Liquid limit and Plastic limit:

Liquid limit: The Liquid Limit (LL) is the moisture content at which a fine-grained soil no longer flows like a liquid.

From liquid limit test, the compression index may be estimated, which is used in settlement analysis. If the natural moisture content of soil is higher than liquid limit, the soil can be considered as soft and if the moisture content is lesser than liquid limit, the soil is brittle and stiffer. The value of liquid limit is used in classification of the soil and it gives an idea about plasticity of the soil.

The liquid limit is the moisture content at which the groove formed by a standard tool into the sample of soil taken in the standard cup, closes for 12 mm on being given 25 blows in a standard manner. At this limit, the soil possess low shear strength.

Plastic limit: The Plastic Limit (PL) is the moisture content at which a fine-grained soil can no longer be remoulded without cracking.
Determination of Plastic Limit is as important as Liquid Limit so as to ascertain Plasticity Index, Ip of the soil. The plastic limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic and semi-solid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a thread ⅛ inch (3 mm) in diameter using a ground glass plate or other acceptable surface.

Fig: **Liquid Limit Apparatus**

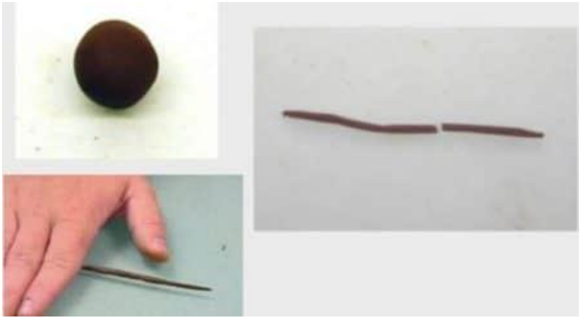

Fig: **Plastic Limit**

Grain size distribution by sieve analysis:

Dry and Wet Sieve Analysis is carried out to quantitatively determine the Particle/Grain Size Distribution for soil particles of size 75 micron and bigger. For soil particles of size 4.75mm and bigger, dry sieve analysis is done and for soil particles of size above 75 micron and below 4.75mm, wet sieve analysis is also needed if the soil particles are coated by clay/silt.
The grain size analysis is widely used in classification of soils. The data obtained from grain size distribution curves is used in the design of filters for earth dams and to determine suitability of soil for road construction, air field etc. Information obtained from grain size analysis can be used to predict soil water movement although permeability tests are more generally used.

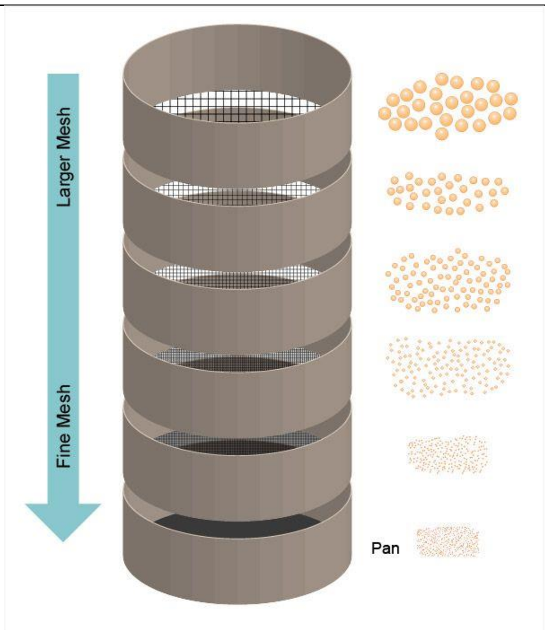

Fig: **Set of Sieves**

Field density by core cutter method:

Core cutter method is used for finding field density of cohesive/clayey soils placed as fill. It is rapid method conducted on field. It cannot be applied to coarse grained soil as the penetration of core cutter becomes difficult due to increased resistance at the tip of core cutter leading to damage to core cutter.

Fig: **Core Cutting Apparatus**

Field density by sand replacement method:

The sand replacement method is used to determine in-place density. The sand replacement method of determination of in situ density uses a sand-pouring cylinder, cylindrical calibrating container, tray with a central circular hole, and a chisel. Determination of field density using the sand replacement method involves three steps. The first step involves calibration of a sand-pouring cylinder. The soil density is measured in the second step and then the water content and dry density is measured in the third step.

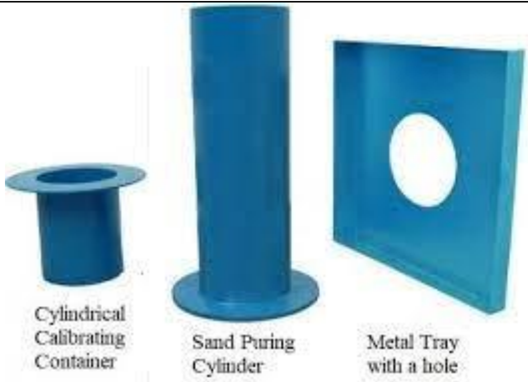

Fig: **Sand Replacement Apparatus**

Relative density of sand:

Relative density or density index is the ratio of the difference between the void ratios of a cohesionless soil in its loosest state and existing natural state to the difference between its void ratio in the loosest and densest states.

$$\text{Relative Density} = \frac{e_{ma} - e}{e_{max} - e_{min}}$$

Porosity of a soil depends on the shape of grain, uniformity of grain size and condition of sedimentation. Hence porosity itself does not indicate whether a soil is in loose or dense state. This information can only be obtained by comparing the porosity or void ratio of the given soil with that of the same soil in its loosest and densest possible state and hence the term, relative density is introduced.

Relative density is an arbitrary character of sandy deposit. In real sense, relative density expresses the ratio of actual decrease in volume of voids in a sandy soil to the maximum possible decrease in the volume of voids i.e how far the sand under investigation can be capable to the further densification beyond its natural state. Determination of relative density is helpful in compaction of coarse grained soils and in evaluating safe bearing capacity in case of sandy soils.

Fig: **Relative Density Apparatus**

Standard and modified compaction test:

Standard or Proctor Compaction Test: The Proctor Compaction Test establishes the maximum unit weight that a particular type of soil can be compacted to using a controlled compactive force at an optimum water content. This is the most common laboratory soil test and the basis for all engineered compacted soil placements for embankments, pavements, and structural fills. In-place measured densities of the compacted fill are compared to the Proctor test results to determine the degree of soil density

Modified Compaction Test: To obtain the graphical relationship of the "dry density' to "moisture content" in the form of "compaction curve", for determining the values of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The Modified Proctor Test is of great importance and is widely used in the construction of roads, highways, earth fill dams, earth filling, Airports, etc.

Standard vs Modified Proctor

Test procedures are similar, but the laboratory compactive effort of the modified method is higher. Using a 10lb (4.54kg) hammer with 18in (457.2mm) free-fall instead of the 5.5lb (2.49kg) hammer with 12in (304.9mm) drop. This results in higher maximum soil densities at lower optimum moisture contents. The modified Proctor is used today concurrently with the standard Proctor. The selection of the method is based on project requirements and specifications.

Fig: **Compaction Apparatus**

Permeability of Soil by Constant and Variable Head Test:

The rate of flow of water, under laminar flow conditions, through a unit cross sectional are of soil mass, under unit hydraulic gradient, is defined as coefficient of permeability. Permeability of the soil governs the magnitude of excess pore water pressure built-up in the embankment or cuttings, during consolidation process or when the embankment is ponded by water. The excess pore water pressure in-turn significantly influences the stability of the embankments and indicate the need, or otherwise, of need for special measures (e.g. sandwich construction) to prevent/quickly dissipate excess pore water pressure. Coefficient of permeability is used to assess drainage characteristics of soil, rate of consolidation and to predict rate of settlement of soil bed. The coefficient of permeability is generally determined by two procedures.

Constant Head Test: The constant head permeability test is a common laboratory testing method used to determine the permeability of granular soils like sands and gravels containing little or no silt. This testing method is made for testing reconstituted or disturbed granular soil samples.

Variable Head Test: Variable head permeability test is one of several techniques by which the permeability of soil is determined. It is used to evaluate the permeability of fairly less previous soil. Permeability is the measure of the ability of soil to allow water to flow its pores or voids.

Fig: **Soil Permeability of Apparatus**

California Bearing Ratio Test:

CBR is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 and 5 mm . When the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5 mm is used.

The following table gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%.

Table: Standard Load Values at Penetration

Penetration of Plunger (mm)	Standard Load (kg)
2.5	1370
5.0	2055

For Railway Formation purpose, the test is performed on remoulded specimens which are compacted dynamically.

The methodology covers the laboratory method for the determination of C.B.R. of remoulded /compacted soil specimens in soaked state.

Fig: **CBR Test Apparatus**

Consolidation test:

Consolidation test is used to determine the rate and magnitude of soil consolidation when the soil is restrained laterally and loaded axially. The Consolidation test is also referred to as Standard Oedometer test or One-dimensional compression test. This test is carried out on saturated soil specimens, especially in cohesive soils. The consolidation parameters obtained by this test are used to determine the consolidation settlement and time of consolidation for a given loading state (i.e. given height of embankment). These parameters are also used in design of “Ground Improvement measures”, provided for construction of embankment on soft soils.

Fig: **Consolidation Test Setup**

Unconfined Compression Test:

The Unconfined Compression Test is a laboratory test used to derive the Unconfirmed Compressive Strength (UCS) of a soil specimen. Unconfirmed Compressive Strength (UCS) stands for the maximum axial compressive stress that a specimen can bear under zero confining stress. Due to the fact that stress is applied along the longitudinal axis, the Unconfined Compression Test is also known as Uniaxial Compression Test. UCS is a parameter widely used in geotechnical design.
During the test, apart from the axial load, axial and lateral deformation are commonly measured to derive the sample's elastic modulus and Poisson's ratio.

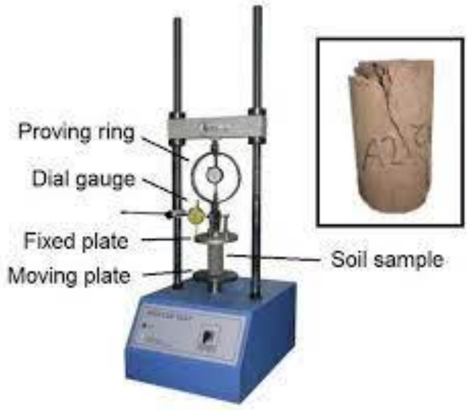

Fig: **Unconfined Compression Machine**

Direct Shear Test:

For any soil Cohesion (C) and Angle of Internal Friction (Ø) are two important engineering properties, which indicate the shear strength of soil. These two parameters are required for design of slopes, calculation bearing capacity of any strata, calculation of consolidation parameters and in many other analyses. Direct shear test is used to predict these parameters quickly, especially in cohesionless soils.

Fig: **Direct Shear Test Machine**

Vane Shear Test:

The laboratory vane shear test for the measurement of shear strength of cohesive soils, is useful for soils of low shear strength of less than about 0.5 kgf/cm2). This test gives the undrained strength of the soil, in undisturbed as well as remoulded conditions both. Vane shear test is a cheaper and quicker method of measuring the shear strength of clay, as compared to very elaborate tri-axial shear test or direct shear test.

Fig: **Vane Shear Apparatus**

Tri-axial test

The tri-axial shear test is most versatile of all the shear test testing methods for getting shear strength of soil i.e. Cohesion (C) and Angle of Internal Friction (Ø), though it is bit complicated. This test can measure the total as well as effective stress parameters both. These two parameters are required for design of slopes, calculation of bearing capacity of any strata, calculation of consolidation parameters and in many other analyses. This test can be conducted on any type of soil, drainage conditions can be controlled, pore water pressure measurements can be made accurately and volume changes can be measured. In this test, the failure plane is not forced, the stress distribution of failure plane is fairly uniform and specimen can fail on any weak plane or can simply bulge.

Fig: **Tri-axial Test Setup**