compressibility and liquid limit greater than 50.

(*e*) Organic silts (OL) and organic silty clays at low plasticity

(*f*) Inorganic silts (MH) of high compressibility

(*g*) Organic clays (OH) of high plasticity

(*h*) Highly organic soils (Pt) with very high compressibility

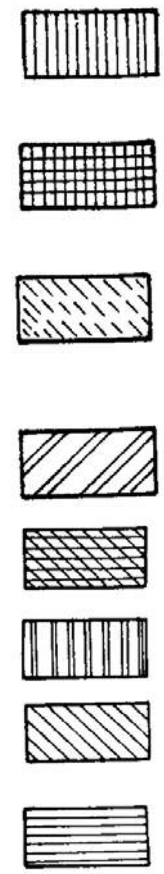


Fig. 1.2. Soil Classification as per IS : 1498-1970 (Reaffirmed 1987).

Application of Soil classification

The soil engineer must always be cautious in use of soil classification. Designs should not be based on soil classification alone. Fundamental soil behaviour like flow phenomenon, compressibility and shear strength can be predicted only through actual measurement in lab. The classification tests are performed on remoulded soils and as such may not truely represent the behaviour of in situ undisturbed soil. Yet classification plays an important role in decision making and provides guidance for detailed investigation.

Following data refers to classification test on 3 samples. Classify soil as per Indian Standard Soil Classification System.

	% Finer than	*% Retained*	
Sieve	*Sample (1)*	*Sample (2)*	*Sample (3)*
4.75 mm	100	20	49
2.00 mm	100	21	11
1.0 mm	99.8	18	7
425 μ	99.65	15	5
212 μ	98.95	7	6
150 μ	97.55	9	4
75 μ	96.85	6	4
	LL = 23%	LL = 0	LL = 35
	PL = 16.77%	NON-PLASTIC	PL = 20
	PI = 6.23		PI = 15

Note :

LL - Liquid limit (W_L)

PL - Plastic limit (W_p)

PI - Plasticity Index ($W_L - W_p$)

In soil sample 1, more than 50% passes 75 micron sieve. Thus, soil is fine grained; and plasticity characteristics are futher required to classify soil with LL = 23 & PI = 6.23, soil lies in hatched zone. Soil is therefore ML-CL.

The readers may identify the soil classification for sample (2) and (3) themselves for better understanding.

Table 1.1. Assessment of Soil Properties
Based on Group Symbol (Adapted from Sowers, 1979)

Group Symbol	*Compaction Charac-teristics*	*Compressibility and Expansion*	*Drainage and Hydraulic Con-ductivity*	*Value as a Fill Material*	*Value as a Pavement Subgrade When Not Subject to Frost*	*Value as a Base Course for Pavement*
GW	Good	Almost none	Good drainage; pervious	Very stable	Excellent	Good
GP	Good	Almost none	Good drainage; pervious	Reasonably stable	Excellent to good	Poor to fair
GM	Good	Slight	Poor drainage; semipervious	Reasonably stable	Excellent to good	Fair to poor
GC	Good to fair	Slight	Poor drainage; semipervious	Reasonably stable	Good	Good to fair, not suitable if subject to frost
SW	Good	Almost none	Good drainage; pervious	Very stable	Good	Fair to poor

(*Contd...*)

Group Symbol	*Compaction Charac-teristics*	*Compressibility and Expansion*	*Drainage and Hydraulic Con-ductivity*	*Value as a Fill Material*	*Value as a Pavement Subgrade When Not Subject to Frost*	*Value as a Base Course for Pavement*
SP	Good	Almost none	Good drainage; pervious	Reasonably stable when dense	Good to fair	Poor
SM	Good	Slight	Poor drainage; impervious	Reasonably stable when dense	Good to fair	Poor
SC	Good to fair	Slight to medium	Poor drainage; impervious	Reasonably stable	Good to fair	Fair to poor, not suitable if sub-ject to frost
ML	Good to poor	Slight to medium	Poor drainage; impervious	Fair stability, good compaction required	Fair to poor	Not suitable
CL	Good to fair	Medium	No drainage; impervious	Good stability	Fair to poor	Not suitable
OL	Fair to poor	Medium to high	Poor drainage; impervious	Unstable, should not be used	Poor, not suitable	Not suitable
MH	Fair to poor	High	Poor drainage; impervious	Fair to poor stability, good compaction required	Poor	Not suitable
CH	Fair to poor	Very high	No drainage; impervious	Fair stability, expands, weakens, shrinks, cracks	Poor to very poor	Not suitable
OH	Fair to poor	High	No drainage; impervious	Unstable, should not be used	Very poor	Not suitable
Pt	Not suitable	Very high	Fair to poor drainage	Should not be used	Not suitable	Not suitable
CI	Good to fair	Medium	No drainage, Impervious	Good stability	Fair to poor	Not suitable

Properties of different soils in respect of their application in roads and airfields are given in Appendix-X.

Flow Chart for Soil Classification System