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Agricultural Engineering Department

Irrigation and Drainage Technology

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SOIL MECHANICS (IDTSM601)

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PURPOSE STATEMENT

By the end of the course, the student will be able to perform the soil tests including the Moisture content test, Bulk density test, Sieve analysis test, Specific gravity test, Hydrometer test, Atterberg limits test, Swelling test, Standard proctor test, Modified proctor test, Sand replacement test, Permeability test, Direct shear test, and the Soil penetration test.

1. PERFORM MOISTURE CONTENT TEST

1.1. Identify main testing equipment

1.2. Prepare samples

1.3. Perform testing procedures

1.4. Record and analyze data

1.5. Prepare the report

Introduction

The soil moisture content is the amount of water present in the soil. Commonly expressed as the amount of water (in mm of water depth) present in a depth of one metre of soil. For example: when an amount of water (in mm of water depth) of 150 mm is present in a depth of one metre of soil, the soil moisture content is 150 mm/m (see Fig. 1).

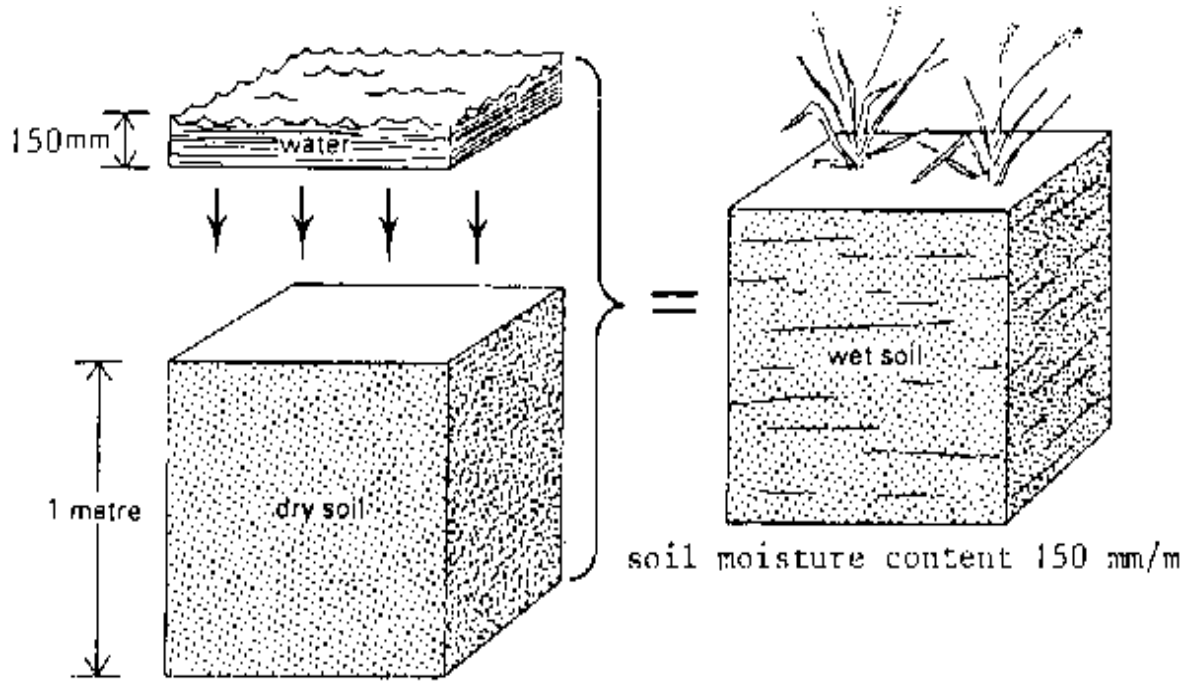


Fig. 1.1. A soil moisture content of 150 mm/m (FAO, n)

The moisture content of soil also referred to as **water content**, is an indicator of the amount of water present in soil (FAO, n; Hossain et al., 2022). Moisture content is the ratio of the mass of water contained in the pore spaces of soil to the solid mass of particles in that material, expressed as a percentage. A standard temperature of 110 ± 5°C is used to determine the mass of the sample (Hossain, Islam, Badhon, & Imtiaz, n).

Purpose of the Test and Practical application

Almost all soil tests determine the natural moisture content of the soil, and it is essential knowledge for all studies of soil mechanics. The natural moisture content provides an idea of the state of the soil in the field.

Moisture content is one of the most important **index properties** used for the correlation of soil behavior and its index properties (Hossain, Islam, Badhon, & Imtiaz, 2022).

- ✓ Index properties are the properties of soil that help in identification and classification of soil for general engineering purpose (Mathur, Kumar, Pandey, & Choudhary, 2017).
- ✓ **The properties of soil index** (Particle size distribution, Particle shape, Relative density, Consistency, Clay and clay mineral content, Particle shape and its orientation, Clay or clay mineral content, water content in the soil).

The moisture content of the soil is used to express the phase relationships of water, air, and solids in a given volume or weight of the material.

Soil Sampling Procedures

Soil sample heterogeneity

- variations in soil parent material
- The process of soil formation,
- Leaching of organic and inorganic materials,
- Biological activities in the soil and volatilization from soils (Houba *et al*., 1990).

It is important to mention that there are influences of human activities (tillage & fertilization history). ***The representativeness of a soil sample*** is influenced by:

- ✓ *uniformity of the composite sample,*
- ✓ *seasonal variations and*
- ✓ *changes in the sample during processing and storage* (Okalebo et al., 2002)

SOIL SAMPLING STRATEGIES

No standard procedure applicable to all soils and conditions.

Fig.1.2. Taking a soil sample with a soil auger at Isparta, Türkiye

Points to keep in mind:

- Series of cores, taken according to some systematic grid layout of the area, should be composted.
- Separate soil cores or replicate sets of composite samples should be analyzed to determine statistical significance of results of the final composite sample.
- The number of soil cores to be composted depends on the heterogeneity of the soil, the degree of precision desired, and the element to be determined.
- Cultivated soils are generally less homogeneous than virgin soils.
- The need for taking separate composite samples in order to represent different horizons of soil profiles or root zones or parts of the area, belonging to different soil types.
- Contamination by crop residues, manure, fertilizers, must be avoided.

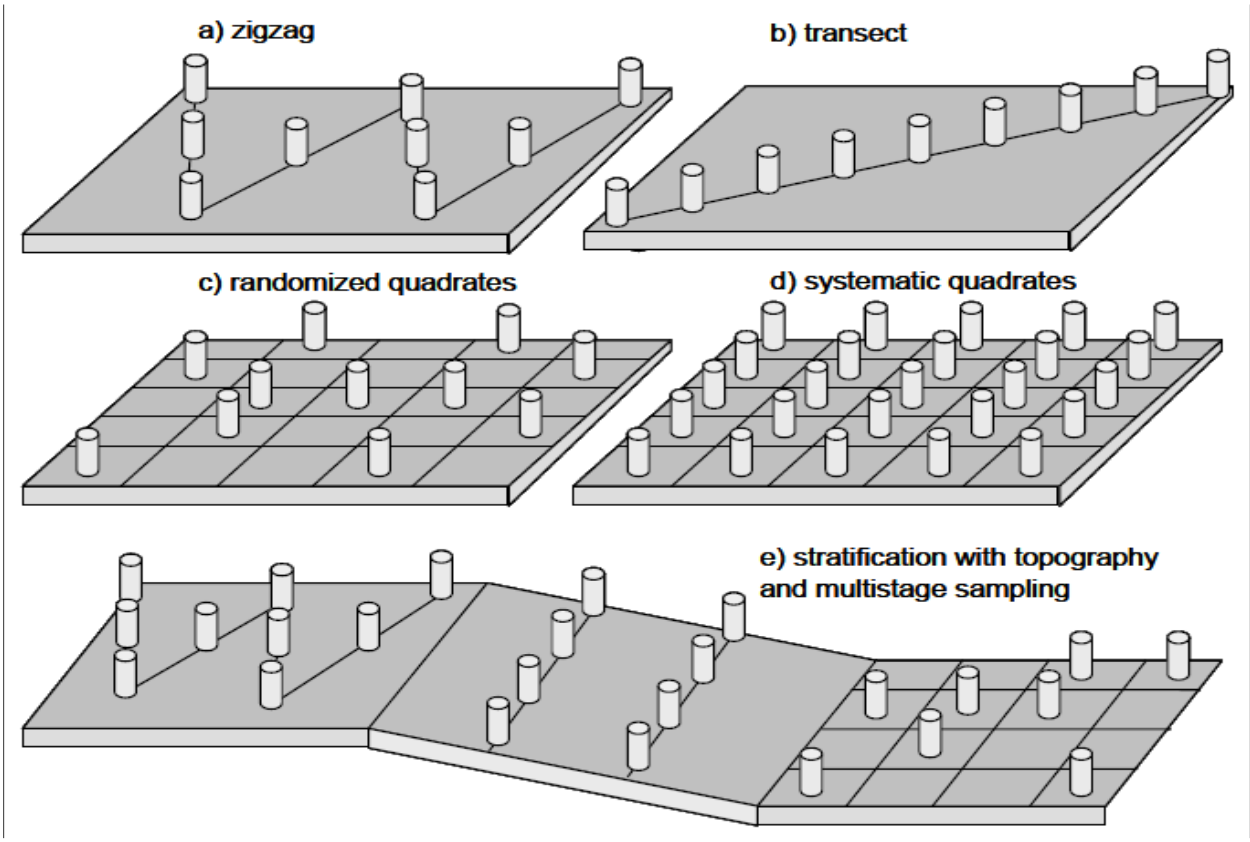


Fig.1.3. Sampling approaches for agricultural lands

Mass Soil Water Content, Θm and Volume Soil Water Content, Θv

The volumetric water content Θv is defined as the volume of water associated with a given volume (usually 1 m3) of dry soil. A comparable expression is the mass water content Θm, or the mass of water associated with a given mass (usually 1 kg) of dry soil.

As compaction reduces total porosity, it also increases Θv (assuming a given Θm), therefore often leaving too little air-filled pore space for optimal root activity. However, if a soil is initially very loose and highly aggregated, moderate compaction may actually benefit plant growth by increasing the volume of pores that hold water between 10 and 1500 kPa of tension (water that plants can utilize) (Weil, R.R. & Brady, N. C., 2016).

Gravimetric Water Content, Θm and Volumetric Water Content, Θv (Weil, R.R. & Brady, N. C., 2016)

The gravimetric procedures for determining mass soil water content θ_m are relatively simple. Assume that you want to determine the water content of a 100 g sample of moist soil. You dry the sample in a convection oven kept at 105 °C and then weigh it again. Assume that the dried soil now weighs 70 g, which indicates that 30 g of water has been removed from the moist soil. Expressed in kilograms, this is 30 kg water associated with 70 kg dry soil.

Since the mass soil water content θ_m is commonly expressed in terms of kg water associated with 1 kg *dry* soil (*not* 1 kg of *wet* soil!), it can be calculated as follows:

$$\frac{30 \text{ kg water}}{70 \text{ kg dry soil}} = \frac{X \text{ kg water}}{1 \text{ kg dry soil}}$$

$$X = \frac{30}{70} = 0.428 \text{ kg water/kg dry soil} = \theta_m$$

To calculate the volume soil water content θ_v, we need to know the bulk density of the dried soil, which in this case we

shall assume to be 1.3 Mg/m^3. In other words, a cubic meter of this soil (*when dry*) has a mass of 1300 kg. From the above calculations we know that the mass of water associated with this 1300 kg of dry soil is 0.428×1300 or 556 kg.

Since 1 m^3 of water has a mass of 1000 kg, the 556 kg of water will occupy 556/1000 or 0.556 m^3.

Thus, the volume water content is 0.556 m^3/m^3 of dry soil:

$$\frac{1300 \text{ kg soil}}{\text{m}^3 \text{ soil}} \times \frac{\text{m}^3 \text{ water}}{1000 \text{ kg water}} \times \frac{0.428 \text{ kg water}}{\text{kg soil}} = \frac{0.556 \text{ m}^3 \text{ water}}{\text{m}^3 \text{ soil}}$$

Assuming a soil that does not swell when wet, the relationship between the mass and volume water contents can be summarized as:

$$\theta_v = D_b \times \theta_m$$

TESTING PROCEDURES

Procedures for soil sample testing

Some Methods of Measuring Soil Water (Weil, R.R.& Brady, N. C., 2016)

Method	Measures soil water: Content	Measures soil water: Potential	Useful range, kPa	Used mainly in: Field	Used mainly in: Lab	Comments
1. Gravimetric	x		0 to < −10,000		x	Destructive sampling; slow (1–2 days) unless microwave used. The standard for calibration.
2. Neutron scattering	x		0 to < −1,500	x		Radiation permit needed; expensive equipment; not good in high-organic-matter soils; requires access tube.
3. Time domain reflectometry (TDR)	x		0 to < −10,000	x	x	Can be automated; accurate to ±1 to 2% volumetric water content; very sandy, clayey, or salty soils need separate calibration; requires wave guides; expensive instrument.
4. Capacitance	x		0 to < −1,500	x		Can be automated; accurate to ±2 to 4% senses volumetric water content; sands or salty soils need special calibration; simple, inexpensive sensors and recording instruments.
5. Resistance blocks		x	−90 to < −1,500	x		Can be automated; not sensitive near optimum plant water contents, may need calibration.
6. Tensiometer		x	0 to −85	x		Can be automated; accurate to ±0.1 to 1 kPa; limited range; inexpensive; needs periodic servicing to add water to tensiometer.
7. Thermocouple psychrometer		x	50 to < −10,000	x	x	Moderately expensive; wide range; accurate only to ±50 kPa.
8. Pressure membrane apparatus		x	50 to < −10,000		x	Used with gravimetric method to construct drier part of water characteristic curve.
9. Tension table		x	0 to −50		x	Used with gravimetric method to construct wetter part of water characteristic curve.

More than one method may be needed to cover the entire range of soil moisture conditions (Weil, R.R. & Brady, N. C., 2016).

Gravimetric Method

The gravimetric method is a direct measurement of soil water content and is therefore the standard method by which all indirect methods are calibrated. The water associated with a given mass (and, if the bulk density of the soil is known, a given volume) of dry soil solids is determined. A sample of moist soil is weighed and then dried at 105 °C for about 24 hours, and finally weighed again. The weight loss represents the soil water.

Equipments

1. Non-corrodible container,
2. Vented, thermostatically controlled drying oven that maintains temperatures between 105°C to 115°C.
3. Balance of sufficient sensitivity (sensitive to 0.01 g),
4. Container handling apparatus (Hossain, Islam, Badhon, & Imtiaz, 2022).

Prepare samples

- It is important that the sample reflects the properties of the larger system of interest.
- Sampling procedures are different for different sorts of investigations.

Procedures for Gravimetric Method

1. Clean, dry and weigh $W_1$the container (Fig 1.4). The balance needs to be tarred before it is used to measure the weight.

Fig.1.4: Taring the balance

2. Weigh W_2 a sample of the specimen in the container (wet soil + Container)

Fig.1.5: Labeled container

3. Keep the container in the oven for 24 hours. Dry the specimen to a constant weight, maintaining the temperature between 105°C to 115°C. (The time will vary with the type of soil, but 16 to 24 hours is usually sufficient.)

Fig. 1.6: Soil sample in the container

4. Record the final constant weight W_3 of the container with the dried soil sample. Peat and other organic soils should be dried at a lower temperature (approximately 60°C) for a longer period of time.

Fig.1.7: Keeping of the soil samples in an oven

RECORD AND ANALYZE DATA

Sample Datasheet

Sample No.	1	2	3
Can No:	#1	#2	#3
Weight of can, W_1	23.51	16.32	19.88
Weight of can + wet soil, W_2	165.21	149.77	158.23
Weight of can + dry soil, W_3	145.65	134.32	137.55

Can No: 1

Weight of can = 23.51 gm

Weight of can + wet soil = 165.21 gm

Weight of can + dry soil = 145.65 gm

Weight of water in the soil sample, M_w= (165.21 – 145.65) = 19.56 gm

Weight of the dry soil. M_s= (145.65 – 23.51) =122.14 gm

Moisture content of the given soil sample = $M_w/M_s \times 100\%$

= 19.56/122.14×100%

= 16.01%

Blank Datasheet

Sample No.			
Can No:			
Weight of can, W_1			
Weight of can + wet soil, W_2			
Weight of can + dry soil, W_3			
Water/Moisture content, W (%)			

Neutron Scattering

A neutron scattering probe, which is lowered into the soil via a previously installed access tube, contains a source of fast neutrons and a detector for slow neutrons. When fast neutrons collide with hydrogen atoms (most of which are part of water molecules), the neutrons slow down and scatter. The number of slow neutrons counted by a detector corresponds to the soil water content.

Dielectric Methods

A dielectric material is poor at conducting an electric current, but can support an electrostatic field (something like a magnetic field). Instruments that measure the dielectric properties of soil can be used to determine the proportion of the soil volume comprised of water because the dielectric constant for water (81) is far greater than for mineral particles (3–5) or for air (1). **Dielectric constant for the whole soil is nearly proportional to the volume of water in the soil in the immediate vicinity (3–4 cm) of the sensor.**

A widely used dielectric method is **time-domain reflectometry** (TDR), which measures two parameters: **(1) the time it takes for an electromagnetic impulse to travel down two or three**

parallel metal transmission rods (wave guides) buried in the soil, and (2) the degree of dissipation of the impulse as it impacts with the soil at the end of the lines.

The transit time is related to the soil's apparent dielectric constant (its insulating properties as compared to a vacuum). The dissipation of the signal is related to the level of salts in the soil solution.

Both **soil *moisture content* and *salinity*** can be measured using TDR. The TDR wave guides may be portable (inserted into the soil for each reading) or may be installed in the soil at various depths and connected by wire to a meter or data logger. The TDR instrument incorporates sophisticated electronics and computer software capable of measuring and interpreting minute voltage changes over precise picosecond time intervals. While quite expensive, the TDR instrument can be used (without soil-specific calibration) in most types of soils to obtain accurate readings for the entire range of soil water contents.

Capacitance Methods

By measuring the rate of change of voltage along a thin metal rod, a capacitance sensor determines the dielectric constant of the soil in which it is embedded. As in the case of the TDR method, variations in measured dielectric constant are mainly due to variations in volumetric water content of the soil. Capacitance sensors are less expensive than neutron or TDR probes and simpler to use. They also do not use hazardous radiation (as does the neutron probe). The sensors are normally accurate to within 3 to 5%, but can be influenced by changes in temperature and salinity, as well as air gaps that occur in very coarse sandy or gravelly soils.

Fig. 1.8. Electronic instruments can measure volumetric water content of soil by determining dielectric (insulating) properties of the soil into which a sensor is inserted. **A time domain reflectometry (TDR) meter, and sensor (left) and a capacitance sensor and meter (right) are shown** (Weil, R.R. & Brady, N. C., 2016).

The TDR instrument calculates the volumetric water content of soil by analyzing the velocity at which electromagnetic waves move through the soil and and the reflected wave patterns generated. Electrical capacitance probes determine volumetric water content by measuring the amount of charge required to raise the voltage between two conductors separated by the soil.

The capacitance instruments are simpler and less expensive than the TDR instruments, but are more likely to require laborious soil-specific calibration. For both methods, it is important that the sensors be installed such that the prongs are completely and snugly buried in soil with no air gap.

Measuring Soil Water Potentials

Tensiometers

The tenacity with which water is attracted to soil particles is an expression of matric water potential ψm. Field **tensiometers** measure this attraction or *tension*.

Electrical Resistance Blocks

Electrical resistance blocks are made of porous gypsum (CaSO4 · 2H2O), suitably embedded with electrodes. When placed in moist soil, the fine pores in the block absorb water in proportion to the soil water potential. The more tightly the water is being held in the soil, the less water the block will be able to absorb. The resistance to flow of electricity between the electrodes embedded in the block decreases in proportion to how much water has been absorbed in the block.

These devices must be calibrated for each soil and the accuracy and range of soil moisture contents measured are limited. However, they are very inexpensive and can be used to measure approximate changes in soil moisture during one or more growing seasons.

Fig.1.9. Instruments that measure soil water potential in the field include the **tensiometer (center) and electrical resistance blocks (right).** The tensiometer tube is filled with water through the screw-off top. Once the instrument is tightly sealed, the white porous tip and the lower part of the plastic tube is inserted into a snugfitting hole in the soil. The vacuum gauge (close up, left) will directly indicate the tension or negative potential generated as the soil draws the water out (curved arrows) through the porous tip (Weil, R.R. & Brady, N. C., 2016).

Thermocouple Psychrometer

Since plant roots must overcome both matric and osmotic forces when they draw water from the soil, there is sometimes a need for an instrument that measures both. The relative humidity of soil air is affected by both matric and osmotic forces, for both constrain the escape of water molecules from liquid water.

In a thermocouple psychrometer, a voltage generated by the evaporation of a water drop is converted into a readout of soil water potential ($\psi o + \psi m$). The thermocouple psychrometer is most useful in relatively dry soils in which imprecisions of ± 50 kPa involve negligible quantities of water.

Pressure Membrane Apparatus

A pressure membrane apparatus is used to subject soils to matric potentials as low as -10,000 kPa. After application of a specific matric potential to a set of soil samples, their soil water contents are determined gravimetrically. This important laboratory tool makes possible accurate measurement of water content over a wide range of matric potentials in a relatively short time. It is used, along with the tension plate, to obtain data to construct soil water characteristic curves.

Fig.1.10. Pressure Membrane Apparatus with soil samples inside. *A photo taken in the Soil Physics Lab, Süleyman Demirel University.*

Water is forced out of the soil through a porous plate (see inset diagram) into a cell at atmospheric pressure. The inset photo (upper left) shows a top view of soil samples contained in metal rings set on the porous plate before bolting on the cover. The pressure applied when the downward flow of water ceases reflects the water potential in the soil. This apparatus will measure much lower soil water potential values (drier soils) than will tensiometers (Weil, R.R. & Brady, N. C., 2016).

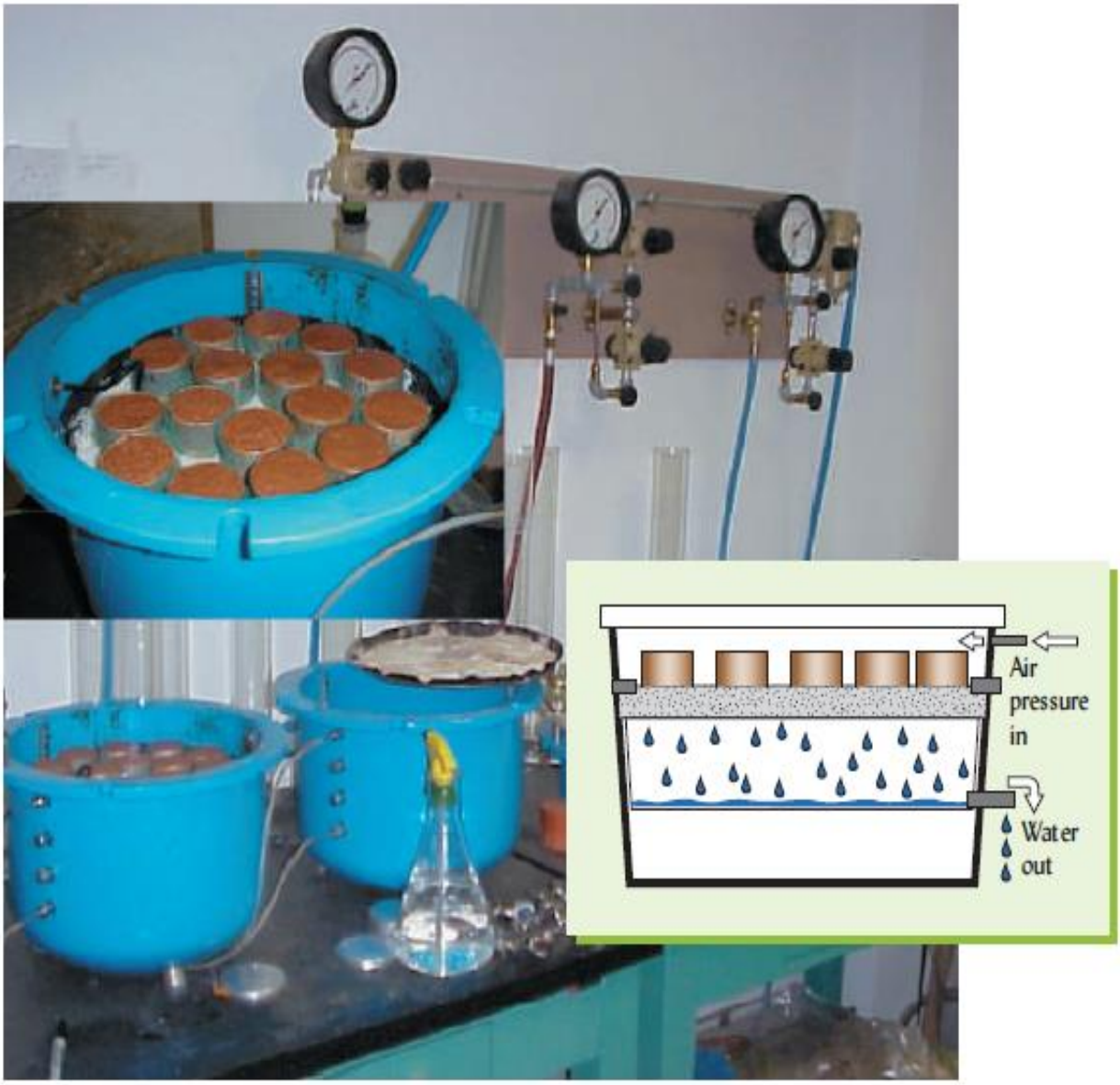


Fig.1.11. Pressure membrane apparatus used to determine relationships between water content and matric potential in soils. An outside source of gas creates a pressure inside the sealed chamber.

Soil Water Overview

Field Capacity

The *field capacity* is the amount of water remaining in the soil a few days after having been wetted and after free drainage has ceased. The matric potential at this soil moisture condition is around -1/10 to – 1/3 bar.

The attraction of water to solid surfaces gives rise to the matric potential ψm, which is always negative because the water attracted by the soil matrix has an energy state lower than that of pure water. These negative pressures are sometimes referred to as *suction* or *tension*. If these terms are used, their values are positive (Weil, R.R. & Brady, N. C., 2016).

The larger pores drain first so gravity drainage, if not restricted, may only take hours, whereas in clay soils (without macropores); gravity drainage may take two to three days. The volumetric soil moisture content remaining at field capacity is about 15 to 25% for sandy soils, 35 to 45% for loam soils, and 45 to 55% for clay soils.

Permanent Wilting Point

The *permanent wilting point* is the water content of a soil when most plants (corn, wheat, sunflowers) growing in that soil wilt and fail to recover their turgor upon rewetting. The matric potential at this soil moisture condition is commonly estimated at -15 bar.

Most agricultural plants will generally show signs of wilting long before this moisture potential or water content is reached (more typically at around -2 to -5 bars) because the rate of water movement to the roots decreases and the stomata tend to lose their turgor pressure and begin to restrict transpiration. This water is strongly retained and trapped in the smaller pores and does not readily flow. The volumetric soil moisture content at the wilting point will have dropped to around 5 to 10% for sandy soils, 10 to 15% in loam soils, and 15 to 20% in clay soils.

Available Water Capacity

The ***total available water (holding) capacity*** is the portion of water that can be absorbed by plant roots. By definition it is the amount of water available, stored, or released between field capacity and the permanent wilting point water contents. The soil types with higher total available water content are generally more conducive to high biomass productivity because they can supply adequate moisture to plants during times when rainfall does not occur.

Sandy soils are more prone to drought and will quickly (within a few days) be depleted of their available water when evapotranspiration rates are high. For example, for a plant growing on fine sand with most of its roots in the top foot of soil, there is less than one inch of readily available water.

A plant transpiring at the rate of 0.25 inches per day will thus start showing stress symptoms within four days if no rainfall occurs. Shallow rooted crops have limited access to the available soil water, and so shallow rooted crops on sandy soils are particularly vulnerable to drought periods. Irrigation may be needed and is generally quite beneficial on soils with low available water capacity.

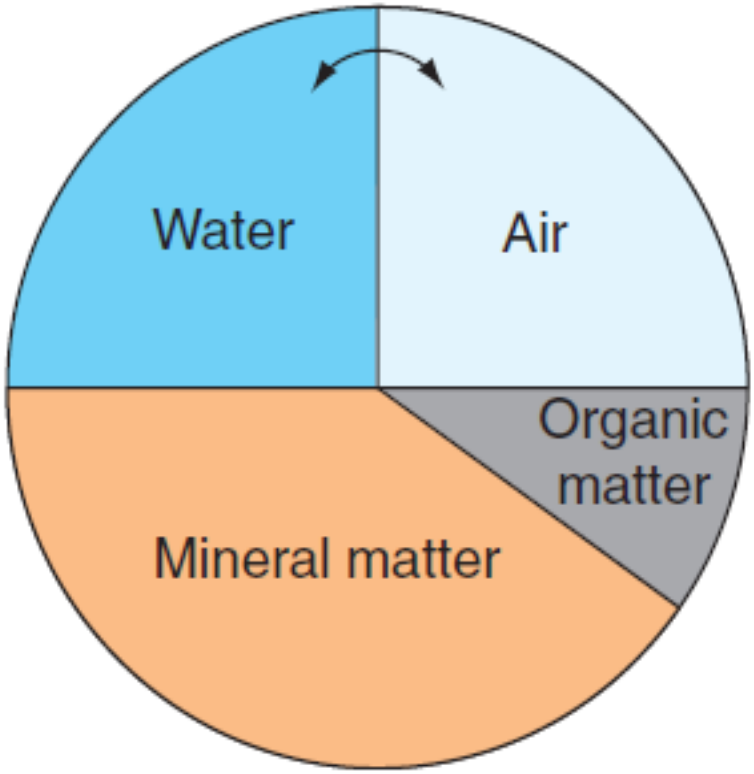


Fig.1.12. Schematic composition (by volume) of a medium-textured soil at a condition considered optimal for plant growth

Solid matter constitutes 50% and the pore space 50% of the soil volume, with the latter divided equally between water and air. The arrows indicate that water and air are related so that an increase in one is associated with a decrease in the other.

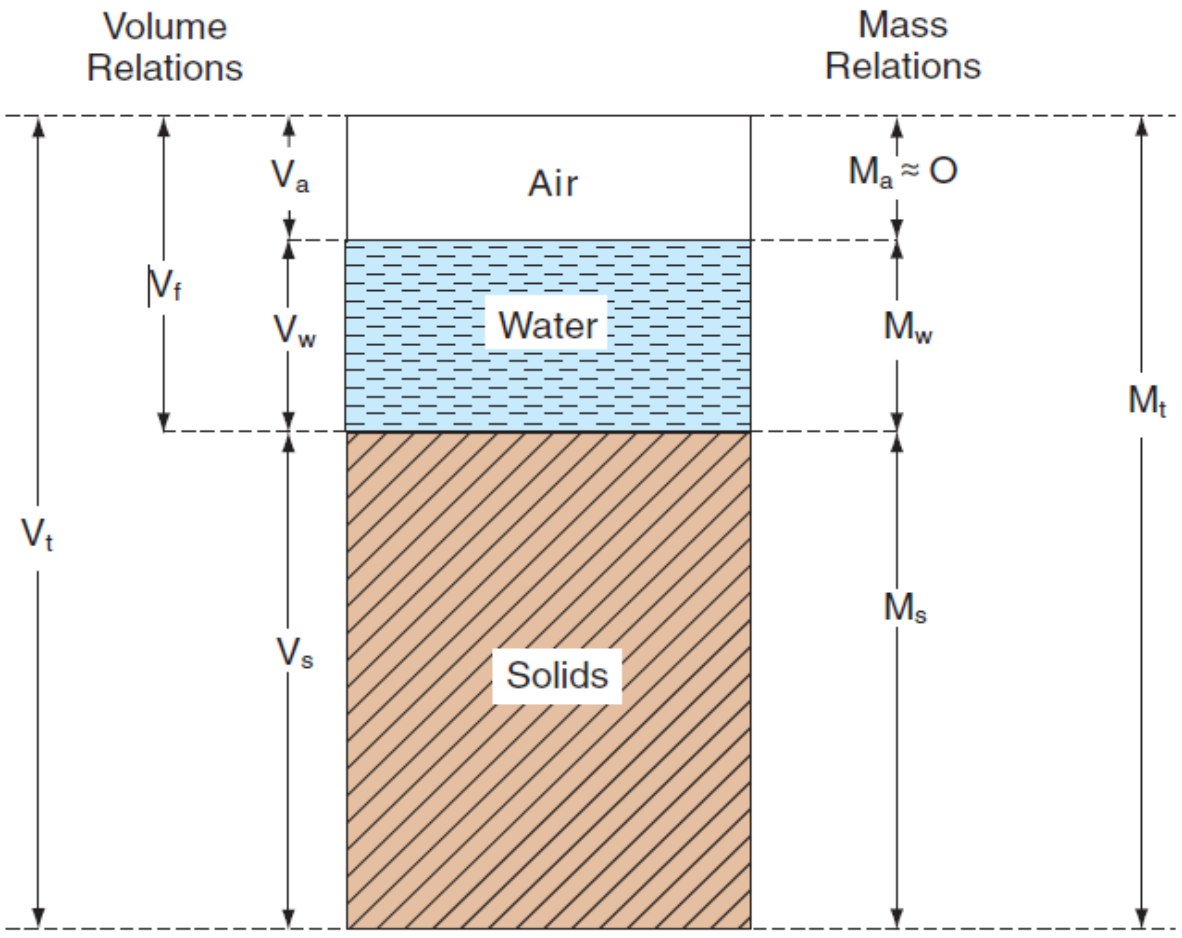


Fig.1.13. Schematic diagram of the soil as a three-phase system

Density of Solids (Mean Particle Density) ρ_s

$$\rho_s = M_s / V_s$$

In most mineral soils, the mean mass per unit volume of solids is about 2600–2700 kg/m3. This is close to the density of quartz, which is generally the most prevalent mineral in the coarsest fraction of the soil. Some of the minerals composing the finest fraction of the soil have a similar density. However, the presence of iron oxides and of various other **"heavy" minerals** (generally defined as those having a density exceeding **2900 kg/m3**) increases the average value of ρs, whereas **the presence of low-density organic matter generally lowers the mean density of the solid phase**.

***Specific Gravity*, σg**

Sometimes the density is expressed in terms of the *specific gravity*, σg, which is the ratio of the density of any material to that of water at 4°C and at atmospheric pressure. The latter density is about 1000 kg/m3, so the specific gravity of the solid phase in a typical mineral soil is about 2.65, a value that is numerically (though not dimensionally) equal to the density expressed in the cgs. system of units (g/cm3).

Dry Bulk Density ρb

$$\rho_b = M_s / V_t = M_s / (V_s + V_a + V_w)$$

The dry bulk density expresses the ratio of the mass of solids to the total soil volume (solids and pores together). Obviously, **ρb *is always smaller than* ρs**. If the pores constitute half the volume, then ρb is half of ρs, namely, about 1300–1350 kg/m3, equivalent to a bulk specific gravity (i.e., the ratio of the soil's bulk density to the density of water at standard conditions) of 1.3–1.35.

Total (Wet) Bulk Density ρt

$$\rho_t = M_t / V_t = (M_s + M_w) / (V_s + V_a + V_w)$$

Dry Specific Volume *v*b

$$\upsilon_b = V_t / M_s = 1 / \rho_b$$

The volume of a unit mass of a dry soil (the reciprocal of the dry bulk density) serves as another useful index of the degree of looseness or compaction of a soil body.

Porosity *f*

$$f = V_f / V_t = (V_a + V_w)/(V_s + V_a + V_w)$$

Porosity is an index of the relative pore space in a soil. Its value generally ranges from 0.3 to 0.6 (30–60%). Coarse-textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the former.

In clayey soils, the porosity is highly variable because the soil alternately swells, shrinks, aggregates, disperses, compacts, and cracks.

Soil properties:

- ✓ Volume relationship (Void Ratio, Porosity, Degree of Saturation & Air Content)
- ✓ Weight relationship
- ✓ Weight-volume relationships (Bulk Density, Density, Dry Density & Relative density).
- ✓ Volume-weight relationships (Unit weights, Dry Unit Weight, Submerged (Buoyant) Unit Weight & Specific Gravity)

Bulk Density

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm3.

Why is bulk density important in soil?

Bulk density **reflects the soil's ability to function for structural support, water and solute movement, and soil aeration**. Bulk densities above thresholds indicate impaired function. Bulk density is also used to convert between weight and volume of soil.

Prepare the report

1) Objective of the test
2) Applications of the test
3) Apparatus used
4) Test procedures
5) Analysis of test results (e.g.: *Complete the table provided and show one sample calculation)*
6) Summary and conclusions (e.g. Comment on the moisture content of the given soil sample) (Hossain, Islam, Badhon, & Imtiaz, 2022).

2. PERFORM BULK DENSITY TEST

2.1. Identify main testing equipment with its accessories

2.2. Prepare samples

2.3. Perform testing procedures

2.4. Record and analyze data

2.5. Prepare the report

Review

Look at some parameters defined in the previous section (unit 1). Considering the Fig. 1.13. (i.e. **schematic diagram of the soil as a three-phase system**). **Bulk density, dry bulk density, wet bulk density (defined)**. Soil bulk density (ρb) is the mass per unit volume of soil.

In agriculture, the reference mass is after oven-drying, and the volume is for the <2-mm fabric, inclusive of solids and pore space. In agriculture, the soil volume is usually for the water content at or very near to field capacity as approximated by laboratory water-retention measurements at 10 or 33 kPa.

In engineering, the mass may include either or both the >2-mm fraction and water. The volume in engineering nearly always is for very moist or wet conditions (Soil Survey Division Staff, 1993).

The engineers' wet density is inclusive of the mass of water, commonly for the satiated condition, and may be inclusive of the fraction >2 mm. The engineers' dry density is the same as the agricultural bulk density, except that the fraction >2 mm may be included. When applying SI units, the unit kilograms per cubic meter gives large numbers, and the more common practice is to use the units tonnes per cubic meter, grams per cubic centimeter, or megagrams per cubic meter, which all give equivalent numerical values in the range of 1.0 to 1.7.

Engineers regularly use pounds per cubic foot. Other terms for bulk density, which are now obsolete, have been used, such as, ***volume weight, bulk specific gravity,*** **and** ***apparent specific gravity***.

Bulk density has application to nearly all soil studies and analyses. Soil quality, soil sufficiency, and sequestration of C have increased interest in bulk density, particularly of surface layers. Diversity among soil layers in strength, thickness, and depth necessitates several kinds of methods that may not result in the same values.

The four methods: **core, clod, excavation, and radiation**.

- ✓ For most agricultural soils and for organic soils, the ***core method*** is applicable.
- ✓ ***The clod method*** has the advantage that samples can be taken while the soil is dry and moistened to a standard state in the laboratory. It has the further advantage that both *moist and dry bulk density* may be obtained. From these densities, derivative quantities can be calculated, one of which is linear extensibility.
- ✓ For soils high in larger rock fragments, for fragile horizons, and for thin horizons, ***excavation methods*** are desirable (Page-Dumroese et al., 1999).
- ✓ ***Radiation methods*** are nondestructive and can be done in situ.

As mass measurements are generally accepted to have low variability, the volume measurements contribute most to variability of bulk density. Culley (1993) stated that "…four samples should be sufficient to estimate the mean density to within 10% of the true value, 95% of the time for a uniform soil type." Terry et al. (1981) reported that for two forested soils in North Carolina, 5 to 20 core samples, 7.5 cm in diameter, are needed for a precision of 0.10 g cm−3.

Application of ρb

ρb has 2 principal groups of uses: (i) conversion of data (percentage, cmol kg−1) to a volume basis and (ii) characterization of the soil fabric. Conversion from weight to volume for a soil layer involves ρb of the < 2-mm fabric and the volume of rock fragments:

$$Av = \{Aw\rho_b L[1 - (V_{>2}/100)]\}/F$$

where Av is the amount of a quantity (e.g., cation exchange capacity or organic C) for a specified area and thickness at or near field capacity, Aw is the amount for a specified weight of the <2-mm

fraction, usually 100 g or 1 kg, ρb is the bulk density of the <2-mm fabric (g cm−3 or Mg m−3), *L* is the thickness (cm), *V*>2 is the volume percentage of the >2-mm fraction, and *F* is a factor that is dependent on the units of area and the weight to which the quantity pertains. For an area of 1 m2 and assuming weight percentage data, *F* is 10.

In agriculture, characterization of the bulk density of the < 2-mm fabric has several purposes. The most common applications are ***ease of root penetration*** (Pierce et al., 1983), ***prediction of water transmission*** (Rawls et al., 1998), and as an ***indicator of soil quality*** (Lal et al., 1998; Larson & Pierce, 1994; Arshad et al., 1996; Doran & Parkin, 1994).

Most soils undergo shrinkage on drying, resulting in a continual change in bulk density as water content changes. In sandy soils, the dessication shrinkage is small and usually ignored or assumed to be negligible. By contrast, clayey soils often undergo measurable density changes during wetting and drying.

Soil shrinkage may occur as distributed throughout the entire soil body or the soil may develop dessication cracks and shrinkage is not distributed evenly. As a consequence, two bulk density quantities for the <2-mm fabric may be computed, one exclusive of dessication cracks and another inclusive of the dessication cracks (Grossman et al., 1990).

Methods, Apparatuses and Procedures for Testing ρb

Core Method

- A cylinder is inserted into the soil, and the sample is obtained within the cylinder.
- The volume of the sample is that of the inserted cylinder. The soil must remain within the cylinder on withdrawal from the soil.
- An important advantage of core methods is that samples of standard dimensions may be obtained. Other determinations, such as *K*sat, can be made on a sample that has a standard size and shape.

- We divide the various core methods arbitrarily into those ~ 5 to 15 cm long (short) and into longer cores ~>50 cm.

a. Short Cores

The cores for bulk density should be at least 75 and preferably 100 mm in diameter, and the height preferably should not exceed the diameter. The cylinder wall should be 0.5 to 0.6 mm (Topp et al., 1993). Page-Dumroese et al. (1999) compared cores 50 and 100 mm in diameter. Bulk densities for the smaller diameter were larger.

Cylinders are inserted with force or impact energy. A single cylinder may be used, usually with the bottom sharpened. A superior design consists of two concentric cylinders.

Fig.2.1. Typical double-cylinder, hammer-driven core sampler for obtaining soil samples for bulk density. From Blake and Hartge (1986).

To calculate the bulk density for any of the short-core methods, it is necessary to remove the excess soil protruding from the bottom and top of the core. If the top and bottom of the sample is flush with the ends of the cylinder, then the volume of soil is equal to that of the core. For incompletely filled cores, the volume of the space above the soil may be measured by pouring glass beads into the core and striking off flush (Culley, 1993), or by obtaining the difference in distance from a common reference to the bottom of the empty core and to the top of the soil in the partially filled core. A piece of retractable ruler is used.

The use of beads is probably more accurate than measuring with a ruler; however, the beads are difficult to use in wet or windy conditions.

b. Long Cores

Long core samplers are typically used by engineers and geologists to extract cores from deep borings. There is a device consisting of two cylinders with cutting knives located between, which cuts away the soil as the inner core is pushed downward. Cores 10 to 15 cm in diameter are obtainable. Samples may be obtained to 2 m (Kelley et al., 1947).

There is a device which can obtain samples to 30 m (Holtzclaw et al., 1975). Short cores are the more commonly used. The soil must be coherent enough that the sample remains in the core, and rock fragments >5 mm cannot be abundant.

For the most part, the cores are completely filled. The considerable height of the core (10 cm being the most common) may exceed the thickness of the soil layer of interest.

Materials and Supplies for core methods (Gregorich & Certer, 2007)

1. Double-cylinder core sampler, either hand operated or hydraulically driven

2. Clean, dry, and uniform cylinder with a known internal diameter d (cm) and height h (cm). The volume V (cm3) is

$$V = \frac{1}{4}\pi d^2 h$$

3. Sharp and rigid knife or spatula

4. Balance sensitive to 0.01 g

5. Drying oven capable of 105*o*C, preferably equipped with a circulating fan

6. Plastic bags and corrosion-resistant weighing tins large enough to hold the soil sample and the cylindrical core

7. Disks to protect the ends of cores

8. Masking tape

Procedures

1. Label and weigh cylindrical core sampler; record weight as W1 (g).
2. Label tin bottom and top, weigh together, and record weight as W2 (g).
3. Prepare a smooth ‘‘undisturbed’’ vertical or horizontal surface at the sampling depth.
4. Drive or press core sampler into the soil sufficiently to fill the inner core without inducing compression. Do not rock the sampler. In frictional or dense soils, careful excavation to minimize soil–metal adhesion may help in obtaining a representative core. An application of mineral oil to the core sampler may also be beneficial. Use of oil may affect wetting and drying within the core if it is to be used for water desorption characterization.
5. After careful removal of the undisturbed soil core, examine for signs of shattering or compression. Trim ends of acceptable soil cores flush with the end of the cylinder. Discard and resample if substantial root biomass or large coarse fragments protrude. Remove organic matter thatch at surface before sampling.

6. For cores that completely fill the cylinders, and if only density is to be determined, push the content of the cylinder out into a preweighed tin, which is then closed and weighed (W3, g).
7. Place samples in an oven set to 105*o*C. Drying time varies with core size and oven type. Cores of about 350cm3 usually require about 72 h of drying in ovens equipped with circulating fans. Smaller cores require less time. After drying and cooling in a desiccator, record the weight of the dry soil plus tin bottom and top as W5 (g).

Calculations

$$D_b = \frac{W_5 - W_2}{V}$$

and volumetric water content θ is

$$\theta = \frac{W_3 - W_5}{W_5 - W_2} \times \frac{D_b}{D_w}$$

The wet density (Dbw), used in soil mechanics and also for making comparisons between samples of soil that exhibit volume changes on drying, is

$$D_{bw} = D_b + \theta(\text{g cm}^{-3}) \quad \text{or} \quad \frac{W_3 - W_2}{V}$$

Density of Partially Filled Cores

1. Tare a graduated cylinder of volume Vg1 and then fill with glass beads. The weight of the beads is recorded as Wg1.
2. Obtain the weight (W4) of the partially filled soil core, place a disk under one end, and put it on a tray.
3. Pour glass beads onto the soil and level to the top of the cylinder with a spatula.
4. Place a disk over the top of the cylinder, invert the core, and fill the other end with beads. Transfer the core to a preweighed tin (W2) and dry at 105*o*C.
5. Return excess glass beads from the tray to the cylinder and record their volume and weight as Vg2 and Wg2, respectively.
6. After drying the sample, cool in a desiccator and weigh (W5).
7. Calculate soil volume Vs as

$$V_s = V - \frac{W_{g1} - W_{g2}}{C}$$

where C is the packing density of the glass beads, which should be verified for each analysis.

Beads having a nominal diameter of 260 *m*m pack to a density of about 1.50 g cm-3. Alternatively, the volume of beads can be calculated as Vg1-Vg2; so that Vs=V-(Vg1 -Vg2).

8. Calculate Db as

$$D_b = \frac{W_5 - (W_{g1} - W_{g2}) - W_2 - W_1}{V_s}$$

and θ as

$$\theta = \frac{W_4 - W_1}{V_s \cdot D_w}$$

Correction for Coarse Fragments

For certain applications, the Db of the fine fraction, defined as those particles less than 2 mm in diameter, is of interest. This density is obtained by sieving the soil through a 2 mm sieve, then oven-drying the soil that passed through. The material retained on the sieve is washed, dried, and weighed (recorded as W6). The volume of this fraction, Vc, can be determined by measuring the displacement of water in a graduated cylinder when the fragments are added. Db is then

$$D_b = \frac{W_5 - W_2 - W_1 - W_6}{V - V_c}$$

where W6 is weight and Vc is the volume of oven-dry soil >2 mm in size, and W1, W2, W5, and V are defined in the Section Procedures, pp. 745–746 in steps 1 to 7.

Excavation Method

Excavation methods have applicability to layers that can be described as being one or more of the following: *cohesionless, high in rock fragments >5 mm, or thin (<5 cm thick).* Excavation procedures have the advantage that the depth from which the sample is taken may be controlled by the morphology of the soil, in particular the rupture resistance, and is not set arbitrarily.

For cultivated soils, measurement by excavation permits calculation of the bulk density exclusive of the larger structural units and clods. The approach parallels the correction for rock fragments. Such a bulk density may be useful for *erosion prediction or describing rooting environment*.

Compliant-Cavity Apparatus (Bradford & Grossman, 1982; Kramer et al., 1993; and Grossman et al., 2001).

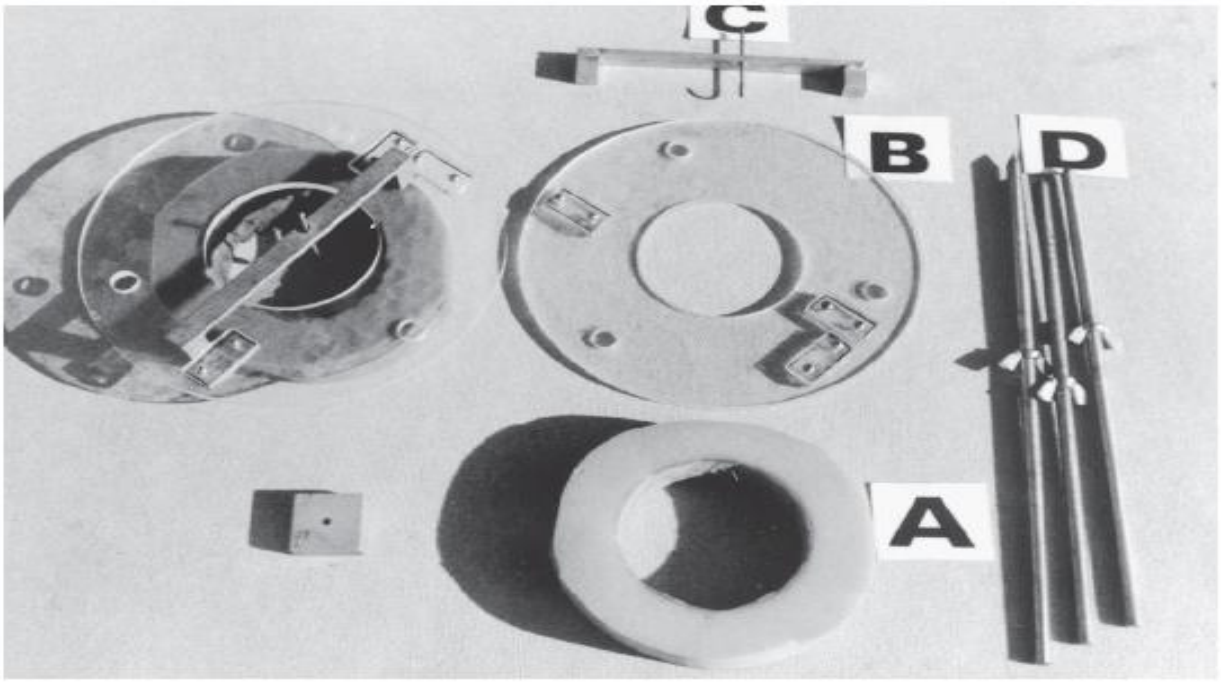


Fig.2.2. Compliant cavity apparatus: annulus of foam (A), rigid annulus that rests concentrically over the foam annulus (B), bar with hook gauge that mounts across the rigid annulus (C), and threaded rod with wing nuts that goes through holes in rigid annulus (D).

1.Annulus of flexible polyurethane foam 13 cm inside, 20 cm outside, and 5 cm high. The polyurethane foam should have an initial load displacement of 15 to 18 kg.

2.Plexiglass ring 0.9 cm thick, 13 cm inside diameter, and 31cm outside diameter, with three equidistant holes 1.5 cm in diameter, located 3 cm from the outside of the ring.

3.Three pieces of plexiglass 2.5 by 5 by 0.9 cm that are attached to the plate with glue or preferably bolts to form a guide for the bar to which the hook gauge is attached. Two are placed at right angles and the third on the other side of the plate. The pieces are located so that a line between the pieces on either side is close to a diameter of the ring. A space between the two pieces 1 cm wide facilitates removing the soil material that collects.

4.Three threaded rods 25 to 40 cm long and 1.3 cm in diameter with wing nuts.

5.An aluminum bar 24 cm long, 2 cm wide, and 0.6 cm thick with square legs 2.5 cm high and 1.9 cm wide. A hole is drilled in the middle of the bar to mount a hook gauge. The hole is placed somewhat away from the longitudinal axis so that the hook can be more readily seen. The hook gauge is made from a No.6 round-headed machine screw. A single nut is placed on the machine screw. Then the machine screw is placed through the hole in the bar. A second nut is then placed on the machine screw. The two nuts are used to secure the machine screw to the bar. The machine screw is then sharpened, heated, and finally bent to form a hook.

6. 500- and 1000-mL graduated cylinders

7. 0.01- to 0.03-mm (1/2 to 1 mil) plastic film

8. 60-mL syringe

9. Hard rubber mallet (Note: striking with a steel hammer causes the wing nuts to break.)

10. Hand-digging equipment (**e.g., trowel, kitchen spoon, knives, scissors**)

Compliant-Cavity Procedure

The foam annulus is placed on the soil surface. The rigid annulus is placed over the foam annulus so that the two central holes are coincident. Threaded rods are inserted into the holes in the ring and driven into the soil beneath with the rubber mallet. The assembly is securely mounted onto the soil surface by screwing down wing nuts. The cavity is lined with plastic film. The bar with the attached hook gauge is then placed across the cavity. The cavity is filled to the tip of the hook gauge with a known quantity of water using a graduated cylinder (usually 500 mL) to measure the water. The plastic film and the water contained are then removed. Soil is excavated to the desired depth, and the volume determination is repeated. The difference between the two water volumes is the volume of the soil excavated. The walls of the excavation should be as vertical as feasible. The excavated soil is oven-dried and a correction is made for the mass and the volume of rock fragments.

Polyurethane-Foam Apparatus (Mueller & Hamilton, 1992; Page-Dumroese, 1992.)

1. Expanding polyurethane foam
2. Large glass container of water
3. Hand digging equipment, such as is used in the Compliant Cavity Method

Polyurethane Procedure

Dig a 500- to 1500-mL hole with the bottom surface flattened (but not horizontal). Apply the foam in circular fashion starting at the deepest part of the hole. Add a small excess; place a weighted cardboard plate over the hole. Allow to cure. Trim so the plastic mold is flush with the ground

surface. Wash the plastic mold to remove adhering soil. Determine the volume of the foam mold by weight displacement in water.

Ring-Excavation Apparatus. (Grossman et al.,2001.)

1. Metallic cylinder, 20 cm in diameter, 10 to 20 cm high, and about 1 mm thick
2. Shelf standard (slotted rod) 1.5 cm wide, 1 cm high, and 25 cm long
3. Piece of retractable ruler 30 cm long with 0.1-mm divisions
4. Depth-measurement tool.
5. Piece of wood 10 by 10 by 30 cm
6. Hand digging equipment as for the Compliant Cavity method

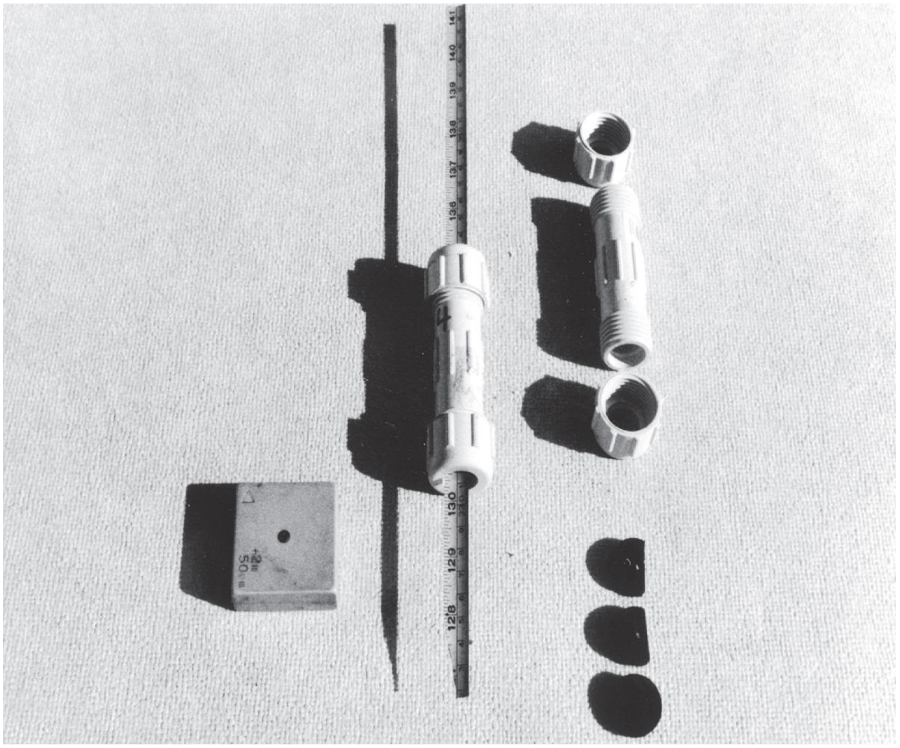


Fig.2.3. Depth measurement tool made from a compression coupler with washers from which a sector is removed. The partial washers align the piece of retractable measuring tape.

Ring-Excavation Procedure

A 20-cm-diameter ring is assumed. Insert the ring with impact energy or force to below the depth of excavation. Place a piece of shelf standard across the ring near to a diameter. Measure the distance to the ground surface at eight points equally spaced along the diameter using the depth-measurement tool to measure the distance. Rotate the piece of shelf standard 90° and make eight more measurements. Average the 16 measurements.

Excavate the soil to the desired depth. Repeat the distance measurements. Calculate the change in distance on removal of the soil. Multiply the change in distance by the cross sectional-area of the ring to obtain the volume of the soil.

3. PERFORM SIEVE ANLYSIS TEST

3.1. Identify main testing equipment with its accessories

3.2. Preparation of sample

3.3. Perform testing procedures

3.4. Record and analyze data

3.5. Prepare report

Sieve analysis also known as ***a mechanical method: analysis by Sieving***. The grain-size analysis is used in the classification of soils for engineering purposes. The resulting grain-size distribution curves are used as part of the criteria for road engineering, i.e., for road embankment construction or for determining the susceptibility of a soil to frost action (Gregorich & Carter, 2017).

This grain-size analysis is an attempt to determine the relative proportions of the different grain sizes that make up a given soil mass. This type of analysis has limitations; Day (1965) states that the probability of a particle passing through a sieve in a given time of shaking depends on the nature of the particle, the number of particles of that size, and the properties of the sieve. Gee and Or (2002) suggest that good reproducibility requires careful standardization of the procedure.

The typical particle-size range for sieving is 50 to 2000 μm. Several limitations of sieving have been noted in the past. Day (1965) indicated that the probability of a particle passing through a sieve in a given time of shaking depends on **the nature of the particle, the number of particles of that size, and the properties of the sieve. Particle shape and sieve-opening shape affect the probability of passage**.

For example, a particle whose shape permits its passage only in one orientation has a limited chance of getting through, except after prolonged shaking. Sieve openings are generally unequal in size, and extensive shaking is required before all particles have had the opportunity of approaching the largest openings.

In fact, it is rare that complete sorting of a given size range can be achieved. Good reproducibility requires careful standardization of procedure.

Load and Particle Shape Effect on Sieving Time

The sieving process involves two primary regions: (i) an initial region involving the passage of particles much finer than mesh openings and (ii) a region related to passage of near-mesh particle sizes (Allen, 1997).

Apparatus for Sample Preparation

1. Drying trays
2. Wooden rolling pin
3. Na–HMP solution (50 g L−1)
4. Sieves. Large 20.5-cm (8 in.) diameter sieve with a 2-mm (2000-μm) square-hole screen. Other screen sizes needed include 5, 20, and 75 mm (USDA, 1982); 5 mm (#4),13 mm (1/2 in.), 20 mm (3/4 in.), 25 mm (1 in.), 50 mm (2 in.), and 75 mm (3 in.) (ASTM, 2000d).
5. Ruler or caliper capable of measuring to 250 mm (10 in.)

Sample Preparation Method

Spread the bulk sample thinly (in 2- to 3-cm-thick layers, maximum) on trays and air-dry. Thoroughly mix and roll the sample with a wooden rolling pin to break up clods to pass a 2-mm sieve. Sieve out the >2-mm size fractions. Continue rolling and sieving until only coarse fragments that do not slake in water or HMP solution remain on the 2-mm screen. Use a rubber roller for samples with easily crushed coarse fragments. Sieve larger size fractions, record weights, and use total sample weight to calculate the percentage of total sample <2 mm.

Sometimes it is desirable to keep the sample at field moist conditions. If this is determined appropriate, force the field moist sample through the 2-mm screen by hand, using a large rubber stopper, double bag the sample in plastic, and store for further use. From a separate subsample, determine the water content so that a check can be made on possible drying effects during storage.

Whether material >2 mm in diameter is sieved depends on the purpose for the data set. For soil-survey purposes, methods specified by the USDA (1982) may be used. For engineering purposes, the material >2 mm can be sieved according to requirements specified by ASTM method D-2487 (ASTM, 2000a).

Sample size depends upon the maximum size fragments present. Suggested sample sizes are:

1. Particles up to 20 mm in diameter—use 5 kg or more.

2. Particles up to 75 mm in diameter—use 20 kg or more.
3. Particles up to 250-mm diameter—use 100 kg or more.

Because of the large samples required, the volume percentage of particles coarser than about 20 mm is usually estimated. A suggested procedure for handling coarser fragments follows.

1) Weigh and sieve the entire sample through 75- and 20-mm screens.
2) Weigh the >75-mm and the 75- to 20-mm fractions.
3) Take a subsample of the <20-mm fraction for laboratory processing.
4) Weigh the <20-mm sample before and after air-drying and correct the total sample weight for the loss of water from field conditions.
5) Separate and weigh the 2- to 5-mm and the 5- to 20-mm fractions.
6) If fine earth adheres to the coarse fraction, wash the coarse material, dry, reweigh, and apply the appropriate corrections.
7) Calculate the coarse fractions as a percentage of the <20-mm material (or the <75-mm, or the <250-mm, depending upon the size limit involved in sampling).

Note that for taxonomic (classification) purpose, stones or rock fragments >250 mm (10 in.) are separated and used to estimate the volume of coarse fragments for family placement of soils. A large caliper or ruler can be used to check the dimensions of the >250-mm material. In addition, weight measurements and volume-displacement techniques can be used to evaluate coarse-fragment volume.

Sieving of materials <2000 μm (2 mm) depends on the size separations required, but should always be done as a wet-sieve procedure because dry materials <2000 μm tend to aggregate. Dry sieving of soils containing any silt or clay size particles will always underestimate the primary particle sizes.

MATERIALS AND REAGENTS

1. Sieves and pan (20 cm diameter). Recommended ASTM sieve sizes No. 4 (4.76mm), No. 10 (2.00 mm), No. 40 (0.42 mm), and No. 200 (0.074 mm)

2. Sieve brush

3. Glass beaker (500 mL)

4. Porcelain evaporation dish (20 cm diameter)

5. Balance (capacity 1000 g; sensitivity 0.1 g)

6. Mortar and rubber-tipped pestle

7. Drying oven (105*o*C)

8. Sieve shaker

PROCEDURES

1. Thoroughly clean and weigh each sieve to be used to 0.1 g.

Note: Sieves should always be brushed and cleaned from the bottom side. Particles, which are forced through the sieve from the top, may enlarge the openings and reduce the accuracy and life expectancy of the sieve. Particles, which are stuck in the mesh, may be loosened by tapping the side wall of the sieve against the palm of the hand.

2. Select and weigh a representative sample of approximately 500 g, separate the soil into individual soil particles by crushing with fingers or a rubber-tipped pestle.

The size of sample that is considered to be representative is dependent upon the maximum size fragment present or to be analyzed (Gee and Or 2002). *Refer to the list below for representative sample guidelines*:

- ✓ **Particles up to 5 mm—500 g**
- ✓ **Particles up to 20 mm—5 kg**
- ✓ **Particles up to 75 mm—20 kg** (Gregorich & Carter, 2007)

Note: For fine-grained soils that dry into hard clods or aggregates, the best and most reproducible method to perform sieve analysis is to take a quantity of oven dried soil, break the sample as fine as possible, wash on a No. 200 sieve, oven-dry, and sieve the residue through a stack of sieves by shaking horizontally mechanically or by hand for 10 min.

3. The initial washing of the soil should be carefully conducted to avoid damaging the sieve or losing any soil by splashing the material out of the sieve. Wash the soil through the sieve using tap water until the wash water runs clear.
4. Using a wash bottle, carefully back-wash the residue into a large porcelain evaporation dish, decant as much excess water as possible, making sure not to lose any of the sample. Oven-dry the remainder of the soil–water suspension for 16 to 24 h at 105*o*C.
5. Remove sample from the drying oven, place a watch glass on top of the evaporation dish, and allow the dish and contents to cool to room temperature. Record the weight of the sample (Sw).

6. Pass the sample through the stack of sieves, using the following sieve sizes: #4, #10, #40, and #200. It is recommended that #20, #60, #100, and #140 sieves also be included in the stack to improve the fit to the semilogarithmic curve.
7. Shake the sample with the sieve shaker for 10 min, weigh each sieve, and record the weight of the sieve plus soil. Subtract the initial weight of the sieve as determined in step 1 and calculate the amount of the total sample retained on each sieve (as a percentage).
8. Sum the total weight of the sieve residues and compare this to the sample weight (Sw) recorded in step 5. If there is greater than 2% discrepancy, the test should be repeated
9. Calculate the percentage passing each sieve by starting with 100% and subtracting the percent sample retained on each step as a cumulative procedure.

10. Plot a semilogarithmic grain-size distribution curve. If less than 10% of the total sample passes the #200 sieve, the test is finished; if more than 10% passes, then continue with a particle size distribution method.

11. From the grain-size distribution curve calculate the coefficient of uniformity (C=D60/D10) where D refers to the effective diameter of the soil particles and subscripts (10 and 60) denote the percent which is smaller. An indication of the spread or range of grain size is given by Cu, with a large Cu value indicating that D60 and D10 sizes differ appreciably.

4. PERFORM SPECIFIC GRAVITY TEST

4.1. Identify main testing equipment with its accessories

4.2. Preparation of sample

4.3. Perform testing procedures

4.4. Record and analyze data

4.5. Prepare report

Particle density is the term used instead of **Specific Gravity of particles**. Knowledge of the particle density is essential in relation to other tests, especially for calculating porosity and voids and for computation of particle size analysis from a sedimentation procedure (**Hydrometer analysis**). It is also important when compaction and consolidation properties are considered.

Soil Particle Density (Gregorich & Carter, 2007)

A soil Dp of 2.65 g cm3 is commonly assumed. This value corresponds to the Dp for quartz. For a soil consisting of three constituents x1, x2, and x3 (fraction expressed by weight) with particle densities of Dp1, Dp2, and Dp3, soil Dp can be calculated as follows (Culley 1993):

$$\frac{1}{D_p} = \frac{x_1}{D_{p1}} + \frac{x_2}{D_{p2}} + \frac{x_3}{D_{p3}}$$

The Dp of a soil sample is calculated from two measured quantities, the weight and volume of particles. *The weight is determined by weighing and volume by calculation from the weight and density of water (or other fluid) displaced by the sample.*

MATERIALS AND SUPPLIES

1. Pycnometer (or 100 mL volumetric flask)
2. Distilled water
3. Thermometer
4. Air-dried soil sieved through a 2 mm sieve
5. Balance sensitive to 0.001 g
6. Drying oven capable of 105*o*C

PROCEDURE

1. Dry duplicate soil samples in a 105*o*C oven beforehand to determine the gravimetric water content (Θw) of air-dried soil.
2. Degas distilled water by gently boiling for several minutes and cooling to room temperature. Record the temperature of this water and corresponding density of water (Dw) at this temperature.
3. Fill a pycnometer with the degassed water. Insert the stopper in the pycnometer. Ensure the capillary bore in the stopper is filled. Wipe the pycnometer bottle dry and weigh (Ww).
4. Pour out about half of the water from the pycnometer. Replace the stopper, dry the outside of the bottle, and weigh it.
5. Add approximately 10 g of air-dried soil and again weigh the pycnometer and stopper. (Note: the difference in weights obtained in (5) and (4) is the weight of the air-dried soil, Wa). The weight of the oven-dried soil Ws is

$$W_s = \frac{W_a}{1 + \theta_w}$$

6. Refill the pycnometer with water. Replace the stopper and again make sure that the capillary bore is filled. Weigh the pycnometer, water, and soil (Wsw).

CALCULATION

$$D_p = \frac{d_w W_s}{W_s - (W_{sw} - W_w)}$$

Note: if a 100 mL volumetric flask is used, add 50 g of air-dried soil and follow all procedures as for a pycnometer.

5. PERFORM HYDROMETER TEST

5.1. Identify main testing equipment with its accessories

5.2. Preparation of sample

5.3. Perform testing procedures

5.4. Record and analyze data

5.5. Prepare report

PROCEDURE FOR PRETREATMENTS

1) Removal of Carbonates
2) Removal of Organic Matter
3) Removal of Soluble Salts
4) Removal of Iron Oxides (Optional)

Removal of Carbonates

1. Weigh 10 g of 2-mm air-dried soil into a 300 mL fleaker (tared to 1 mg). If the sample appears to be sandy, weigh a larger sample (e.g., 30 g).
2. Add 50 mL of water, mix, and add 1 M HCl slowly until pH reaches between 3.5 and 4.0 and remains there for 10 min. Stronger HCl can be used to avoid having a large volume of solution in soils high in carbonate content. Soils requiring a large amount of HCl to adjust the pH are washed several times with water to remove excess acid by using the filter candle system.

Removal of Organic Matter

1. Add 10 mL of hydrogen peroxide (H2O2, 30% or 50%) to the fleakers cover and allow to stand. If a violent reaction occurs, repeat cold H2O2 treatment until no more frothing occurs.
2. When frothing subsides, heat contents of fleakers to 90*8*C. Continue adding H2O2 and continue heating until most of the organic matter is removed (as observed by the color and rate of reaction of the sample).
3. Rinse down the sides of the reaction vessel occasionally. Continue heating the sample for about 45 min after the final addition of H2O2 to remove excess H2O2.

Note: It may be necessary to transfer samples containing high amounts of organic matter (>5%) to large beakers (e.g., 100 mL tall). If excessive frothing occurs, cool the container either with cold water or by the addition of methyl alcohol to avoid sample loss.

Removal of Soluble Salts

1. Place the fleakers in a rack and filter the remaining peroxide and water off from step 3 to remove organic matter using a filter candle system.
2. Add 150 mL of water in a jet strong enough to stir the sample, and filter the suspension through the filter candle system. Five such washings and filterings are usually enough, except for soils containing large amounts of coarse gypsum. To test for salts, check with silver nitrate (AgNO3) for Cl^- and barium chloride for $SO4^{-2}$
3. Remove soil adhering to the filter candle by applying gentle back pressure and using a rubber-tipped finger to loosen any remaining material.

Note: If iron oxides are to be removed do not complete step 4 at this time.

4. Place the sample in an oven at 105*o*C overnight, cool in a desiccator, and weigh to the nearest milligram. Use the weight of the oven-dried treated sample as the base weight for calculating the percentages of the various particle size fractions.

Removal of Iron Oxides

1. Add 150 mL of citrate–bicarbonate buffer to the samples in the fleakers. Stir and add 3 g of sodium hydrosulfite (Na2S2O4) gradually, as some samples may froth.
2. Place fleakers in a water bath at 80*o*C and stir intermittently for 20 min.
3. Remove fleakers from the bath, place in the holding rack, and filter the suspension through the filter candle system. If the sample remains a brownish color, repeat steps 1 to 3 inclusively. If the samples are completely gray (gleyed) proceed to step 4.
4. Wash five times with a jet of water strong enough to stir the sample and filter the suspension through the filter candle system.
5. To determine the oven-dry weight for calculations, repeat step 4 to remove soluble salts.

A hydrometer can be used to measure the density of a soil suspension after various times of settling and, hence, the particle size distribution. **Such measurements can be made on suspensions prepared by any of the pretreatments outlined above.** In reality, however, the hydrometer is commonly used to estimate particle size distribution without any pretreatment, except dispersion with Calgon (Gregorich & Carter, 2017). The hydrometer method outlined here is a simplified version of Day (1965).

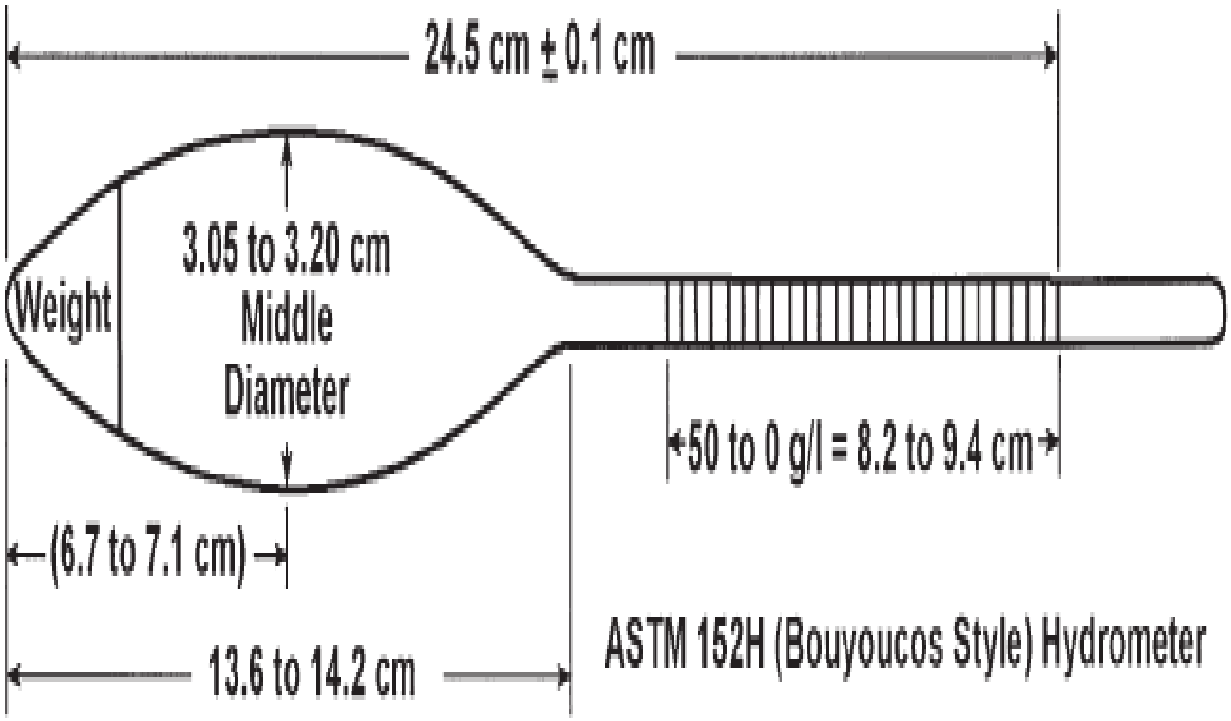


Fig.5.1. Schematic diagram of ASTM 152 H-type hydrometer

Fig.5.2. Hydrometer, ASTM 152H Scale

Materials and Reagents

1. Standard hydrometer, ASTM No. 1. 152H, with Bouyoucos scale in g L1
2. Electric stirrer
3. Plunger
4. End-over-end shaker
5. Cylinders with 1000 mL mark 36 + 2 cm from the bottom of the inside
6. Amyl alcohol
7. Calgon solution (50 g L1). Contains sodium hexametaphosphate, a dispersing agent
8. Constant-temperature room

Fig.5.3. Particle size analysis set

CALIBRATION OF HYDROMETER

1. Add 100 mL of Calgon solution to the cylinder and make the volume to 1000 mL with distilled water. Mix thoroughly with plunger and let stand until the temperature is constant (between 20^{o}C and 25^{o}C).
2. Lower the hydrometer into the solution carefully, and determine the scale reading RL (the hydrometer-scale reading of the blank) at the upper edge of the meniscus surrounding the stem.

Hydrometer Procedure

1. Weigh 40 g of soil (100 g if loamy sand or sandy soil) into a 600 mL beaker, add 100 mL of Calgon solution, and 300 mL of distilled water, and allow the sample to soak overnight.
2. Weigh another sample of the same soil (10g) for determination of oven-dried weight. Dry overnight at 105^{o}C, cool, and weigh.
3. Transfer the Calgon -treated sample to a dispersing cup and mix for 5 min with an electric mixer (milkshake machine), or transfer the suspension to shaker bottles and shake overnight on an end-over-end shaker.
4. Transfer the suspension to a cylinder and add distilled water to bring the volume to 1000 mL.
5. Allow time for the suspensions to equilibrate to room temperature (between 20oC and 25^{o}C).

6. Insert the plunger and move it up and down to mix contents thoroughly. Dislodge sediment with strong upward strokes of the plunger near the bottom and by spinning the plunger while the disk is just above the sediment. Finish stirring with two or three slow, smooth strokes. Record the time of completion of stirring. Add a drop of amyl alcohol if the surface of the suspension is covered with foam.
7. Lower the hydrometer carefully into the suspension and take readings after 40 s (R40 s).
8. Remove the hydrometer carefully after the 40s reading, rinse it, and wipe it dry.
9. Reinsert the hydrometer carefully and take another reading after 7 h (R7 h).

CALCULATIONS (Gregorich & Carter, 2017)

$$\text{Sand}\% = 100 - (R_{40\,\text{s}} - R_{\text{L}}) \times \frac{100}{\text{oven-dried soil (weight in grams)}}$$

$$\text{Clay}\% = (R_{7\,\text{h}} - R_{\text{L}}) \times \frac{100}{\text{oven-dried soil (weight in grams)}}$$

$$\text{Silt}\% = 100 - (\text{sand}\% + \text{clay}\%)$$

The simplified hydrometer method described in the chapter is not recommended for calcareous or saline soils or soils with greater than 2% organic C. For detailed hydrometer methods, please refer to Day (1965).

6. PERFORM ATTERBERG LIMITS TEST

6.1. Identify main testing equipment with its accessories

6.2. Preparation of sample

6.3. Perform testing procedures

6.4. Record and analyze data

6.5. Prepare report

Plasticity is the capability of a soil to undergo unrecoverable deformation at constant volume without cracking or crumbling. As gravimetric water contents, the two *Atterberg limits* (*plastic limit*, *w*P, and *liquid limit*, *w*L) define the range of soil wetness over which a soil exhibits plastic behavior. Together with the shrinkage limit, these test indices represent the three major points of transition in soil consistency amongst the solid, semisolid, plastic, and liquid states.

Soil consistence **and** ***consistency*** are closely related terms used by pedologists and soil engineers, respectively, to describe the degree of resistance to deformation or rupture exhibited by a structured soil when subjected to externally applied mechanical stresses (McBride, R. A., 2002). The Atterberg limits are used primarily in classifying cohesive soil materials for engineering purposes (American Society for Testing and Materials [ASTM], 2000a) and are strongly correlated to other fundamental soil properties (DeJong et al., 1990). They are also used widely in the estimation of other test indices useful for soil-engineering interpretations, such as shear strength and bearing capacity, compressibility, swelling potential, and specific surface (reviewed in McBride, 1989).

The following figure shows the ASTM plasticity chart that has been in use since 1983 to classify fine-grained soils and the fine-grained fraction of coarse-grained soils (Howard, 1984).

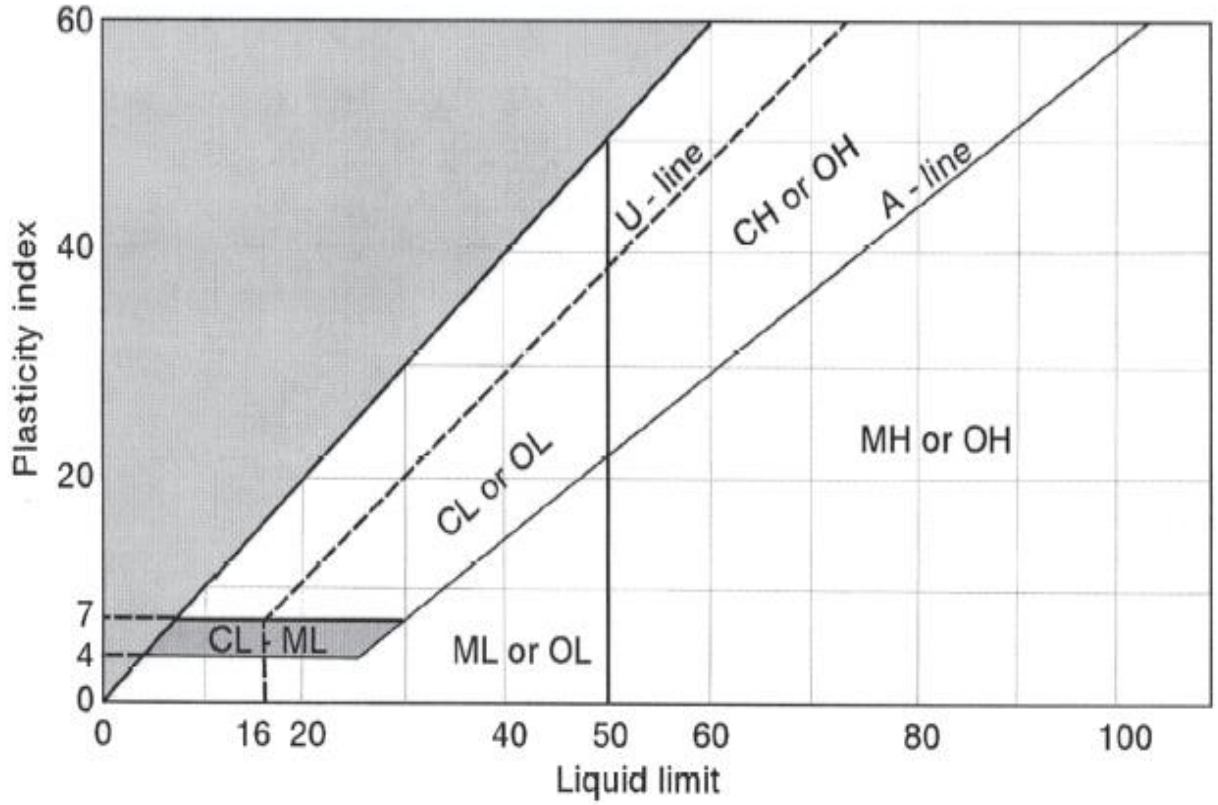


Fig. 6.1. Plasticity chart (After ASTM, 2000a)

For ***inorganic soils*** (fines), the A-line represents the division between clays (plot on or above the A-line) and silts (plot below the A-line). ***Organic clays and silts*** can plot above or below the A-line. Valid test data should not plot above or to the left (i.e., *w*L < 16) of the U-line (upper limit).

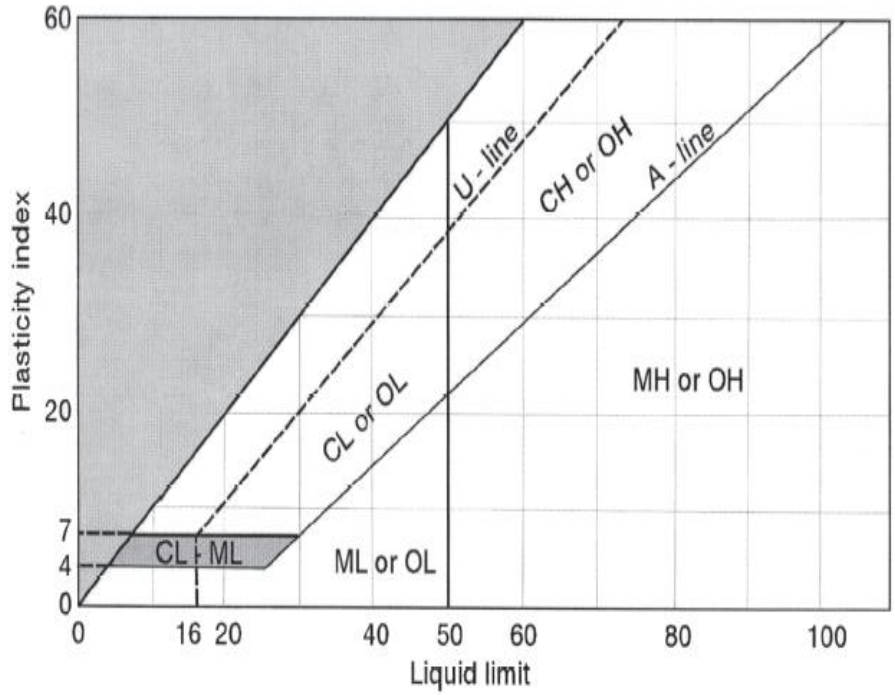


Fig.6.1. Plasticity chart (After ASTM, 2000a)

Considerable effort has been directed at researching alternative and procedurally unified test methods, including desorption by pressure-plate extraction (reviewed in McBride, 1989), consolidation of soil–water suspensions (McBride & Bober, 1989; McBride & Baumgartner, 1992), measurement of paste viscosity, and drop-cone penetration. Some methods have shown very promising results, but only *w*L determination by cone penetration has been standardized to date and is the preferred method of the British Standards Institute (BSI) (BS 1377:Part 2:1990, BSI, 2000).

Liquid Limit

The ***liquid limit*** **(or *upper plastic limit*)** of a cohesive soil is defined as the minimum gravimetric water content (percentage) at which a small sample of soil will barely flow under a standard treatment (Soil Science Society of America [SSSA], 1997).

This water content represents an arbitrary limit between the liquid and plastic states of consistence when the soil is in a remolded condition.

In accordance with the standard ASTM (Casagrande) test procedure, it is the water content at which a pat of soil, cut by a standard-sized groove, will flow together for a distance of 13 mm under the impact of 25 blows in a standard ASTM liquid-limit device.

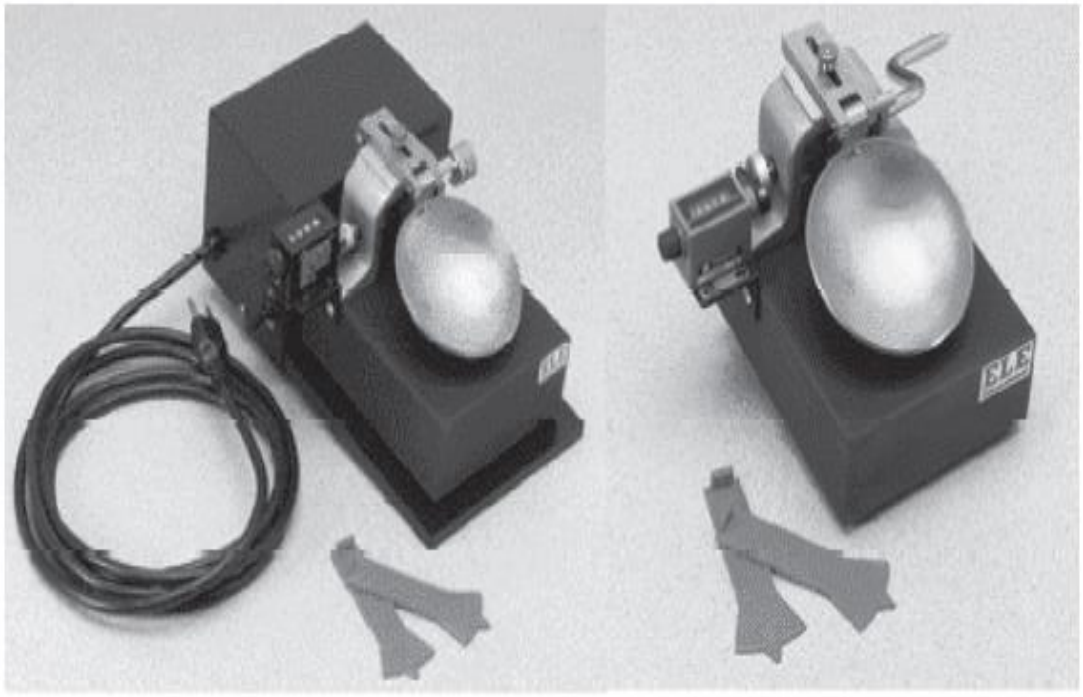


Fig.6.2. Liquid-limit device

Measured with a drop-cone penetrometer, it is the water content corresponding to a penetration depth of 20 mm (BSI, 2000). The **undrained cohesion of soils in this consistency state** is approximately 1.7 kPa (Wroth & Wood, 1978).

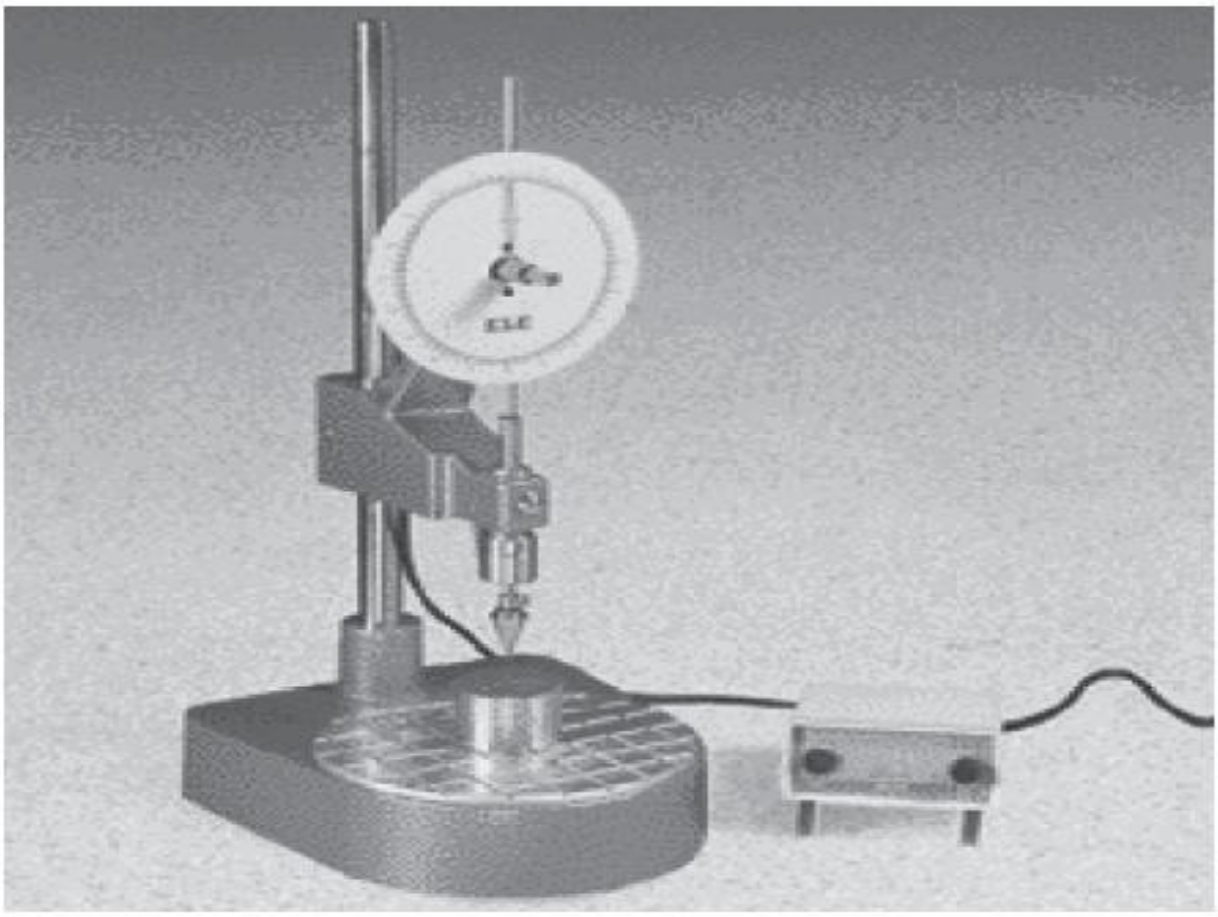


Fig.6.3. Standard drop-cone penetrometer

Casagrande Method

See ASTM D4318-98 (ASTM, 2000b), AASHTO T89-90 (AASHTO, 2000a), and BS 1377:Part 2:1990 (BSI, 2000).

Equipment and Supplies

1. ASTM liquid-limit device with grooving tool (**Fig. 6.2**)
2. Metal spatula (70–80 mm long, 20 mm wide)
3. Evaporating dish (100–120 mm in diameter)
4. Containers for water content determination

5. Balance (sensitive to 0.01 g)
6. Drying oven (105°C)
7. Air-dry soil sample of about 100 g and passing a No. 40 (425 μm) sieve

Procedure

1. Place the soil sample in the evaporating dish and thoroughly mix with 15 to 20 mL of distilled water by alternately and repeatedly stirring, kneading, and chopping with a spatula. Make further additions of water in increments of 1 to 3 mL. Thoroughly mix each increment of water with the soil, as previously described, before adding another increment of water.
2. When sufficient water has been thoroughly mixed with the soil to produce a consistency that will require 30 to 35 drops of the cup to cause closure, place a portion of the mixture in the cup above the spot where the cup rests on the base and squeeze it down and spread it into position with as few strokes of the spatula as possible. Care should be taken to prevent the entrapment of air bubbles within the soil mass. With the spatula, level the soil and at the same time trim it to a depth of 10 mm at the point of maximum thickness. Return the excess soil to the evaporating dish. Divide the soil in the cup by firm strokes of the grooving tool along the diameter through the centerline of the cam follower so that a clean, sharp groove of the proper dimensions is formed. To avoid tearing of the sides of the groove or slipping of the soil pat on the cup, up to six strokes, from front to back or from back to front counting as one stroke, are permitted. Each stroke should penetrate a little deeper until the last stroke from back to front scrapes the bottom of the cup clean. Make the groove with as few strokes as possible.
3. Lift and drop the cup by turning the crank at the rate of 2 rps, until the two halves of the soil pat come in contact at the bottom of the groove along a distance of about 13 mm. Record the number of drops (N) required to close the groove along a distance of 13 mm.
4. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil pat at right angles to the groove and including that portion of the groove in which the soil flowed together and place it in a suitable tared container. Weigh and record the mass. Oven-dry the soil in the container to a constant mass at 105°C and reweigh as soon as it has cooled, but before hygroscopic water can be absorbed. Record this mass. Record the loss in mass due to drying as the mass of water.

5. Transfer the soil remaining in the cup to the evaporating dish. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.
6. 6. Repeat Steps 2 to 5 for at least two additional trials, with the soil collected in the evaporating dish, to which sufficient water has been added to bring the soil to a more fluid condition. **The object of this procedure is to obtain samples of such consistency that the number of drops required to close the groove will be above and below 25. The number of drops should be less than 35 and should exceed 15.** The test should always proceed from the drier to the wetter condition of the soil.

Calculations

1. Calculate the gravimetric water content of the soil (θm), expressed as a percentage of water in the sample on a dry mass basis (% kg kg−1), as follows:

$$\theta_m = \left[\frac{(\text{mass of wet soil}) - (\text{mass of oven-dry soil})}{\text{mass of oven-dry soil}}\right] 100$$

2. Plot a flow curve representing the relationship between gravimetric water content and corresponding numbers of drops of the cup on a semilogarithmic graph with θm as abscissae on the linear scale, and the number of drops (*N*) as ordinates on the logarithmic scale. The flow curve is a straight line drawn as nearly as possible through the three or more plotted points.

3. Take the water content corresponding to the intersection of the flow curve with the $N = 25$ ordinate as the liquid limit (or upper plastic limit) of the soil. Report the *w*L test index to the nearest whole number.

Before testing, inspect the ASTM liquid-limit device to determine that the device is in good working order, that the pin connecting the cup is not worn sufficiently to permit side play, that the

screws connecting the cup to the hanger arm are tight, and that a groove has not been worn in the cup through prolonged usage. Also ensure that the dimensions of the grooving tool are to specification (ASTM, 2000b).

By means of the gauge on the handle of the grooving tool and the adjustment plate, adjust the height to which the cup is lifted so that the point on the cup that comes in contact with the base is exactly 10 mm above the base. Secure the adjustment plate by tightening the screws. With the gauge still in place, check the adjustment by revolving the crank rapidly several times. If the adjustment is correct, a slight ringing sound will be heard when the cam strikes the cam follower. If the cup is raised off the gauge or no sound is heard, make further adjustments. A ***motorized version of the liquid-limit device with a blow*** (revolution) counter is commercially available (Fig.6.2) and should be used if possible to minimize operator variability.

One-Point Casagrande Method

See ASTM D4318-98 (ASTM, 2000b), AASHTO T89-90 (AASHTO, 2000a), BS 1377: Part 2:1990 (BSI, 2000).

Procedure

1. The requirements for the apparatus, the soil sample preparation, and the mechanical device adjustments are identical to those mentioned for the Casagrande Method.
2. Proceed in accordance with procedural Steps 1 through 5 (see Casagrande Method) , except that a water-content sample is taken only for the accepted trial. The accepted trial requires between 20 and 30 drops of the cup to close the groove, and at least two consistent consecutive closures are to be observed before taking the water-content sample to calculate the liquid limit. The test should always proceed from the drier to the wetter condition of the soil.

Calculations

1. Calculate the percentage gravimetric water content (θm) of the soil for the accepted trial (same as for Casagrande Method).

$$\theta_m = \left[\frac{(\text{mass of wet soil}) - (\text{mass of oven-dry soil})}{\text{mass of oven-dry soil}} \right] 100$$

2. Determine the liquid limit using the following formula:

$$w_L = \theta_m (N/25)^{0.12}$$

where *N* is the number of drops of the cup required to close the groove at the test water content.

3. Report the *w*L test index to the nearest whole number.

Drop-Cone Penetrometer Method

See BS 1377:Part 2:1990 (BSI, 2000).

Equipment and Supplies

1. A standard drop-cone penetrometer (Fig.6.3.)
2. A cone of stainless steel or duralumin approximately 35 mm long, with a smooth, polished surface and an angle of 30 ± 1°. The mass of the cone together with its sliding shaft is 80.00 ± 0.05 g.
3. A noncorrodible air-tight container
4. A metal cup approximately 55 mm in diameter and 40 mm deep with the rim parallel to the flat base
5. Metal spatula (70–80 mm long, 20 mm wide)
6. Evaporating dish (100–120 mm diam.)

7. Containers for water content determination.
8. Balance (sensitive to 0.01 g)
9. Drying oven (105°C)
10. Air-dry soil sample of about 200 g and passing a No. 40 (425 μm) sieve

Procedure

1. A sample weighing at least 200 g is placed on the evaporating dish and mixed thoroughly with distilled water using the spatula until the mass becomes a thick homogeneous paste. This paste is then allowed to stand in the air-tight container for about 24 h to allow the water to permeate throughout the soil mass.
2. The sample is then removed from the container and remixed for at least 10 min. If necessary, further water is added so that the first cone-penetration reading is approximately 15 mm.
3. The remixed soil is pushed into the cup with a spatula, taking care not to trap air. The excess soil is removed to give a smooth surface. The cone is lowered so that it just touches the surface of the soil. When the cone is in the correct position, a slight movement of the cup will just mark the surface of the soil and the reading of the dial gauge is noted to the nearest 0.1 mm. The cone is then released for a period of 5 ± 1 s. If the apparatus is not fitted with an automatic release and locking device, care should be taken not to jerk the apparatus during these operations. After the cone has been locked in position, the dial gauge is lowered to the new position of the cone shaft, and the reading is noted to the nearest 0.1 mm. The difference between the readings at the beginning and end of the test is recorded as the depth of cone penetration.
4. The cone is lifted out and cleaned carefully. A little more wet soil is added to the cup, and the process is repeated. If the difference between the first and second penetration readings is less than 0.5 mm, the average of the two penetrations is recorded. If the second penetration is more than 0.5 mm and less than 1 mm different from the first, a third test should be carried out. If the overall range is then not more than 1 mm, a water content sample (about 10 g) is taken from the area penetrated by the cone, and the water content is determined. The average of the three penetrations is recorded. If the overall range is more than 1 mm, the soil should be removed from the cup and remixed, and the test is repeated until consistent results are obtained.

5. The operations described in Steps 3 and 4 are to be repeated at least four times using the same sample to which further increments of distilled water have been added. The amount of water added should be chosen so that a range of penetration values of approximately 15 to 25 mm is covered.

Calculations

The relationship between the gravimetric water content (θm) and the depth of cone penetration is plotted with the percentage water contents as abscissae and the cone penetrations as ordinates, both on linear scales. The best straight line fitting the plotted points is drawn through them. The water content corresponding to a cone penetration of 20 mm is taken as the liquid limit of the soil and is expressed to the nearest whole number. The method of obtaining the *w*L should be stated (i.e., using the cone penetrometer).

A version of the drop-cone penetrometer equipped with a digital automatic controller (and direct readout) is commercially available and should be used if possible to minimize operator variability. The 20-mm penetration-depth standard should be used with caution, as many studies outside of Britain have documented both under-and overestimation of the Casagrande *w*L using the cone-penetration method (compare McBride & Baumgartner, 1992; Leroueil & Le Bihan, 1996).

Plastic Limit

The ***plastic limit*** **(or *lower plastic limit*)** of a cohesive soil is defined as the minimum gravimetric water content (percentage) at which a small sample of soil material can be deformed without rupture (SSSA, 1997). This water content represents an arbitrary limit between the plastic and semisolid states of consistence when the soil is in a remolded condition. In accordance with the standard ASTM (Casagrande) test procedure, it is the water content at which a soil will just begin to crumble when rolled into a thread approximately 3.2 mm in diameter. The undrained cohesion of soils in this consistency state is approximately 170 kPa (Wroth & Wood, 1978).

Casagrande Method

See ASTM D4318-98 (ASTM, 2000b); AASHTO T90-87 (AASHTO, 2000b); BS 1377: Part 2:1990 (BSI, 2000).

Equipment and Supplies

1. Evaporating dish (100–120 mm diam.)
2. Metal spatula (70–80 mm long, 20 mm wide)
3. Surface for rolling (e.g., a ground-glass plate)
4. Containers for water content determination
5. Balance (sensitive to 0.01 g)
6. Drying oven (105°C)
7. Air-dry soil sample of about 15 g and passing a No. 40 (425 μm) sieve

Procedure

1. If the plastic limit only is required, take about 15 g of air-dried soil, place into an evaporating dish, and thoroughly mix with distilled water until the mass becomes plastic enough to be easily shaped into a ball. Take a portion of this ball weighing about 8 g for the test sample.
2. If both the liquid and plastic limits are required, take a test sample weighing about 8 g from the thoroughly wet and mixed portion of the soil prepared for the liquid limit test. Take the sample at any stage of the mixing process at which the mass becomes plastic enough to be easily shaped into a ball without sticking to the fingers excessively when squeezed. If the sample is taken before completion of the liquid limit test, set it aside and allow it to season in air until the *w*L test has been completed. If the sample is taken after completion of the *w*L test and is still too dry to permit **rolling to a 3.2-mm thread**, add more water.
3. Squeeze and form the 8-g test sample taken in accordance with Steps 1 or 2 into an ellipsoidal-shaped mass. With just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length, roll this mass between the fingers and the ground-glass plate lying on a smooth horizontal surface. The rate of rolling should be between 80 and 90 strokes min−1,

counting a stroke as one complete motion of the hand forward and back to the starting position again.

4. When the **diameter of the thread becomes about 3.2 mm, break the thread into six or eight pieces. Squeeze the pieces together between the thumbs and fingers of both hands into a uniform mass roughly ellipsoidal in shape and reroll**. Continue this alternate rolling to **a thread 3.2 mm in diameter**, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling, and the soil can no longer be rolled into a thread. The crumbling may occur when the **thread has a diameter greater than 3.2 mm**. This is considered a satisfactory end point, provided the soil has been previously rolled into a **thread 3.2 mm in diameter**.

The crumbling will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles; others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. *Heavy clay soils* require much pressure to deform the thread, particularly as they approach the plastic limit, and finally, the thread breaks into a series of barrel-shaped segments each about **6.4 to 9.5** mm in length.

At no time should the operator attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, and continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for marginally plastic soils by making the initial diameter of the ellipsoidal-shaped mass nearer to the required 3.2-mm final diameter.

5. Gather the portions of the crumbled soil together and place into a suitable tared container. Weigh the container and soil and record the mass. Oven-dry the soil in the container to constant mass at 105°C and weigh. Record this mass. Record the loss in mass as the mass of water.

Calculations

1. Calculate the percentage gravimetric water content (θm) of the remolded soil as per the following equation:

$$\theta_m = \left[\frac{(\text{mass of wet soil}) - (\text{mass of oven-dry soil})}{\text{mass of oven-dry soil}} \right] 100$$

Report this value as the *w*P test index to the nearest whole number.

2. Calculate the *plasticity index* (or *plasticity number*) (PI) of a soil as the numerical difference between its liquid and plastic limits, as follows:

$$\mathrm{PI} = w_\mathrm{L} - w_\mathrm{P}$$

3. Report the difference calculated in step 2 equation (previous one) as the plasticity index, except under the following conditions:

When the *w*L or *w*P test indices cannot be determined, report the plasticity index as **NP (nonplastic).** When the soil is **extremely sandy**, the *w*P test is to be performed before the *w*L test. If the *w*P cannot be determined, report the plasticity index as **NP**. When ***w*P ≥ *w*L**, report the plasticity index as **NP**.

Test reproducibility and rapidity can be improved by using a soil rolling device of the sort proposed by Bobrowski and Griekspoor (1992) without significantly deviating from the standard manual methods. Once the two Atterberg limits are known, the field water content (θm) of a soil can be compared with its plastic consistency range by calculating the ***liquidity index* (LI)**:

$$\mathrm{LI} = (\theta_\mathrm{m} - w_\mathrm{P})/\mathrm{PI}$$

The degree of plasticity of the clay size fraction of a soil can also be expressed by a ratio referred to as the ***activity* or *activity number* (*A*)**:

$$A = \mathrm{PI}/\%\ \mathrm{clay}$$

7. PERFORM SWELLING TEST

7.1. Identify main testing equipment with its accessories with its accessories

7.2. Preparation of sample

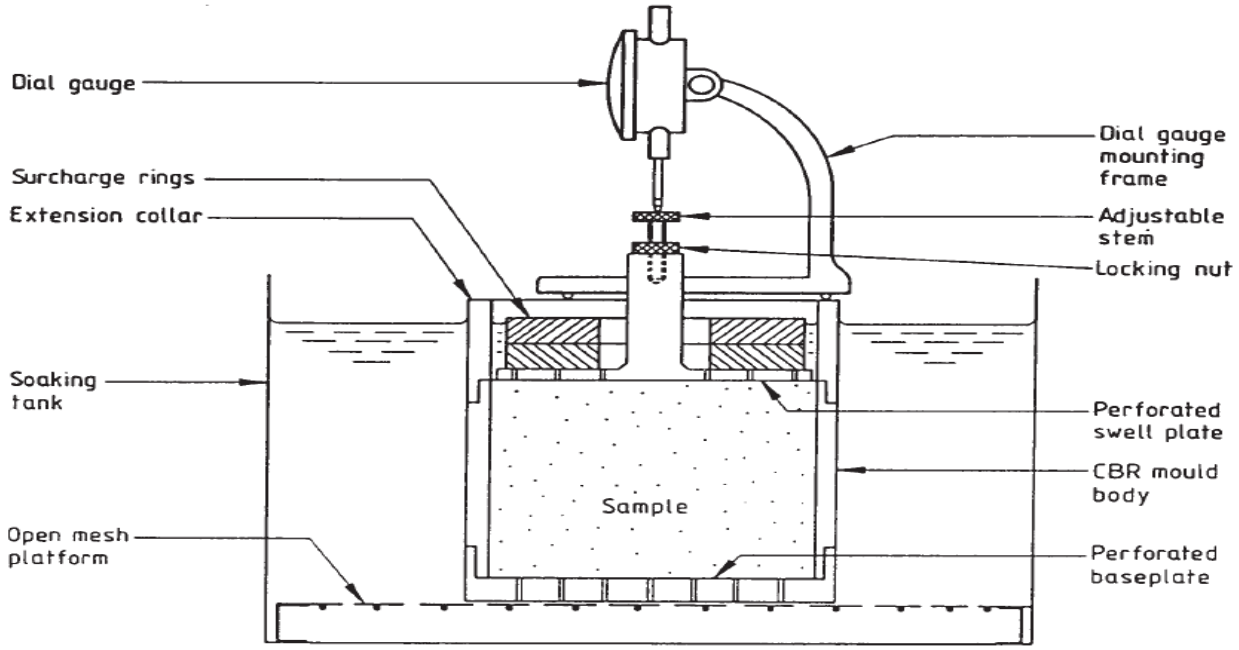
7.3. Perform testing procedures

7.4. Record and analyze data

7.5. Prepare report

The soil swelling is tested as a part of the CBR (Calfornia Bearing Ratio) test – three points method. **There is an apparatus for measuring the swelling of a soil sample during the soaking procedure for the CBR test.**

Apparatus for measuring the swelling of a sample during soaking for the CBR test



The CBR value is a requirement in design for pavement materials of natural gravel. The CBR value is the resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50 mm diameter, expressed as a percentage of the known resistance of the plunger to 2.5 mm in penetration in crushed aggregate, taken as 13.2 kN).

Equipments

- Test sieves, sizes 20 mm and 5 mm.
- Three cylindrical metal moulds, i.e. CBR moulds, having a nominal internal diameter of 152 mm and a height of 127 mm. The moulds shall be fitted with a detachable baseplate and a removable extension. The internal face shall be smooth, clean and dry before use.
- Two metal rammers of weights 2,5 kg and 4,5 kg.
- A steel rod.

- A steel straightedge
- Spatula
- A balance, capable of weighing up to 25 kg readable to 5 kg.
- Apparatus for moisture content determination.
- Filter paper 150 mm in diameter.
- Perforated baseplates, fitted to the CBR moulds in place of the normal baseplate.
- Perforated swell plates, with an adjustable stem to provide a seating for a dial gauge.
- Tripod, mounting to support the dial gauge.
- A dial gauge, having a travel of 25 mm and reading to 0,01 mm to be fitted to the tripod for measuring swell.
- A soaking tank, large enough to allow the CBR mould with base plate to be submerged, preferably supported on an open mesh platform.
- Annular surcharge discs for soaking, each having a mass known to + 50g. Halfcircular segments may be used. Combined weight 4,5 kg.
- Petroleum jelly.
- A cylindrical metal plunger/piston with diameter 49,65 mm.
- A CBR compression machine. The machine shall be capable of applying at least 45 kN at a rate of penetration of the plunger of 1 mm/min to within ± 0,2 mm/min.
- A loading ring.
- A dial gauge with 2 mm travel, reading to 0,01 mm for measuring the penetration of the plunger into the specimen.
- A stopwatch
- Annular surcharge discs for penetration test. Combined weight 5.5 kg.

Sample Preparation

1) The CBR test shall be carried out on material passing the 20 mm test sieve. If the soil contains particles larger than this, the fraction retained on the 20 mm test sieve shall be removed and weighed before preparing the test sample. If this fraction is greater than 25%, the test is generally considered unreliable in emulating site conditions, and such test results must consequently be treated with care.

2) Take a portion of material large enough to provide about 25 kg of material passing a 20 mm sieve.
3) Bring the sample to the optimum moisture content (OMC ± 0,3%) according to the BS Heavy compaction test. The soil shall be thoroughly mixed and shall normally be sealed and stored for at least 24 h before compacting into the moulds.

Test Procedure – Soaking

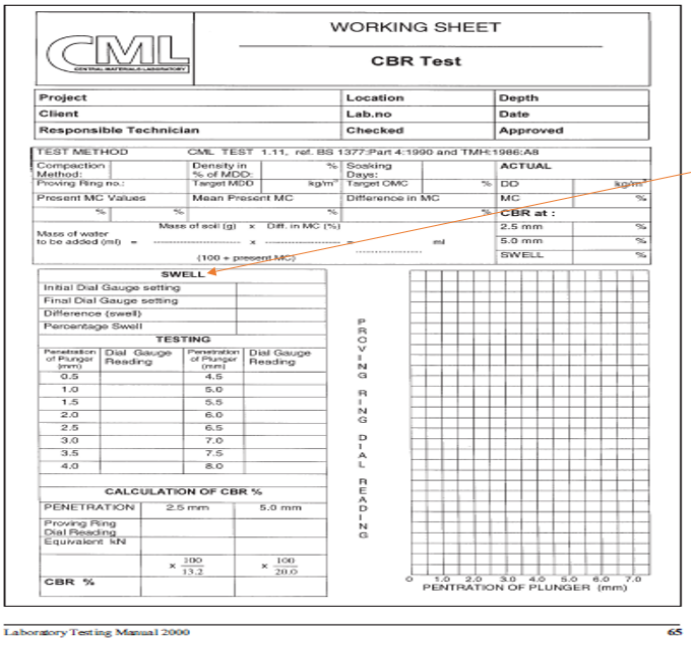
1) Place a filter paper on top of each sample and fit perforated baseplates on top of moulds and invert the moulds.
2) Remove the baseplates from the moulds. Fit the collar to the end of the mould, packing the screw threads with petroleum jelly to obtain a watertight joint.
3) Place the mould assembly in the empty soaking tank. The surface of the moulded material which was against the base plate should now be facing upwards. Place a filter paper on top of the sample followed by the perforated swell plate. Fit annular surcharge discs weighing 4.5 kg around the stem on the perforated swell plate.
4) Mount the dial gauge support on top of the extension collar, secure the dial gauge in place and adjust the stem on the perforated plate to give a convenient zero reading.
5) Fill the soaking tank with water to just below the top of the mould extension collar. Start the timer when the water has just covered the baseplate.
6) Record readings of the dial gauge each day.
7) After 4 days of soaking, take off the dial gauge and its support, remove the mould assembly from the soaking tank and allow the to drain for 15 min.
8) Carefully remove the surcharge discs, perforated swell plate and extension collar.
9) If the sample has swollen, trim it level with the end of the mould.
   - **The sample is then ready for testing (i.e. CBR Testing)**

Notes: Make certain that the baseplate is tightly screwed on, so that there is no gap between the baseplate and the sample. To ensure that the water has free access to the bottom of the material in the mould, suitable means must be fitted to the bottom of the soaking tank.

One surcharge disc of 2 kg simulates the effect of approximately 70 mm of superimposed construction on the formation being tested.

Record the time taken for water to appear at the top of the sample. If this has not occurred in three days, flood the top of the sample and leave to soak for a further day giving the normal soaking period of 4 days. The normal soaking period is 4 days. In all handling of the moulded material care should be taken not to jar the material.

Working Sheet for Recording Data



WORKING SHEET

CBR Test

Project	Location	Depth
Client	Lab.no	Date
Responsible Technician	Checked	Approved

TEST METHOD: CML TEST 1.11, ref. BS 1377:Part 4:1990 and TMH1986:A8

Compaction Method:		Density in % of MDD:	%	Soaking Days:	ACTUAL
Proving Ring no.:		Target MDD	kg/m³	Target OMC %	DD kg/m³
Present MC Values		Mean Present MC		Difference in MC	MC %
%	%		%	%	CBR at :
Mass of water to be added (ml) =	Mass of soil (g) x Diff. in MC (%) / (100 + present MC)			ml	2.5 mm %
					5.0 mm %
					SWELL %

SWELL	
Initial Dial Gauge setting	
Final Dial Gauge setting	
Difference (swell)	
Percentage Swell	

TESTING			
Penetration of Plunger (mm)	Dial Gauge Reading	Penetration of Plunger (mm)	Dial Gauge Reading
0.5		4.5	
1.0		5.0	
1.5		5.5	
2.0		6.0	
2.5		6.5	
3.0		7.0	
3.5		7.5	
4.0		8.0	

CALCULATION OF CBR %

PENETRATION	2.5 mm	5.0 mm
Proving Ring Dial Reading Equivalent kN		
	x 100/13.2	x 100/20.0
CBR %		

PROVING RING DIAL READING

0 1.0 2.0 3.0 4.0 5.0 6.0 7.0

PENTRATION OF PLUNGER (mm)

Laboratory Testing Manual 2000 65

CML

CENTRAL MATERIALS LABORATORY

WORKING SHEET

CBR Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD		CML TEST 1.11, ref. BS 1377:Part 4:1990 and TMH1:1986:A8					
Compaction Method:		Density in % of MDD:	%	Soaking Days:		**ACTUAL**	
Proving Ring no.:		Target MDD	kg/m³	Target OMC	%	DD	kg/m³
Present MC Values		Mean Present MC		Difference in MC		MC	%
%	%	%		%		**CBR at :**	
Mass of water to be added (ml) =	Mass of soil (g)	x	Diff. in MC (%)	=	ml	2.5 mm	%
	(100 + present MC)					5.0 mm	%
						SWELL	%

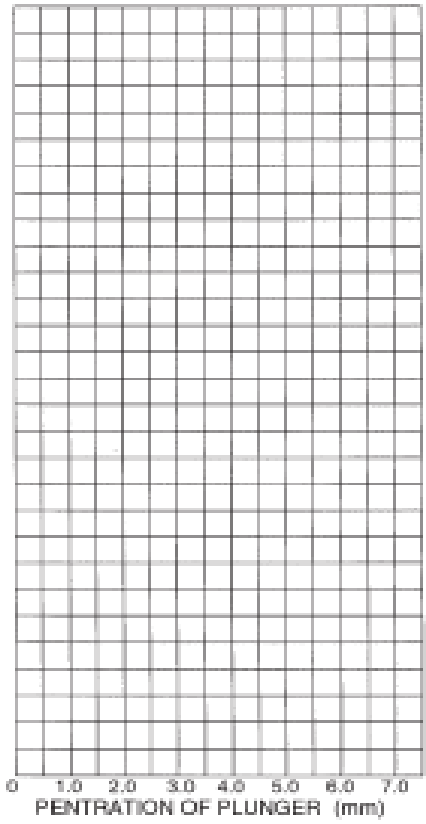
SWELL	
Initial Dial Gauge setting	
Final Dial Gauge setting	
Difference (swell)	
Percentage Swell	

TESTING

Penetration of Plunger (mm)	Dial Gauge Reading	Penetration of Plunger (mm)	Dial Gauge Reading
0.5		4.5	
1.0		5.0	
1.5		5.5	
2.0		6.0	
2.5		6.5	
3.0		7.0	
3.5		7.5	
4.0		8.0	

CALCULATION OF CBR %

PENETRATION	2.5 mm	5.0 mm
Proving Ring Dial Reading		
Equivalent kN		
	x 100/13.2	x 100/20.0
CBR %		



Swell Calculation

The Swell (in %) is calculated from the equation:

$$S = \frac{(k - L)}{127} \text{x } 100$$

Where

S is the swell expressed as a percentage of the height of the moulded material before soaking, i.e 127 mm.

K is the dial gauge reading after 4 days' soaking

L is the dial gauge reading before soaking

8. PERFORM STANDARD PROCTOR TEST

8.1. Identify main testing equipment

8.2. Preparation of sample

8.3. Perform testing procedures

8.4. Record and analyze data

8.5. Prepare report

Introduction

For construction of highways, airports, and other structures, it is often necessary to compact soil to improve its strength. Proctor (1933) developed a laboratory compaction test procedure to determine the maximum dry unit weight of compaction of soils which can be used for specification of field compaction. This test is referred to as the' *standard Proctor compaction test* and is based on the compaction of the soil fraction passing No, 4 U.S. sieve (Braja M. D., 2002).

The **Proctor compaction test** is a laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density. The test is named in honor of Ralph Roscoe Proctor, who in 1933 showed that the dry density of a soil for a given compactive effort depends on the amount of water the soil contains during soil compaction. His original test is most commonly referred to as the standard Proctor compaction test; his test was later updated to create the modified Proctor compaction test. These laboratory tests generally consist of compacting soil at known moisture content into a cylindrical mold with a collar of standard dimensions of height and diameter using a compactive effort of controlled magnitude.

The soil is usually compacted into the mold to a certain amount of equal layers, each receiving a number of blows from a standard weighted hammer at a specified height. This process is then repeated for various moisture contents and the dry densities are determined for each. The graphical relationship of the dry density to moisture content is then plotted to establish the compaction curve. The maximum dry density is finally obtained from the peak point of the compaction curve and its corresponding moisture content, also known as the optimal moisture content.

The testing described is generally consistent with the American Society for Testing and Materials (ASTM) standards, and are similar to the American Association of State Highway and Transportation Officials (AASHTO) standards. Currently, the procedures and equipment details for the standard Proctor compaction test is designated by ASTM D698 and AASHTO T99. Also, the modified Proctor compaction test is designated by ASTM D1557 and AASHTO T180-D

Equipments (Braja M. D., 2002)

1. Compaction mold
2. No.4 U.S. sieve
3. Standard Proctor hammer (5.5lb)
4. Balance sensitive up to 0.01 lb
5. Balance sensitive up to 0.1 g
6. Large flat pan
7. Jack
8. Steel straight edge
9. Moisture cans
10. Drying oven
11. Plastic squeeze bottle with water

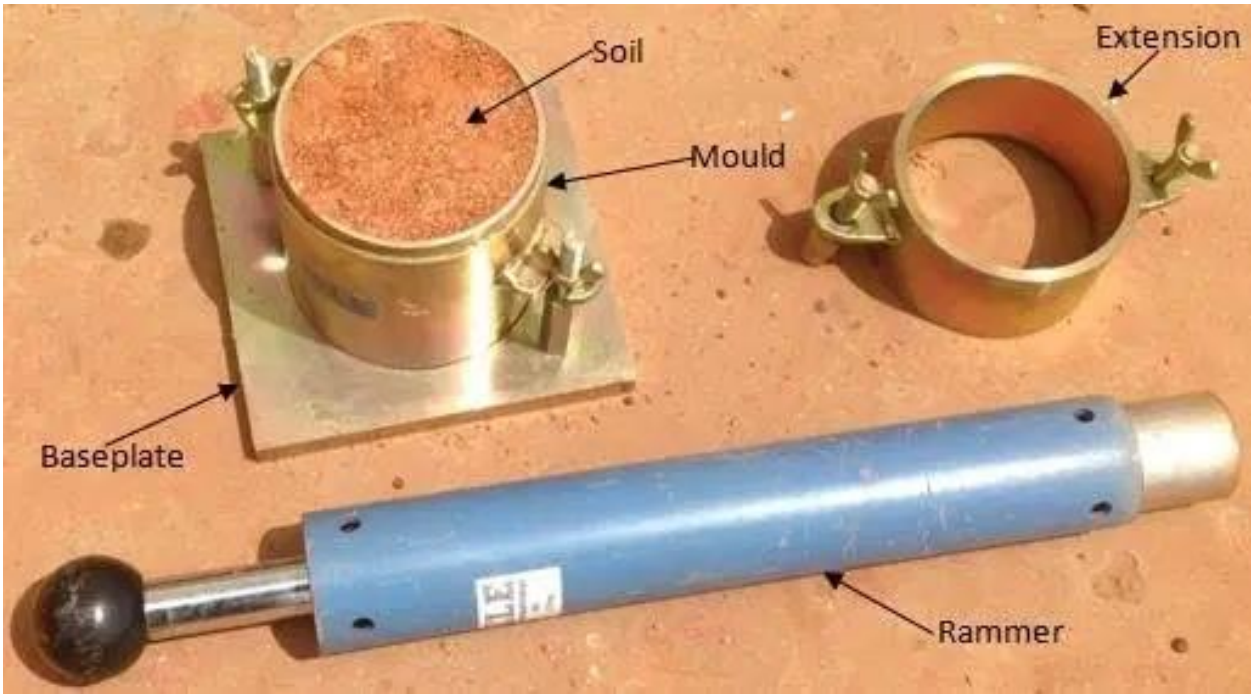


Fig. 8.1. Some equipments for a standard proctor test

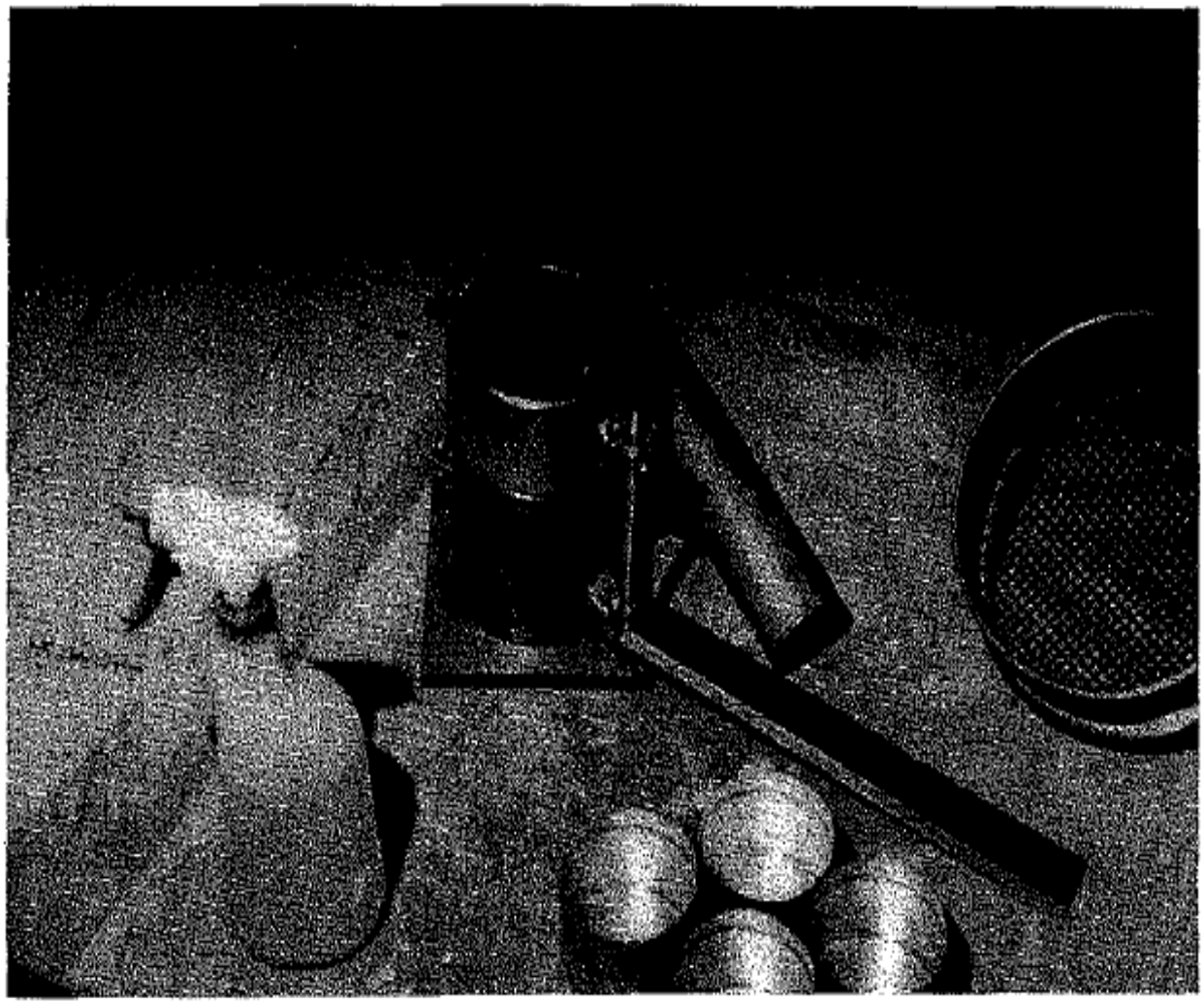


Fig.8.2. Equipment for Proctor compaction test (Braja M. D., 2002)

Figure 8.2. shows the equipment required for the compaction test with the exception of the jack, the balances, and the oven.

Proctor Compaction Mold and Hammer

A schematic diagram of the Proctor compaction mold, which is 4 in. (101.6mrn)in diameter and 4.584 in. (116.4) in height, is shown in Fig. *8-3a.*There is a base plate and an extension that can be attached to the top and bottom of the mold, respectively. The inside of the mold is 1/30 ft3 (943,9 cm3).

Procedure

1. Obtain about 10 lb (4.5 kg) of air-dry soil on which the compaction test is to be conducted. Break all the soil lumps.
2. Sieve the soil on a No.4 U.S. sieve. Collect all of the minus-4 material in a large pan. This should be about 6lb (2.7 kg) or more.
3. Add enough water to the minus-4 material and mix it in thoroughly to bring the moisture content up to about 5%.
4. Determine the weight of the Proctor mold + base plate (not the extension), W1 (lb).
5. Now attach the extension to the top of the mold.
6. Pour the moist soil into the mold in *three* equal layers. Each layer should be compacted uniformly by the standard Proctor hammer 25 *times* before the next layer of loose soil is poured into the mold.

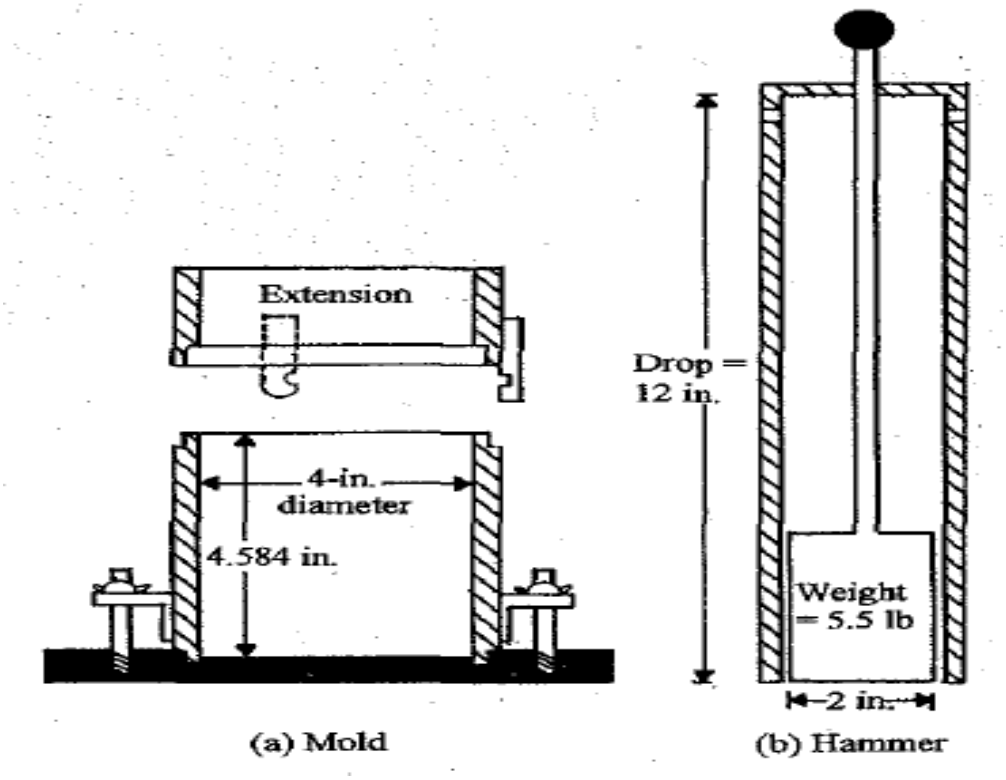


Fig. 8. 3. Standard Proctor mold and hammer (Braja M. D., 2002)

***Note**:* The layers of loose soil that are being poured into the mold should be such that, *at the end of the three-layer compaction*, the soil should extend *slightly above* the top of the rim of the compaction mold.

7. Remove the top attachment from the mold. Be careful not to break off any of the compacted soil inside the mold while removing the top attachment.
8. Using a straight edge, trim the excess soil above the mold (Fig. 8.4). Now the top of the compacted soil will be even with the top of the mold.

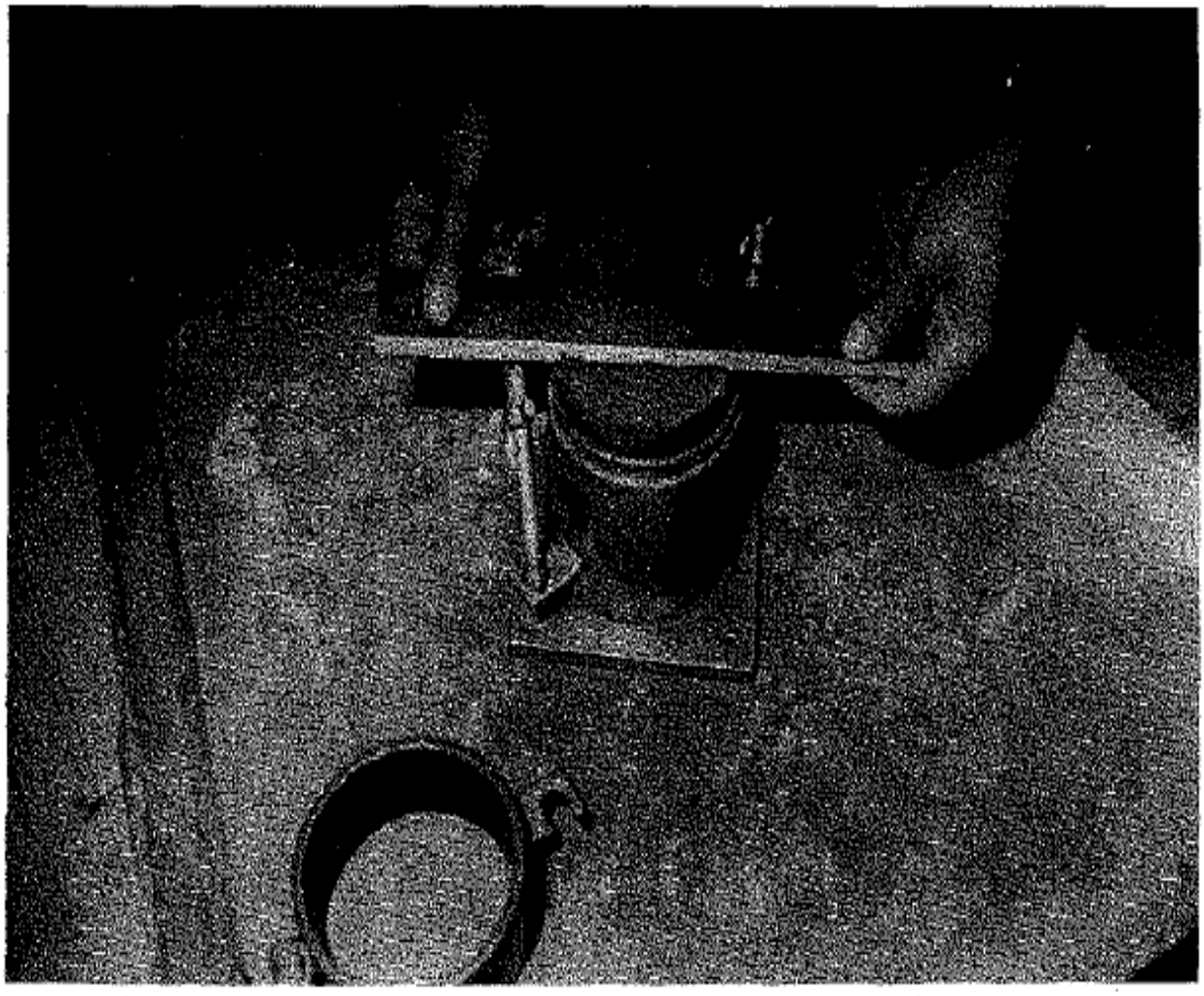


Fig.8.4. Excess soil being trimmed (Step 8) (Braja M. D., 2002)

9. Determine the weight of the mold + base plate +- compacted moist soil in the mold, *W2* (lb).

10. Remove the base plate from the mold. Using a jack, extrude the compacted soil cylinder from the mold.

11. Take a moisture can and determine its mass, *W3* (g).

12. From the moist soil extruded in Step 10, collect a moisture sample in the moisture can (Step II) and determine the mass of the can + moist soil, *W4* (g).

13. Place the moisture can with the moist soil in the oven to dry to a constant weight.

14. Break the rest of the compacted soil (to No.4 size) by hand and mix it with the leftover moist soil in the pan. Add more water and mix it to raise the moisture content by about 2% .

15. Repeat Steps 6 through 12. In this process, the weight of the mold + base plate + moist soil *(W2* will first increase with the increase in moisture content and then decrease. Continue the test until at least two successive down readings are obtained.

16. The next day, determine the mass of the moisture cans + soil samples, *W5* (g) (from Step 13).

Calculation

Description of soil *Light brown clayey silt* Sample No. *2*

Location _____

Volume of mold *1/30* ft³ Weight of hammer *5.5* lb Number of blows/layer *25* Number of layers *3*

Tested by _____ Date _____

Test	1	2	3	4	5	6
1. Weight of mold, W_1 (lb)	10.35	10.35	10.35	10.35	10.35	10.35
2. Weight of mold + moist soil, W_2 (lb)	14.19	14.41	14.53	14.63	14.51	14.47
3. Weight of moist soil, $W_2 - W_1$ (lb)	3.84	4.06	4.18	4.28	4.16	4.12
4. Moist unit weight, $\gamma = \frac{W_2 - W_1}{1/30}$ (lb / ft³)	115.2	121.8	125.4	128.4	124.8	123.8
5. Moisture can number	202	212	222	242	206	504
6. Mass of moisture can, W_3 (g)	54.0	53.3	53.3	54.0	54.8	40.8
7. Mass of can + moist soil, W_4 (g)	253.0	354.0	439.0	490.0	422.8	243.0
8. Mass of can + dry soil, W_5 (g)	237.0	326.0	401.0	441.5	374.7	211.1
9. Moisture content, $w\,(\%) = \frac{W_4 - W_5}{W_5 - W_3} \times 100$	8.7	10.3	10.9	12.5	15.0	18.8
10. Dry unit weight of compaction $\gamma_d\ (\text{lb / ft}^3) = \frac{\gamma}{1 + \frac{w\,(\%)}{100}}$	106.0	110.4	113.0	114.1	108.5	104.2

Table 8.1. Standard Proctor Compaction Test - Determination of Dry Unit Weight

Dry Unit Weight and Moisture Content at Compaction

The sample calculations for a standard Proctor compaction test are given in Table 8.1. Referring to the Table 8.1,

***Line* 1-** Weight of mold, *W1* to be determined from test (Step 4).

***Line* 2** - Weight of mold + moist compacted soil, *W2*, to be determined from test (Step 9).

***Line* 3** - Weight of moist compacted soil = *W2* – W1 (Line 2 - Line 1).

***Line* 4** - Moist unit weight

$$\gamma = \frac{\text{weight of compacted moist soil}}{\text{volume of mold}} = \frac{W_2 - W_1\,(\text{lb})}{1/30\ \text{ft}^3}$$

$$= (30\ \text{lb}/\text{ft}^3) \times (\text{Line 3})$$

***Line* 6** - Mass of moisture can, *W3*, to be determined from test (Step 11).

***Line* 7** - Mass of moisture can + moist soil, *W4*, to be determined from test (Step 12).

***Line* 8** - Mass of moisture can + dry soil, *W5*, to be determined from test (Step 16).

***Line* 9 –** Compaction moisture content.

$$w\,(\%) = \frac{W_4 - W_5}{W_5 - W_3} \times 100$$

***Line 10*-** Dry unit weight

$$\gamma_d = \frac{\gamma}{1 + \frac{w\,(\%)}{100}} = \frac{\text{Line 4}}{1 + \frac{\text{Line 9}}{100}}$$

Zero-Air-Void Unit Weight

The maximum theoretical dry unit weight of a compacted soil at a given moisture content will occur when there is no air left in the void spaces of the compacted soil. This can be given by

$$\gamma_{d\,(\text{theory-max})} = \gamma_{zav} = \frac{\gamma_w}{\frac{w\,(\%)}{100} + \frac{1}{G_s}} \qquad \textbf{(Eq. 8.1)}$$

where

γ_{zav} = zero-air-void unit weight
γ_w = unit weight of water
w = moisture content
G_s = specific gravity of soil solids.

Since the values of Ɣw and G*s* will be known, several values of w (%) can be assumed and Ɣ*zav* can be calculated. The Table 8. 2. shows the calculations for Ɣ*zav* for the soil tested and reported in Table 8.1.

Graph

Plot a graph showing Y d(Line 10, Table 8.1) versus w (%) (Line 9, Table 8.1) and determine the *maximum dry unit weight of compaction* [Ɣ d(max)l. Also dete.rmine the *optimum moisture content,* wopt' which is the moisture content corresponding to Ɣd(max)' On the same graph, plot Ɣ*zav* versus w (%).

Note: For a given soil, *no portion* of the experiment curve of Ɣ *d* versus w (%) should plot to the *right* of the zero-air-void curve.

The Figure 8.5. shows the results of calculations made in Tables 8.1 and 8.2.

Description of soil Light brown clayey silt Sample No. 2

Location

Tested by Date

Specific gravity of soil solids, G_s	Assumed moisture content, w (%)	Unit weight of water, γ_w (lb/ft^3)	γ_{zav}[a] (lb/ft^3)
2.68	10	62.4	131.9
2.68	12	62.4	126.5
2.68	14	62.4	121.6
2.68	16	62.4	117.0
2.68	18	62.4	112.8
2.68	20	62.4	108.7

Table 8.2 Standard Proctor Compaction Test - Zero Air-Void Unit Weight

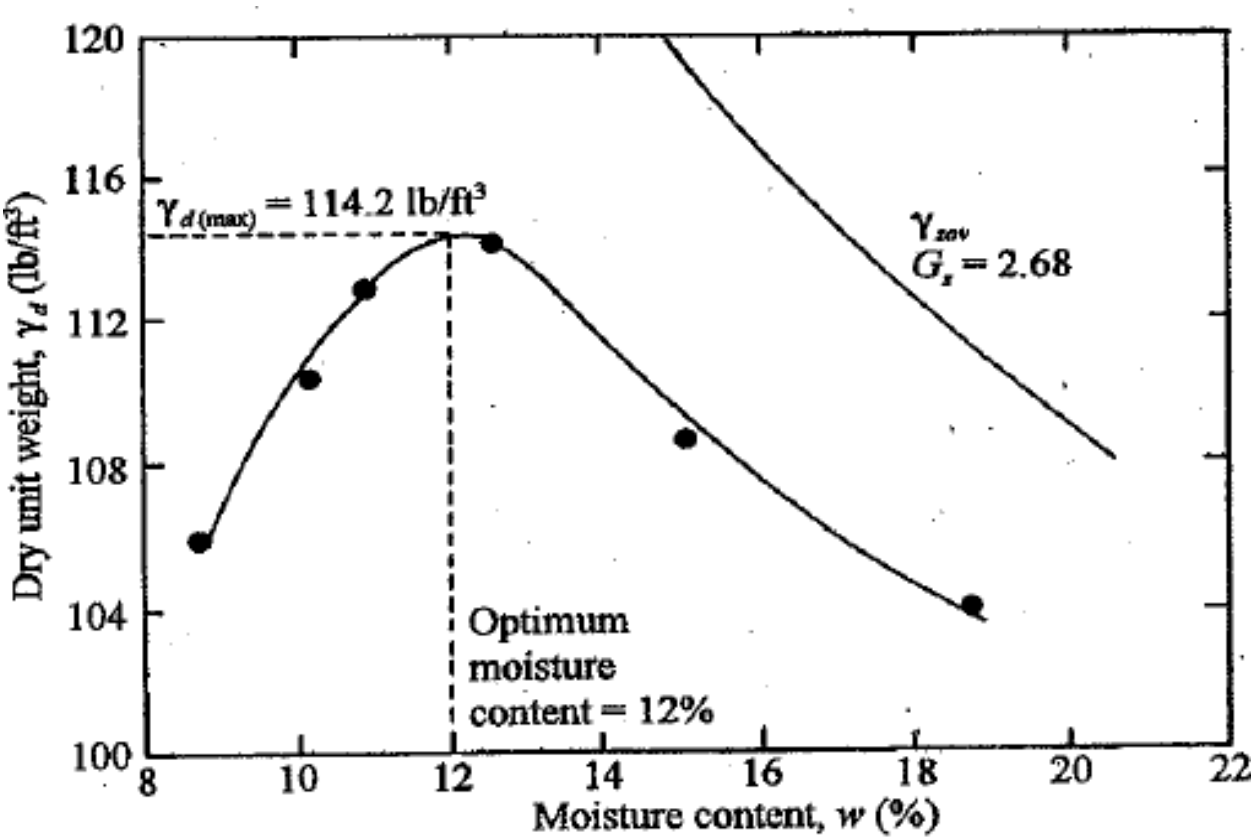


Fig.8.5. Plot of Vd VS. *w (%)* and Vzav VS. *W* (%) for test results reported in Tables 8.1 and 8.2

9. PERFORM MODIFIED PROCTOR TEST

9.1. Identify main testing equipment with its accessories

9.2. Preparation of sample

9.3. Perform testing procedures

9.4. Record and analyze data

9.5. Prepare report

In the preceding chapter, we have seen that water generally acts as a lubricant between solid particles during the soil compaction process. Because of this, in the initial stages of compaction, the dry unit weight of compaction increases. However, another factor that will control the dry unit weight of compaction of a soil at a given moisture content is the energy of compaction. For the standard Proctor compaction test, the energy of compaction can be given by

$$\frac{(3 \text{ layers})(25 \text{ blows/layer})(5.5 \text{ lb})(1 \text{ ft/blow})}{\frac{1}{30} \text{ ft}^3} = 12{,}375 \frac{\text{ft} \cdot \text{lb}}{\text{ft}^3} \; (593 \text{ kJ/m}^3)$$

The modified Proctor compaction test is a standard test procedure for compaction of soil using a higher energy of compaction. In this test, the compaction energy is equal to

$$56{,}250 \frac{\text{ft} \cdot \text{lb}}{\text{ft}^3} \; (2694 \text{ kJ/m}^3).$$

Equipments (Braja M. D., 2002)

The equipment required for the modified Proctor compaction test is the same as in Chapter 8 with the exception of the standard Proctor hammer (Item 3). The hammer used for this test weighs 10 lb and drops through a vertical distance of 18 in. Figure 9.1 shows the standard and modified Proctor test hammers side by side.

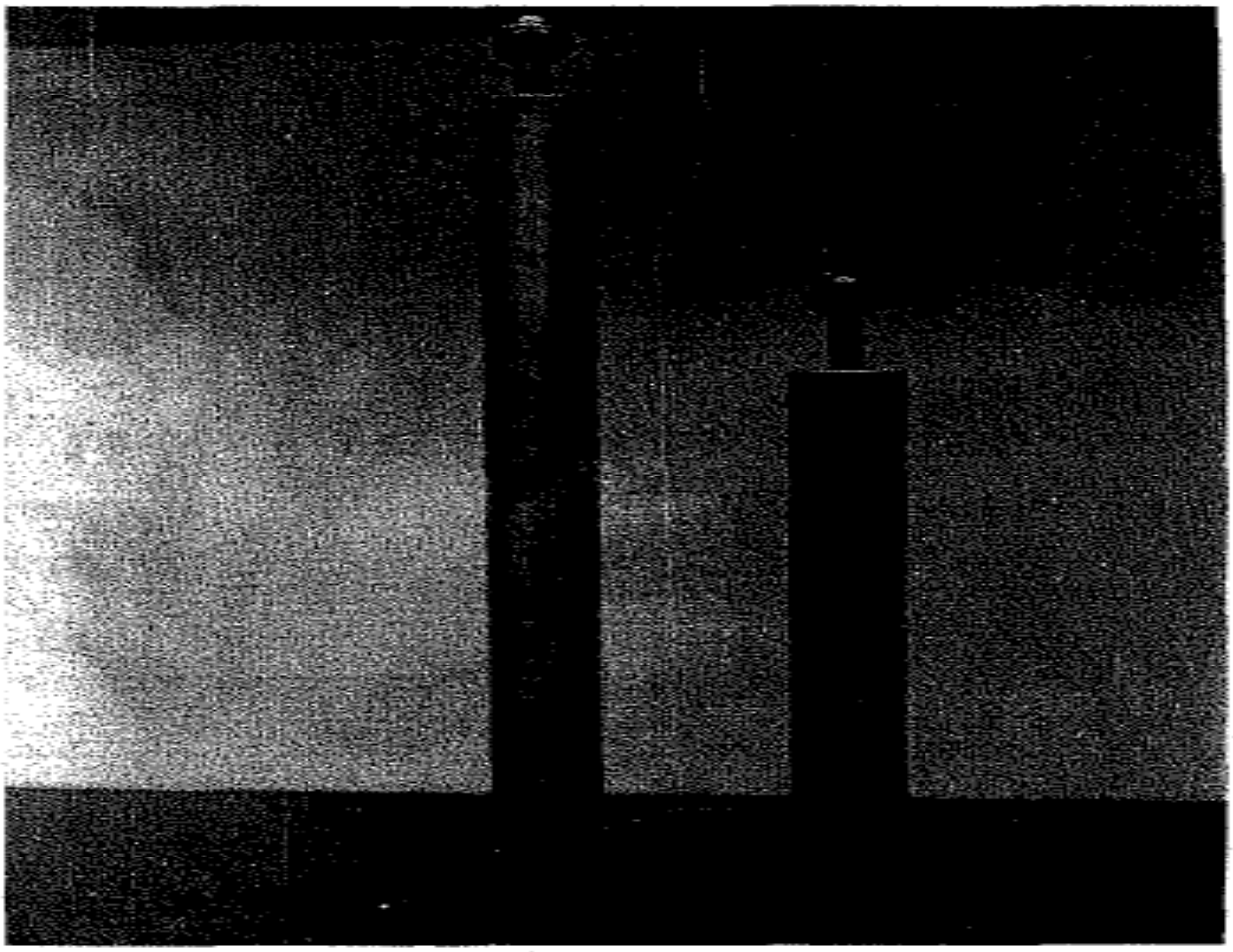


Figure 9.1. Comparison of the standard and modified Proctor compaction hammer.

Note: The left-side hammer is for the modified Proctor compaction test.

Procedure

The procedure is the same as described in Chapter 8, except for Item 3. The moist soil has to be poured into the mold in five equal layers. Each layer has to be compacted by the modified Proctor hammer with 25 blows per layer (Braja M. D., 2002).

Calculation, Graph, and Zero-Air-Void Curve

Same as in Chapter 8 (Braja M. D., 2002).

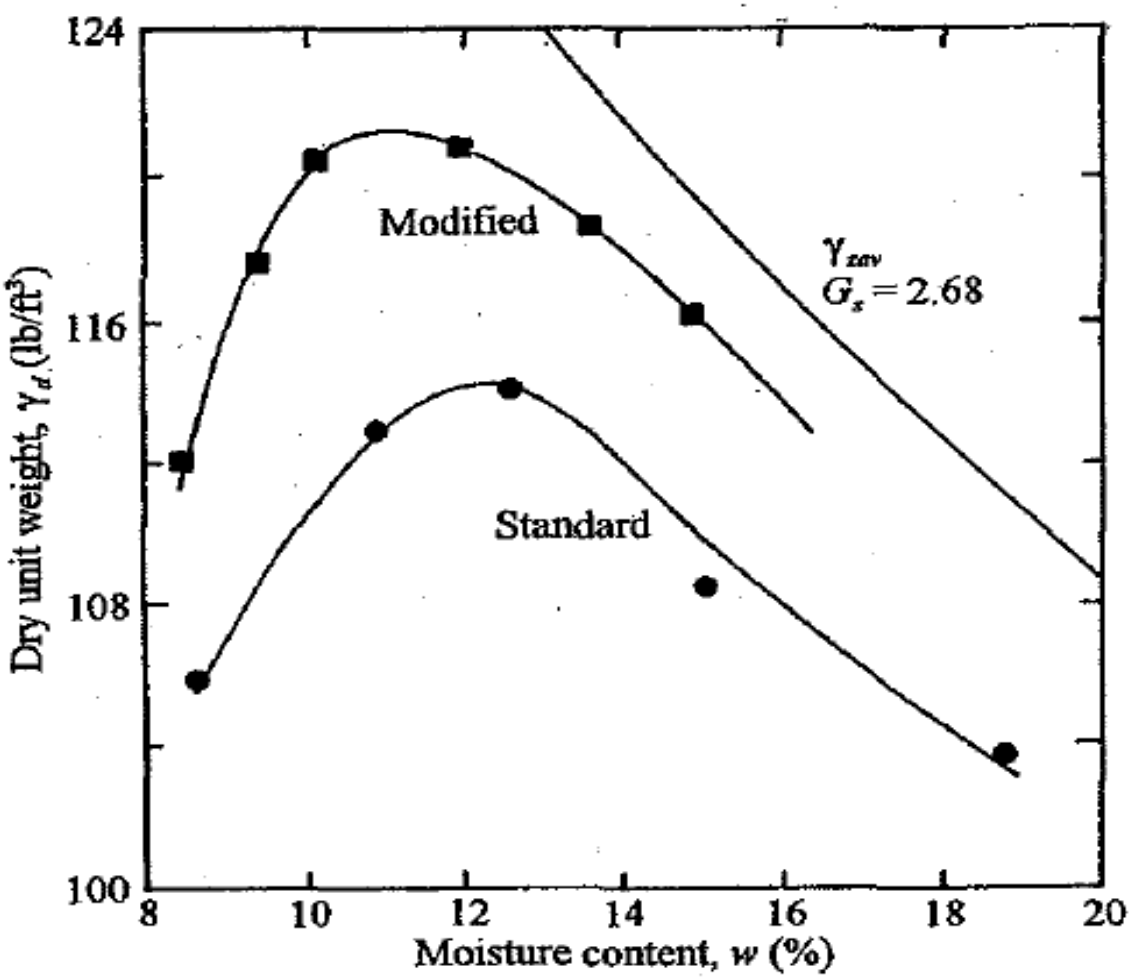


Figure 9.2. Comparison of standard and modified, Proctor compaction test results for the soil reported in Tables 8.1 and 8.2.

The modified Proctor compaction test results for the same soil as reported in Tables 8.1 and 8.2 and Fig. 8.5 are shown in **Fig. 9.2**. A comparison of ɤd Vs.w (%) curves obtained from standard and modified Proctor compaction tests shows that

a) The maximum dry unit weight of compaction increases with the increase in the compacting energy, and
b) The optimum moisture content decreases with the increase in the energy of compaction **(Braja M. D., 2002).**

There are four different methods suggested by ASTM and AASHTO for this test, and they are shown in Table 9.1.

Summary of Modified Proctor Compaction Test Specifications (ASTM 0-1557, MSHTOT-180)

Description	Method A	Method B	Method C	Method D
Mold:				
Volume (ft^3)	$1/30$	$1/13.33$	$1/30$	$1/13.33$
Height (in.)	4.58	4.58	4.58	4.58
Diameter (in.)	4	6	4	6
Weight of hammer (lb)	10	10	10	10
Height of drop of hammer (in.)	18	18	18	18
Number of layers of soil	5	5	5	5
Number of blows per layer	25	56	25	56
Test on soil fraction passing sieve	No. 4	No. 4	¾ in.	¾ in.

10. PERFORM SAND REPLACEMENT TEST

10.1. Identify main testing equipment with its accessories

10.2. Preparation of sample

10.3. Perform testing procedures

10.4. Record and analyze data

10.5. Prepare report

The sand replacement test method is used to determine in situ dry density of soil. The procedures, materials, equipment, and specifications of this test is based on the Indian Standard (IS 2720 part 28).This test is of significant importance and it has been widely used in various construction project sites. For the purpose of tests described in this standard, *soils* shall be grouped as shown below:

Fine-grained soils	Soils containing not less than 90 percent passing a 2·0-mm IS Sieve (*see* IS : 460-1962*)
Medium-grained soils	Soils containing not less than 90 percent passing a 20-mm IS Sieve (*see* IS : 460-1962*)
Coarse-grained soils	Soils containing not less than 90 percent passing a 40-mm IS Sieve (*see* IS : 460-1962*)

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS: 2-1960.

Section I. Method Suitable for Fine- and Medium grained Soils: Small Pouring Cylinder Method

Scope

1.1. This method covers the determination, in-place, of the dry density (in g/cm3 or kg/m3) of natural or compacted fine- and medium-grained soils for which a small sand-pouring cylinder is used. *The method is applicable to layers not exceeding 150 mm in thickness.*

With granular materials having little or no cohesion, particularly when they are wet, there is a danger of errors in the measurement of dry density by this method. These errors are caused by the slumping of the sides of the excavated density hole and always result in an over-estimation of the density.

EQUIPMENTS

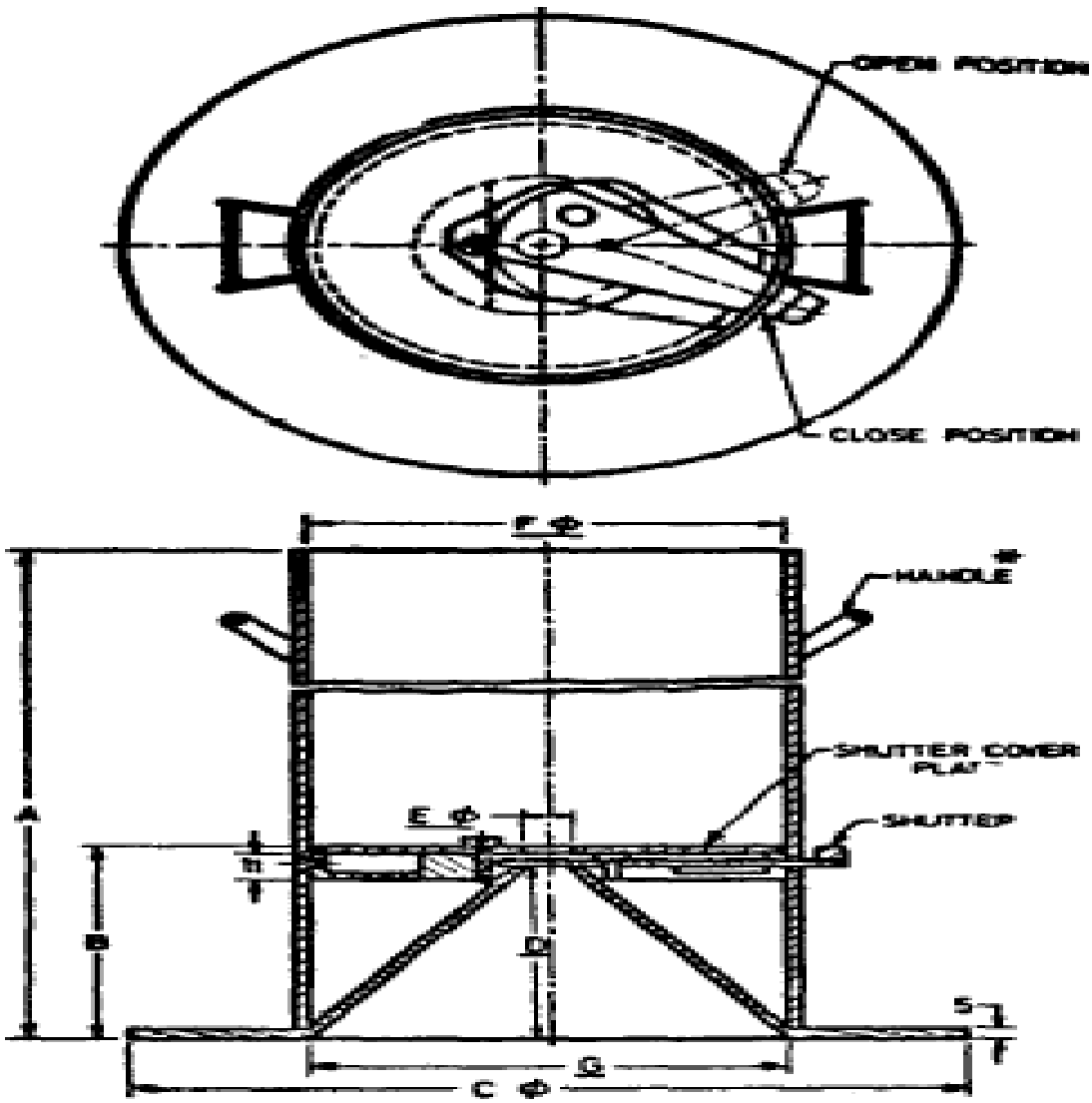


Fig.1. Sand Pouring Cylinder for the determination of density

1) **Small Sand-Pouring Cylinder** - similar in essential details to that shown in Fig. 1.
2) Tools for excavating holes – suitable tools, such as a scraper tool similar to that shown in Fig.2 to make a level surface; bent spoon, dibber shown in Fig 3.
3) **Cylindrical Calibrating Container** – with an internal diameter of 100 mm and an internal depth of 150 mm of the type illustrated in Fig.4 fitted with a flange approximately 50 mm

wide and about 5 mm thick surrounding the open end. The volume of the container should be given to an accuracy of 0.25 percent.

4) **Balance** – accurate to 1 g.
5) **Plane Surface**: Glass or Perspex plate or Other Plane Surface – about 450 mm square 9 mm thick or larger.
6) **Metal Containers** – to collect excavated soil. A convenient size is one about 150 mm diameter and 200 mm deep with a removable cover.
7) **Cylindrical Steel Core-Cutter** – of steel, 127.4 ± 0.1 mm long and 100 mm ± 0.1 mm internal diameter with a wall thickness of 3 mm beveled at one end. One suitable type is illustrated in Fig.5 . The cutter shall be kept adequately greased.
8) **Metal Tray with Hole** – 300 mm square and 40 mm deep with a 100 mm hole in the centre.

Material (Sand)

- Clean, uniformly graded natural sand passing the 1.00 mm IS Sieve and retained on the 600-micron IS Sieve shall be used.
- It shall be free from organic matter, and shall have been oven dried and stored for a suitable period to allow its water content to reach equilibrium with atmospheric humidity.

Note:

- Generally a storage period, after oven drying, of about 7 days is sufficient for the water content of the sand to reach equilibrium with the atmospheric humidity.
- The sand should not be stored in air-tight containers and should be thoroughly mixed before use. If sand is salvaged from holes in compacted soils after carrying out the test, it is advisable to sieve, dry and store this sand again before it is used in further sand replacement tests.

PROCEDURE

12.1. Calibration of Apparatus

12.1.1. The method given in 12.1.1.1. to 12.1.1.4 shall be followed for the determination of the weight of sand in the cone of the pouring cylinder.

12.1.1.1. The pouring cylinder shall be filled so that the level of the sand in the cylinder is within about 10 mm of the top. Its total initial weight (***W1***) shall be found and shall be maintained constant throughout the tests for which the calibration is used. A volume of sand equivalent to that of the excavated hole in the soil (or equal to that of the calibrating container shall be allowed to run out of the cylinder under gravity. The shutter on the pouring cylinder shall then be closed and the cylinder placed on a plane surface, such as a glass plate.

12.1.1.2. The shutter on the pouring cylinder shall be opened and sand allowed to run out. When no further movement of sand takes place in the cylinder the shutter shall be closed and the cylinder removed carefully.

12.1.1.3. The sand that has filled the cone of the pouring cylinder (that is ; the sand that is left on the plane surface) shall be collected and weighed to the nearest gram.

12.1.1.4. These measurements shall be repeated at least three times and the mean weight (**W2**) taken.

12.1.2. The method described in 12.1.2.1 to 12.1.2.3 shall be followed for the determination of the bulk density of the sand (ϒs).

12.1.2.1. The internal volume (*V*) in ml of the calibrating container shall be determined from the weight of water contained in the container when filled to the brim (see note 1 under 12.2.2.). The volume may also be calculated from the measured internal dimensions of the container.

12.1.2.2. The pouring cylinder shall be placed concentrically on the top of the calibrating container after being filled to the constant weight (***W1***) as in 12.1.1.1. The shutter on the pouring cylinder shall be closed during this operation. The shutter shall be opened and sand allowed to run out. When no further movement of sand takes place in the cylinder the shutter shall be closed. The pouring cylinder shall be removed and weighed to the nearest gram.

12.1.2.3.. These measurements shall be repeated at least three times and the mean weight (***W3***) taken.

- Since variations in atmospheric humidity affect the water content of the sand, and hence its bulk density, the calibration should be made (or at least checked) during each day's work.

- To overcome the effects of slight variations in grading and particle shape between batches of sand, each batch should be sampled and calibrated.

12.2. Measurement of Soil Density

The following method shall be followed for the measurement of soil density.

12.2.1. A flat area, approximately 450 mm square, of the soil to be tested shall be exposed and trimmed down to a level surface preferably with the aid of the scraper tool.

12.2.2. The metal tray with a central hole shall be laid on the prepared surface of the soil with the hole over the portion of the soil to be tested. The hole in the soil shall then be excavated using the hole in the tray as a pattern to the depth of the layer to be tested up to a maximum of 150 mm (see note 1 below).

- ✓ **Note 1**: *If for any reason it is necessary to excavate the holes to depths other than 150 mm, the calibrating container should be replaced by one, the depth of which is the same as the hole excavated or its effective depth should be reduced to that of the hole excavated.*

- ✓ **Note 2**: *Care shall be taken in excavating the hole to see that the hole is not enlarged by levering the dibber against the side of the hole, as this will result in lower densities being recorded.*

The excavated soil shall be carefully collected, leaving no loose material in the hole and weighed to the nearest gram (***Ww).*** The metal tray shall be removed before the pouring cylinder *is* placed in position over the excavated hole.

The following alternative method shall be used for fine-grained cohesionless soils:

- The steel core cutter shall be pressed evenly and carefully into the soil until its top edge is flush with the levelled surface.
- Soil to a depth of 100 mm (see Note 1) within the core cutter shall then be excavated by means of suitable tools.

- The excavated soil shall be carefully collected and weighed to the nearest gram (***Ww).***
- The core cutter shall remain in position during the remainder of the testing procedure.

12.2.3. The water content (***W***) of the excavated soil shall be determined by the method specified in IS: 2720 (Part II) – 1973. Alternatively the whole of the excavated soil may be dried and weighed (*W*d).

12.2.4. The pouring cylinder filled to the constant weight (*W*1) as in 12.1.1. shall be so placed that the base of the cylinder covers the hole concentrically. The shutter on the pouring cylinder shall be closed during this operation. The shutter shall then be opened and sand allowed to run out into the hole. The pouring cylinder and the surrounding area shall not be vibrated during this period. When no further movement of sand takes place the shutter shall be closed. The cylinder shall be removed and weighed to the nearest gram (W4) (see note below).

Note:

- ✓ *It is necessary to make a number of repeated determinations (at least three) and to average the results, since the dry density of the soil varies appreciably from point to point.*
- ✓ *The number of determinations should be such that an additional one would make no significant difference to the average.*

CALCULATIONS

- The weight of sand (***WS)*** in g, required to fill the calibrating container shall be calculated from the following formula:

$$W_a = W_1 - W_3 - W_2$$

where

W_1 = weight of pouring cylinder and sand before pouring into calibrating container in g,

W_3 = mean weight of cylinder with residual sand after pouring into calibrating container and cone in g, and

W_2 = mean weight of sand in cone in g.

- The bulk density of the sand (ɤs) in kg/m3 shall be calculated from the formula:

$$\gamma_s = \frac{W_s}{V} \times 1\,000$$

where

V = volume of calibrating container in ml.

The weight of sand (***Wb)*** in g, required to fill the excavated hole shall be calculated from the following formula:

$$W_b = W_1 - W_4 - W_2$$

where

W_1 = weight of cylinder and sand before pouring into hole in g,
W_4 = weight of cylinder and sand after pouring into hole and cone in g, and
W_2 = mean weight of sand in cone in g.

The bulk density ɤb, that is, the weight of the wet soil per cubic metre shall be calculated from the following formula:

$$\gamma_b = \frac{W_w}{W_b} \times \gamma_s \text{ kg/m}^3$$

where

W_w = weight of soil excavated in g,
W_b = weight of sand required to fill the hole in g, and
γ_s = bulk density of sand in kg/m³.

The dry density ɤd, that is, the weight of the dry soil shall be calculated from the following formula:

$$\gamma_d = \frac{100\,\gamma_b}{100 + w} \text{ kg/m}^3$$

or

$$\gamma_d = \frac{W_d}{W_b} \times \gamma_s \text{ kg/m}^3$$

where

w = water content of the soil in percent,
W_d = weight of dry soil from the hole in g, and
W_b = weight of sand required to fill the hole in g.

REPORTING OF RESULTS

The following values shall be reported:

a) Dry density of soil in kg/m3 to the nearest whole number. The dry density may also be calculated and reported in g/ems correct to the second place of decimal.
b) Water content of the soil in percent reported to two significant figures.

The method used for obtaining the test results shall be stated as the small pouring cylinder method. The use of steel core cutter, if made, shall also be mentioned. The results of the test shall be recorded suitably. A recommended pro forma for the record of the test results is given below.

DETERMINATION OF DRY DENSITY OF SOIL, IN-PLACE, BY SAND REPLACEMENT

(Small Pouring Cylinder/Large Pouring Cylinder)

A-1. The test results for the two methods, namely, small pouring cylinder and large pouring cylinder may be tabulated as given below using the appropriate symbols and words in each case:

Project: Tested by:

Location: Date:

State whether steel core cutter was used.

Calibration

1. Mean weight of sand in cone (of pouring cylinder) (W_2), in g	
2. Volume of calibrating container (V), in ml	
3. Weight of sand (+ cylinder) before pouring (W_1), in g	
4. Mean weight of sand (+ cylinder) after pouring (W_3), in g	
5. Weight of sand to fill calibrating container ($W_a = W_1 - W_3 - W_2$), in g	
6. Bulk density of sand $\gamma_s = \frac{W_a}{V} \times 1\,000$ kg/m³	

Measurement of Soil Density
1. Determination No.
2. Weight of wet soil from hole (W_w), in g
3. Weight of sand (+ cylinder) before pouring (W_1), in g
4. Weight of sand (+ cylinder) after pouring (W_4), in g
5. Weight of sand in hole ($W_b = W_1 - W_4 - W_2$), in g
6. Bulk density $\gamma_b = \frac{W_w}{W_b} \times \gamma_s$ kg/m³
7. Water content container No.
8. Weight of soil for water content determination, in g
9. Weight of oven dried soil, in g
10. Water content (w), percent
11. Dry density $\gamma_d = \frac{100\gamma_b}{100+w}$ kg/m³

According to the Indian Standard (IS 2720 part 28), there are details about the procedures, materials, equipment, and specifications of the sand displacement test using the **Method suitable for Fine-, Medium and Coarse-grained Soils: Large Pouring Cylinder Method.**

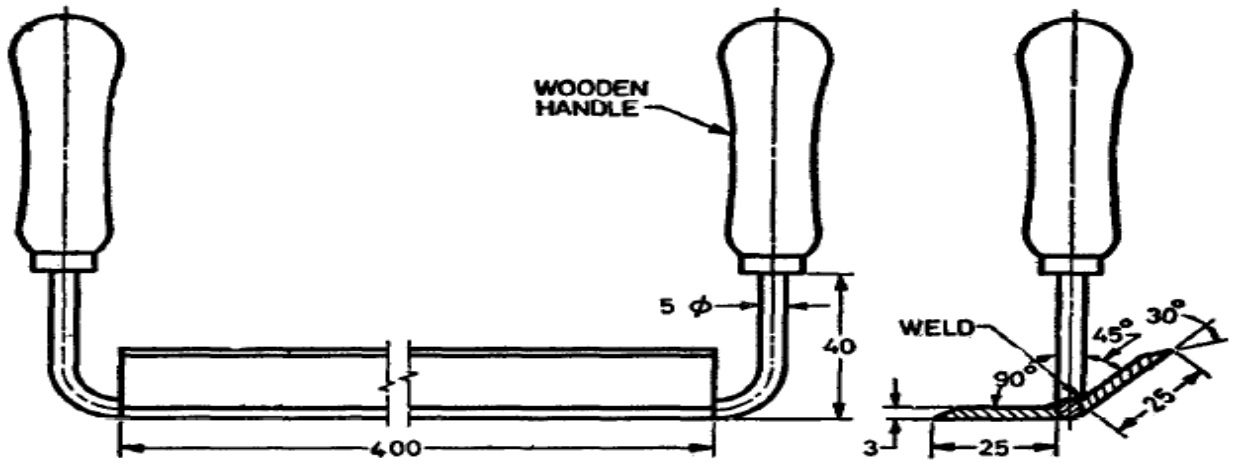
*The handle may be required for large pouring cylinder only.

Pouring Cylinder Size	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*Capacity in Litres*
Small (for fine- and medium-grained soils)	380	85	200	75	13 ±0·1	115	115	3
Large (for fine-, medium- and coarse-grained soils)	610	175	350	160	25 ±0·1	215	215	16·5

NOTE 1 — This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.
NOTE 2 — Essential dimensions are underlined.
NOTE 3 — Tolerance on essential dimensions ±1 mm.

All dimensions in millimetres.

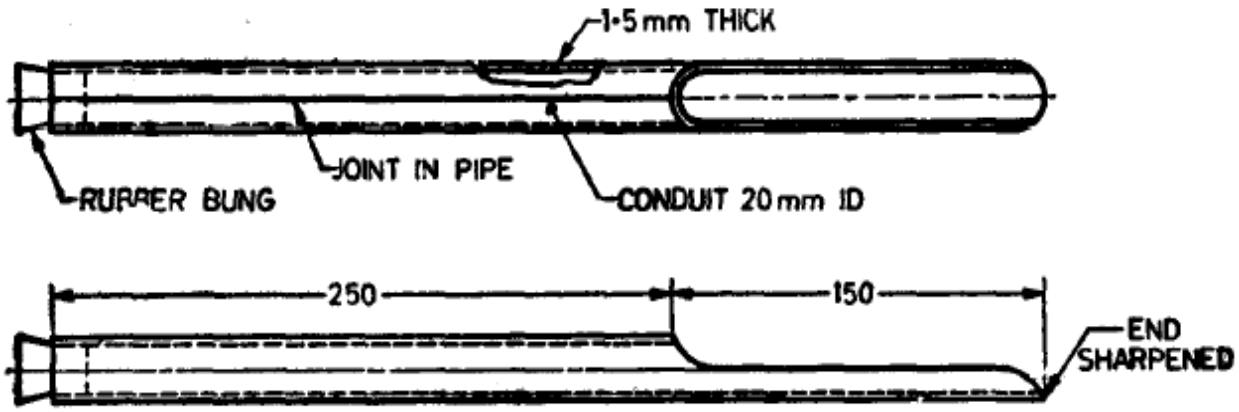
Fig.1. Sand Pouring Cylinder for the Determination of Density



NOTE — This design has been found satisfactory, but alternative designs may be employed.

All dimensions in millimetres.

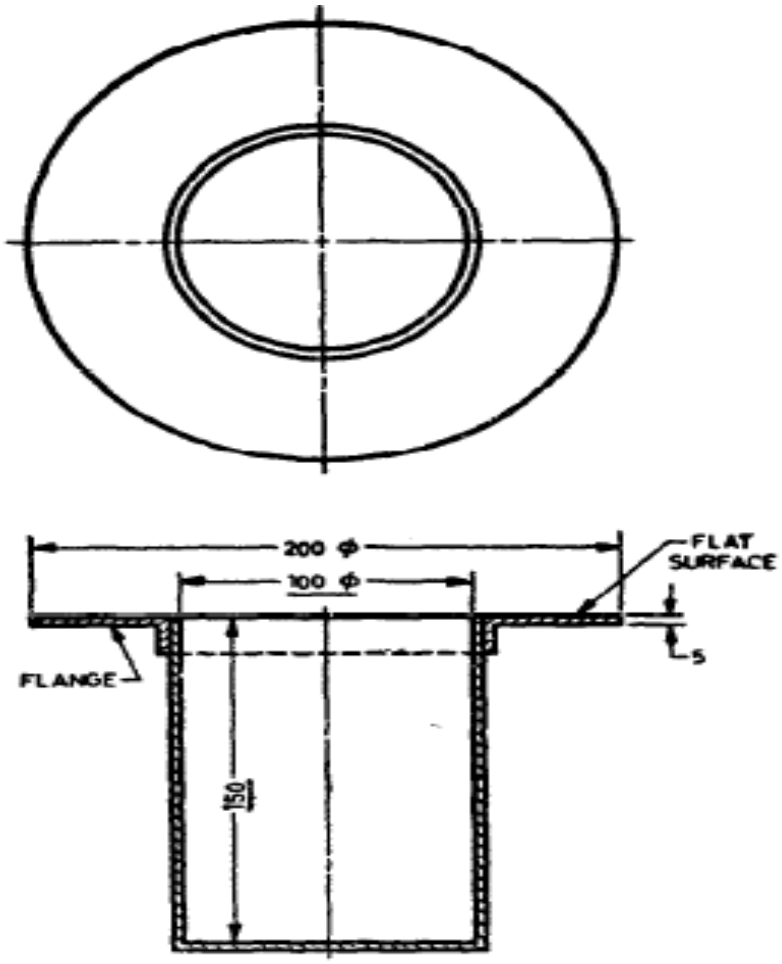
Fig. 2. Scraper for Levelling of Surface of Soil



NOTE — This design has been found satisfactory, but alternative designs may be employed.

All dimensions in millimetres.

Fig.3. Dibber for digging density holes



NOTE 1 — This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

NOTE 2 — Essential dimensions are underlined.

NOTE 3 — Tolerance on essential dimensions ± 0·1 mm.

All dimensions in millimetres.

Fig.4. Calibrating container for use with small pouring cylinder

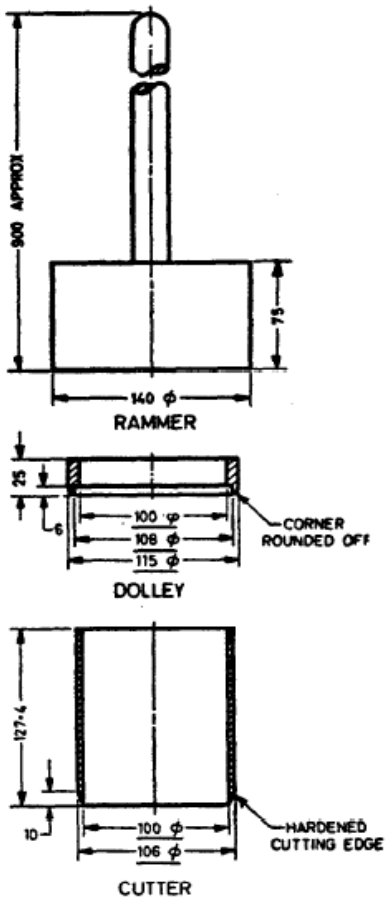


Fig.5. Core-Cutter Apparatus for Soil Density Determination

- All dimensions in millimeters.
- These designs have been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.
- Essential dimensions are underlined.
- Tolerance on essential dimensions ± 0.1 mm.

11. PERFORM PERMEABILITY TEST

11.1. Identify main testing equipment with its accessories

11.2. Preparation of sample

11.3. Perform testing procedures

11.4. Record and analyze data

11.5. Prepare report

The fundamental soil property involved in water flow is permeability. The permeability is especially relevant for engineering problems like determination of rate of leakage through an earth dam. It depends mainly on the particle size, void ratio, density and degree of saturation. The permeability of a soil is a measure of its capacity to allow the flow of water through the pore spaces between solid particles. The degree of permeability is determined by applying a hydraulic pressure gradient in a sample of saturated soil and measuring the consequent rate of flow. The coefficient of permeability is expressed as a velocity.

The specimens are formed in a permeability cell and water is passed through it from a constant level tank. Pressure take-off points located along the sides of the permeability cell are connected to 3 manometer tubes. Water passing through the specimen is collected and measured.

Constant Head Permeability Test in Sand (Braja M. D., 2002)

The rate of flow of water through a soil specimen of gross cross-sectional area, A, can be expressed as

$$q = kiA$$

where q = flow in unit time
k = coefficient of permeability
i = hydraulic gradient

For coarse sands, the value of the coefficient of permeability may vary from 1 to 0.01 cm/s and, for fine sand, it may be in the range of 0.01 to 0.001 cm/s. Several relations between k and the void ratio, e, for sandy soils have been proposed. They are of the form

$$k \propto e^2$$

$$k \propto \frac{e^2}{1+e}$$

$$k \propto \frac{e^3}{1+e}$$

The coefficient of permeability of sands can be easily determined in the laboratory by two simple methods. They are (a) the constant head test and (b) the variable head test. In this chapter, the *constant head test method* will be discussed.

Equipment

1. Constant head permeameter
2. Graduated cylinder (250 cc or 500 cc)
3. Balance, sensitive up to O.1 g
4. Thermometer, sensitive up to 0.1 °C
5. Rubber tubing
6. Stop watch

Constant Head Permeameter

A schematic diagram of a constant head permeameter is shown in Fig. 11-1. This can be assembled in the laboratory at very low cost. It essentially consists of a plastic soil specimen cylinder, two porous stones, two rubber stoppers, one spring, one constant head chamber, a large funnel, a stand, a scale, three clamps, and some plastic tubes. The plastic cylinder may have an inside diameter of 2.5 in. (63.5 mm).

This is because 2.5 in. (63.5 mm) diameter porous stones are usually available in most soils laboratories. The length of the specimen tube may be about 12 in. (304.8 mm).

Procedure

1. Determine the mass of the plastic specimen tube, the porous stones, the spring, and the two rubber stoppers (W1).
2. Slip the bottom porous stone into the specimen tube, and then fix the bottom rubber stopper to the specimen tube.

3. Collect oven-dry sand in a container. Use a spoon, pour the sand into the specimen tube in small layers, and compact it by vibration and/or other compacting means.

Note*:* By changing the degree of compaction, a number of test specimens having different void ratios can be prepared.

4. When the length of the specimen tube is about two-third the length of the tube, slip the top porous stone into the tube to rest firmly on the specimen.
5. Place a spring on the top porous stone, if necessary.
6. Fix a rubber stopper to the top of the specimen tube.

Note*:* The spring in the assembled position will not allow any expansion of the specimen volume, and thus the void ratio, during the test.

7. Determine the mass of the assembly (Step 6 - *W2).*
8. Measure the length *(L)* of the compacted specimen in the tube.
9. Assemble the permeameter near a sink, as shown in Fig. 11-1.
10. Run water into the top of the large funnel fixed to the stand through a plastic tube from the water inlet. The water will flow through the specimen to the constant head chamber. After some time, the water will flow into the sink through the outlet in the constant head chamber.

Note*: Make sure that water does not leak from the specimen tube.*

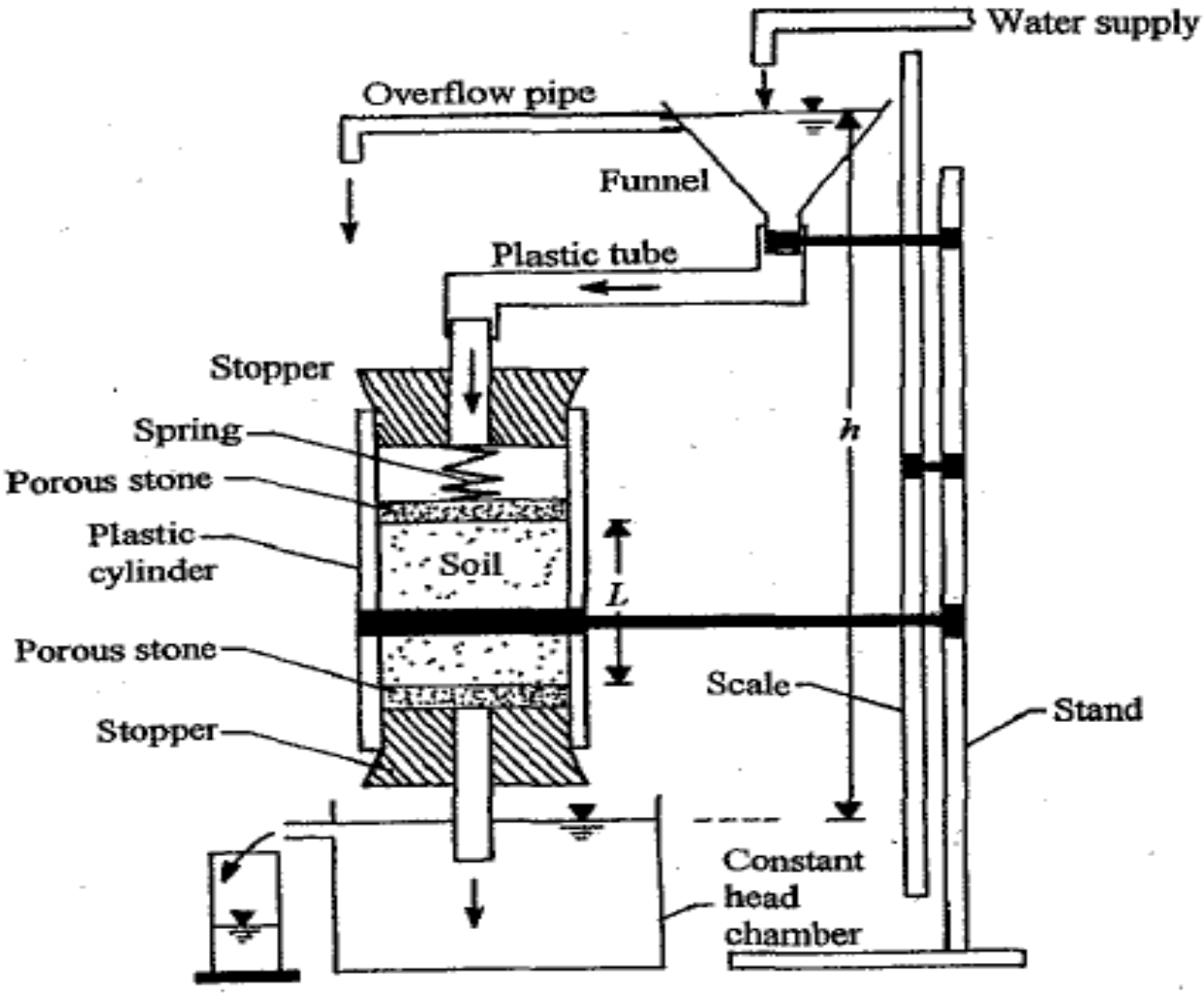


Fig. 11.1. Schematic diagram of constant head permeability test setup.

11. Adjust the supply of water to the funnel so that the water level in the funnel remains constant. At the same time, allow the flow to continue for about 10 minutes in order to saturate the specimen. *Note:* Some air bubbles may appear in the plastic tube connecting the funnel to the specimen tube. Remove the air bubbles: .

12. After a steady flow is established (that is, once the head difference *h* is constant), collect the water flowing out of the constant head chamber *(Q)* in a graduated cylinder. Record the collection time *(t)* with a stop watch.

13. Repeat Step 12 three times. Keep the collection time *(t)* the same and determine *Q*. Then find the average value of *Q*.

14. Change the head difference, *h*, and repeat Steps **II,** 12 and 13 about three times.

15. Record the temperature, *T*, of the water to the nearest degree.

***Note**: This value is sufficiently accurate for this type of test.*

Calculation

1. Calculate the void ratio of the compacted specimen as follows:

Dry density, ρd of the soil specimen as

$$\rho_d = \frac{W_2 - W_1}{\frac{\pi}{4} D^2 L}$$

Thus

$$e = \frac{G_s \rho_w}{\rho_d} - 1$$

where G_s = specific gravity of soil solids
ρ_w = density of water
D = diameter of the specimen
L = length of the specimen

2. Calculate *k* as

$$k = \frac{QL}{Aht}$$

where A = area of specimen = $\frac{\pi}{4} D^2$

1. The value *k is* usually given for a test temperature of water at 20°C. So calculate k20oc as

$$k_{20°C} = k_{T°C} \frac{\eta_{T°C}}{\eta_{20°C}}$$

where $\eta_{T°C}$ and $\eta_{20°C}$ are viscosities of water at T°C and 20°C, respectively.

Table 11-1 gives the values of

$\frac{\eta_{T°C}}{\eta_{20°C}}$ for various values of T (in °C).

Table 11.1. Variation of $\eta_{T°C}/\eta_{20°C}$

Temperature, T (°C)	$\eta_{T°C}/\eta_{20°C}$	Temperature, T (°C)	$\eta_{T°C}/\eta_{20°C}$
15	1.135	23	0.931
16	1.106	24	0.910
17	1.077	25	0.889
18	1.051	26	0.869
19	1.025	27	0.850
20	1.000	28	0.832
21	0.976	29	0.814
22	0.953	30	0.797

Tables 11-2 and 11-3 give sample calculations for the permeability test.

Table 11-2. Constant Head Permeability Test

Determination of Void Ratio of Specimen

Description of soil *Uniform sand* Sample No. _____

Location _____

Length of specimen, L *13.2* cm Diameter of specimen, D *6.35* cm

Tested by _____ Date _____

Volume of specimen, $V = \frac{\pi}{4} D^2 L$ (cm^2)	*418.03*
Specific gravity of soil solids, G_s	*2.66*
Mass of specimen tube with fittings, W_1 (g)	*238.4*
Mass of tube with fittings and specimen, W_2 (g)	*965.3*
Dry density of specimen, $\rho_d = \frac{W_2 - W_1}{V}$ (g / cm^3)	*1.74*
Void ratio of specimen, $e = \frac{G_s \rho_w}{\rho_d} - 1$ (*Note:* $\rho_w = 1$ g/cm^3)	*0.53*

Table 11-3. Constant Head Permeability Test

Test No.	1	2	3
Average flow, Q (cm^3)	*305*	*375*	*395*
Time of collection, t (s)	*60*	*60*	*60*
Temperature of water, T (°C)	*25*	*25*	*25*
Head difference, h (cm)	*60*	*70*	*80*
Diameter of specimen, D (cm)	*6.35*	*6.35*	*6.35*
Length of specimen, L (cm)	*13.2*	*13.2*	*13.2*
Area of specimen, $A = \frac{\pi}{4} D^2$ (cm^2)	*31.67*	*31.67*	*31.67*
$k = \frac{QL}{Aht}$ (cm / s)	*0.035*	*0.037*	*0.034*
Average k = *0.035* cm/s			
$k_{20°C} = k_{T°C} \frac{\eta_{T°C}}{\eta_{20°C}}$ = *0.035(0.889)* = *0.031* cm/s			

The procedure for conducting the constant head penneability tests in sand were discussed in this chapter. The falling head penneability test is another experimental procedure to detennine the coefficient of penneability of sand. There is also a **Falling Head Permeability Test in Sand.**

Falling Head Permeameter

A schematic diagram of a falling head permeameter is shown. in Fig. 11-2. This consists of a specimen tube essentially the same as that used in the constant head test. The top of the specimen tube is connected to a burette by plastic tubing. The specimen tube and the burette are held vertically by clamps from a stand. The bottom of the specimen tube is connected to a plastic funnel by a plastic tube. The funnel is held vertically by a clamp from another stand. A scale is also fixed vertically to this stand.

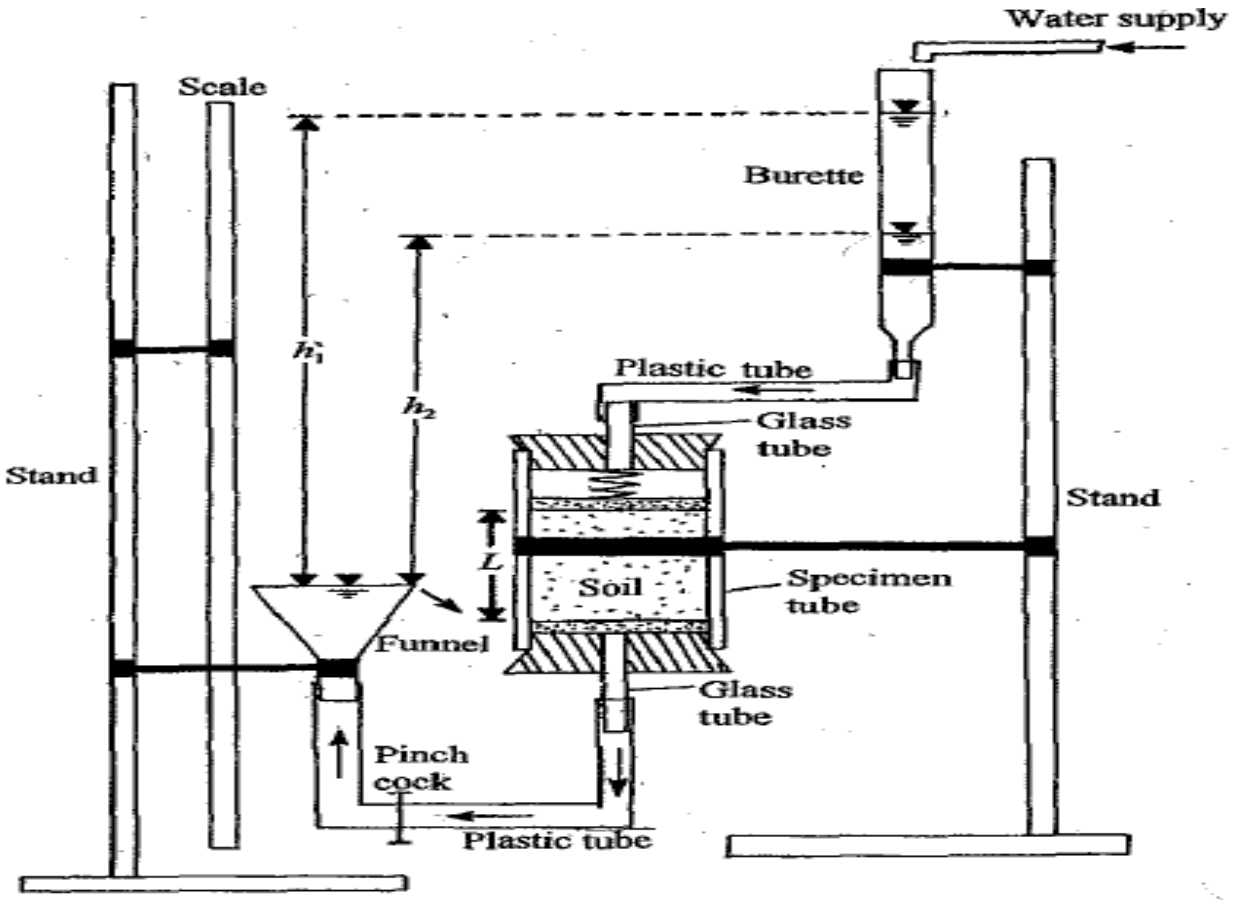


Fig. 11.2. Schematic diagram of falling head permeability test setup

12. PERFORM DIRECT SHEAR TEST

12.1. Identify main testing equipment with its accessories

12.2. Preparation of sample

12.3. Perform testing procedures

12.4. Record and analyze data

12.5. Prepare report

Shear force is *a force acting in a direction that is parallel to (over the top of) a surface or cross section of a body*, like the pressure of air flow over an airplane wing. The word shear in the term is a reference to the fact that such a force can cut, or shear, through the surface or object under strain.

Direct Shear Test on Sand (Braja M. D., 2002)

The shear strength, s, of a granular soil may be expressed by the equation

$$s = \sigma' \tan \phi \quad \textbf{(Eq. 12.1)}$$

where

σ' = effective normal stress
ϕ = angle of friction of soil

The angle of friction, ϕ, is a function of the relative density, of compaction of sand, grain size, shape and distribution in a given soil mass. For a given sand, an increase in the void ratio (i.e., a decrease in the relative density of compaction) will result in a decrease of the magnitude of ϕ. However, for a given void ratio, an increase in the angularity of the soil particles will give a higher value of the soil friction angle. The general range of the angle of friction of sand with relative density is shown in Fig. 12-1.

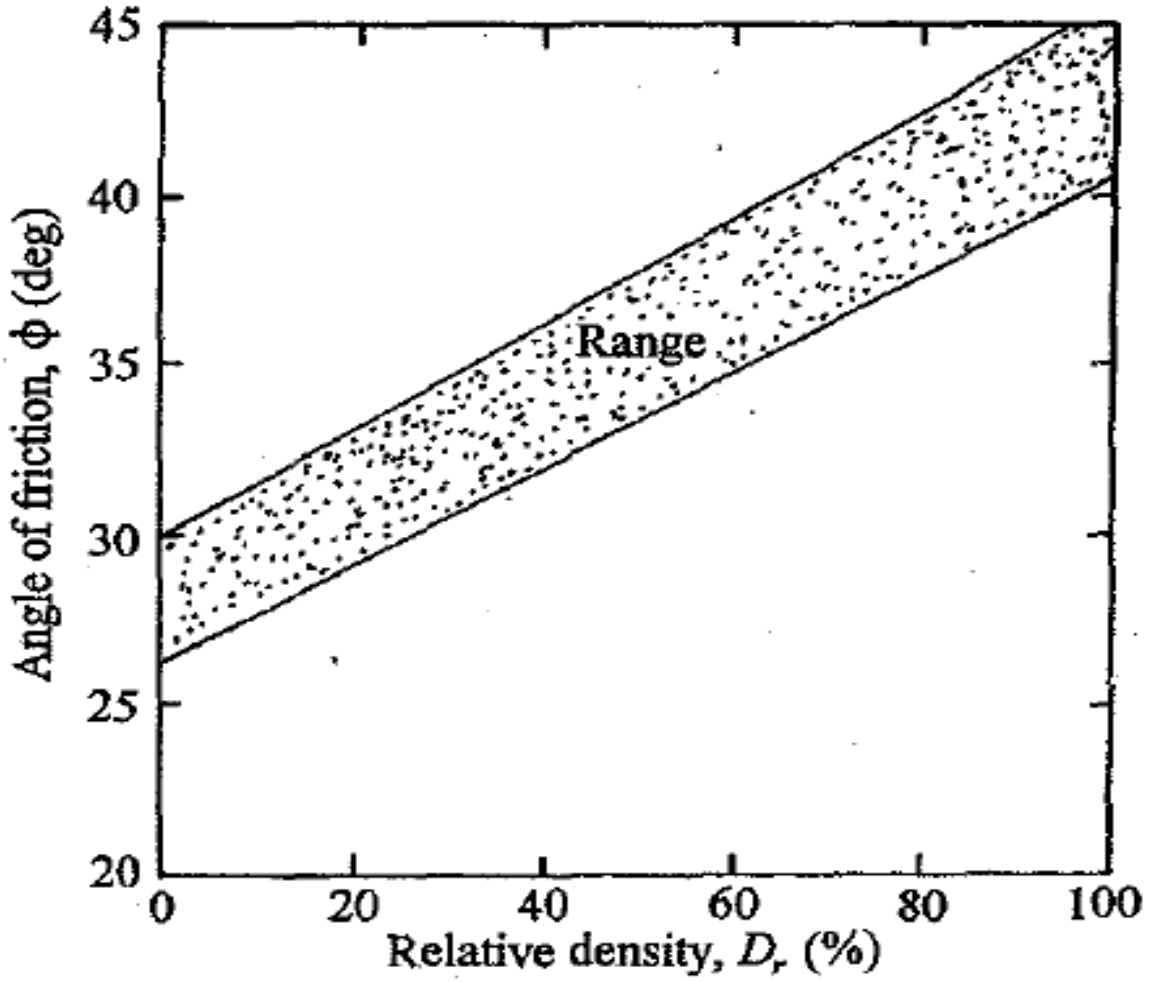


Figure 12.1. General range of the variation of angle of friction of sand with relative density of compaction.

Equipment

1. Direct shear test machine (strain controlled)
2. Balance sensitive to 0.1 g
3. Large porcelain evaporating dish
4. Tamper (for compacting sand in the direct shear box)"
5. Spoon

Figure 12-2 shows a direct shear test machine. It consists primarily of a direct shear box, which is split into two halves (top and bottom) and which holds the soil specimen; a proving ring to measure

the horizontal load applied to the specimen; two dial gauges (one horizontal and one vertical) to measure the deformation of the soil during the test; and a yoke by which a vertical load can be applied to the soil specimen.

A horizontal load to the top half of the shear box is applied by a motor and gear arrangement. In a strain-controlled unit, the rate of movement of the top half of the shear box can be controlled.

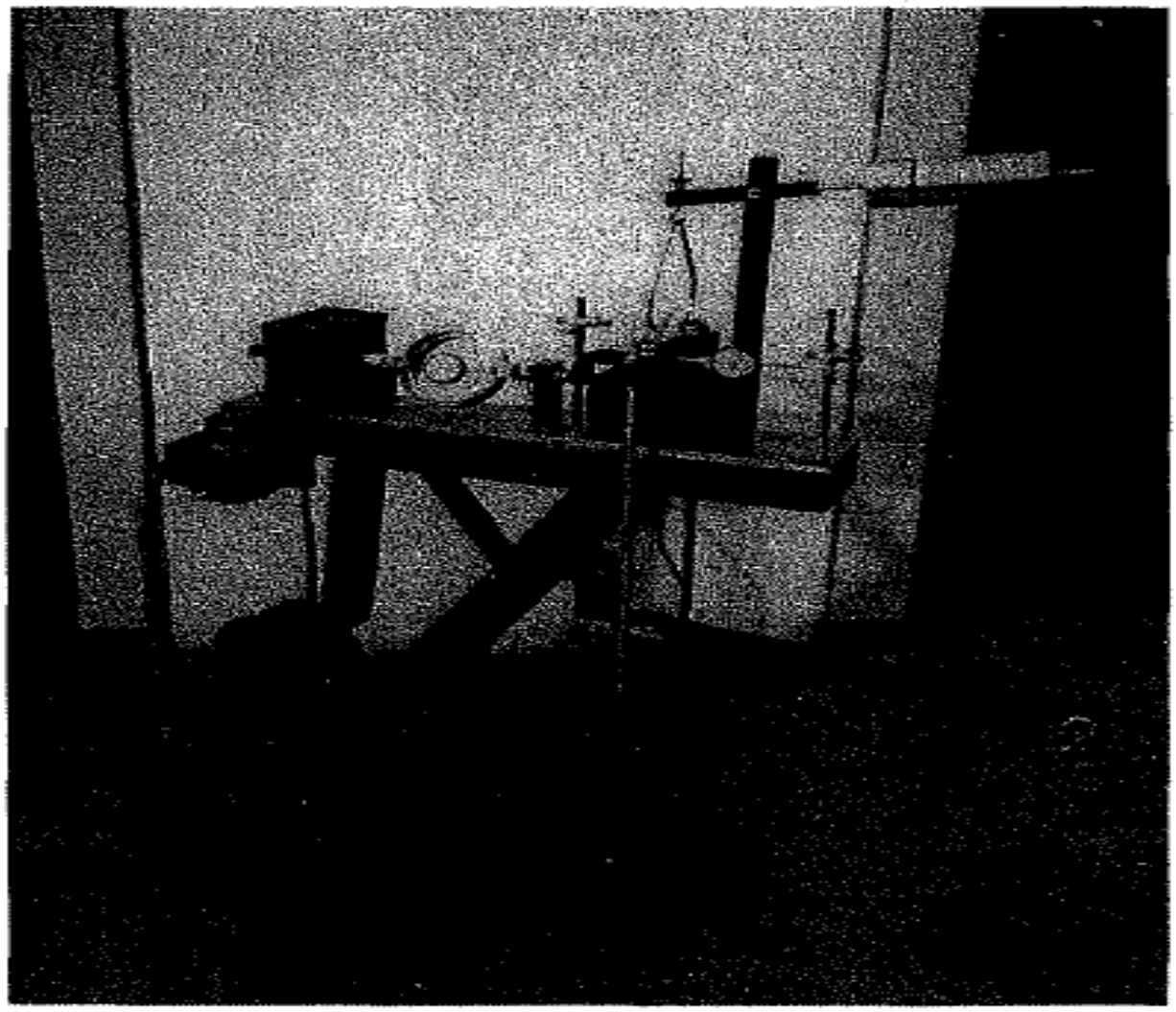


Figure. 12.2. A direct shear test machine.

The Figure 12-3 shows the schematic diagram of the shear box. The shear box is split into two halves-top and bottom. The top and bottom halves of the shear box can be held together by two

vertical pins. There is a loading head which can be slipped from the top of the shear box to rest on the soil specimen inside the box. There are also three vertical screws and two horizontal screws on the top half of the shear box.

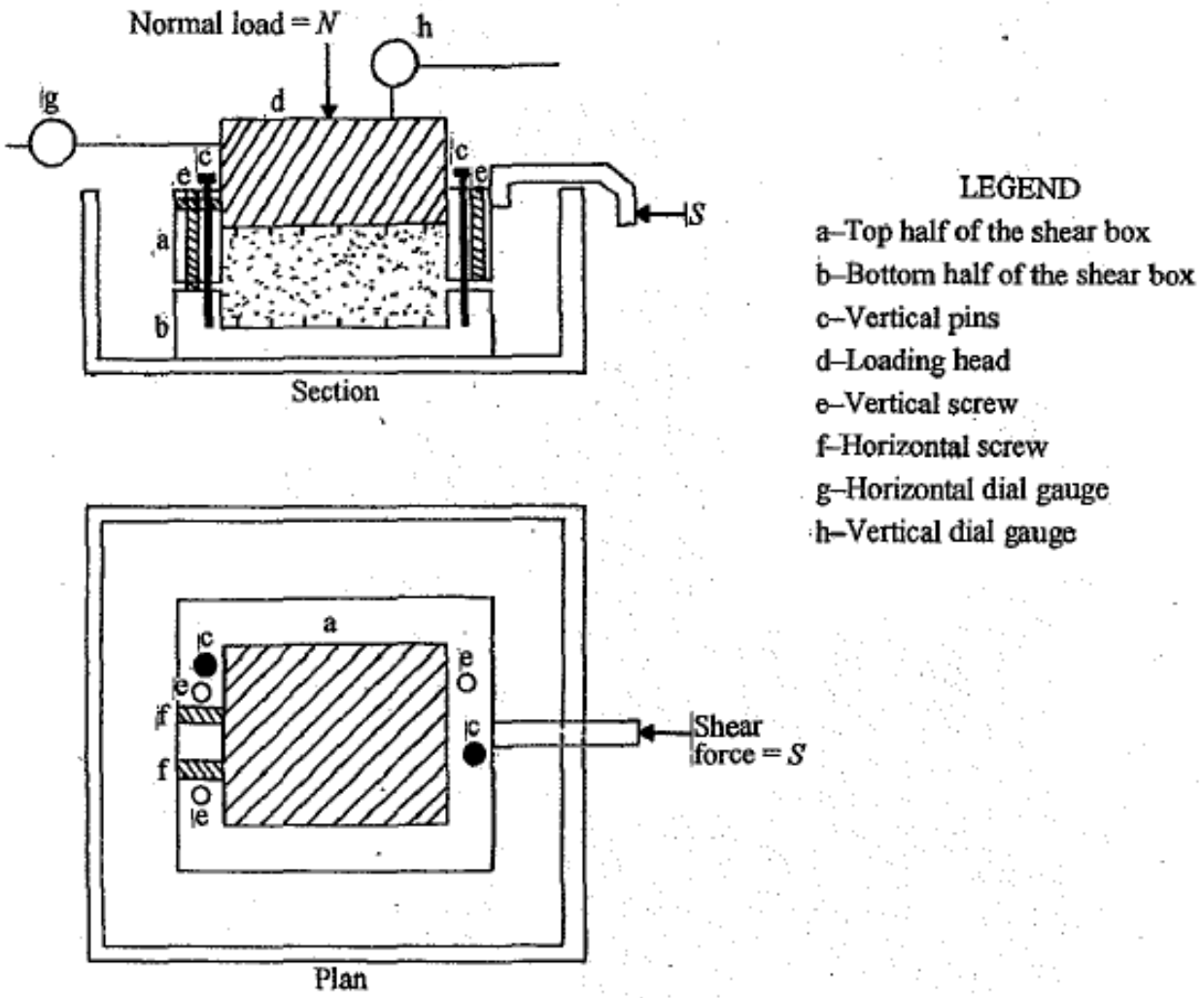


Figure. 12.3. Schematic diagram of a direct shear test box.

1. Remove the shear box assembly. Back off the vertical and two horizontal screws. Remove the loading head. Insert the two vertical pins to keep the two halves of the shear box together.
2. Weigh some dry sand in a large porcelain dish, W1. Fill the shear box with sand in small layers. A tamper may be used to compact the sand layers. The top of the compacted specimen should be about *1/4* in. (6.4 mm) below the top of the shear box. Level the surface of the sand specimen.

3. Determine the dimensions of the soil specimen (i.e., length *L*, width *B*, and height *H* of the specimen).
4. Slip the loading head down from the top of the shear box to rest on the soil specimen.
5. Put the shear box assembly in place in the direct shear machine.
6. Apply the desired normal load, *N*, on the specimen. This can be done by hanging dead weights to the vertical load yoke. The top crossbars will rest on the loading head of the specimen which, in tum, rests on the soil specimen.

Note:

- In the equipment shown in Fig. 12-2, the weights of the hanger, the loading head, and the top half of the shear box can be tared.
- In some other equipment, if taring is not possible, the normal load should be calculated as *N* = load hanger + weight of Yoke + weight of loading head + weight of top half of the shear box.

7. Remove the two vertical pines (which were inserted in Step 1 to keep the two halves of the shear box together).
8. Advance the three vertical screws that are located on the side walls of the top half of the shear box. This is done to separate the two halves of the box. The space between the two halves of the box should be slightly larger than the largest grain size of the soil specimen (by visual observation).
9. Set the loading head by tightening the two horizontal screws located at the top half of the shear box. Now back off the three vertical screws. After doing this, there will be no connection between the two halves of the shear box except the soil.
10. Attach the horizontal and vertical dial gauges (0.001 in./small div) to the shear box to measure the displacement during the test.
11. Apply horizontal load, S, to the top half of the shear box. The rate of shear displacement should be between 0.1 to 0.02 in./min (2.54 to 0.51 mm/min). For every tenth small division displacement in the horizontal dial gauge, record the readings of the vertical dial gauge and the proving ring gauge (which measures horizontal load, 8).

Continue this until after
(a) the proving ring dial gauge reading reaches a maximum and then falls, or

(b) the proving ring dial gauge reading reaches a maximum and then remains constant.

Table 12.1. Direct Shear Test on Sand. Void Ratio Calculation

Description of soil *Uniform sand* Sample No. *2*

Location *Argonaut Circle*

Tested by _____ Date _____

Item	Quantity
1. Specimen length, L (in.)	*2*
2. Specimen width, B (in.)	*2*
3. Specimen height, H (in.)	*1.31*
4. Mass of porcelain dish + dry sand (before use), W_1 (g)	*540.3*
5. Mass of porcelain dish + dry sand (after use), W_2 (g)	*397.2*
6. Dry unit weight of specimen, $\gamma_d\ (\text{lb/ft}^3) = \dfrac{W_1 - W_2\ (\text{g})}{LBH\ (\text{in.}^3)} \times 3.808$	*104.0*
7. Specific gravity of soil solids, G_s	*2.66*
8. Void ratio, $e = \dfrac{G_s \gamma_w}{\gamma_d} - 1$ *Note:* $\gamma_w = 62.4\ \text{lb/ft}^3$; γ_d is in lb/ft^3	*0.596*

Table 12.2. Direct Shear Test on Sand. Stress and Displacement Calculation

Description of soil *Uniform sand* Sample No. *2*

Location *Argonaut Circle*

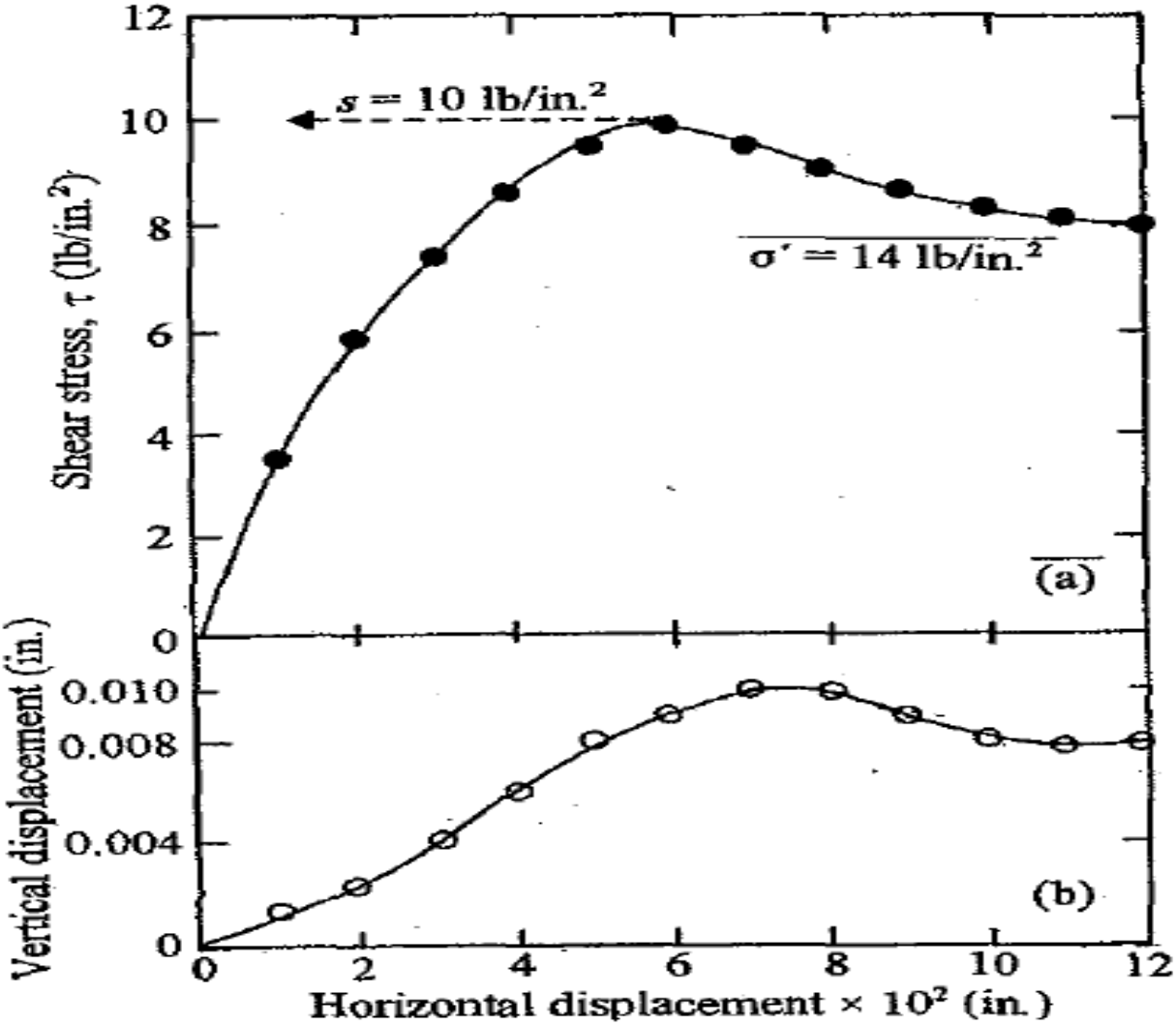
Normal load, N *56* lb Void ratio, e *0.596*

Tested by _____ Date _____

Normal stress, σ' (lb/in.^{2}) (1)	Horizontal displacement (in.) (2)	Vertical displacement (in.) (3)	No. of div. in proving ring dial gauge (4)	Proving ring calibration factor (lb/div.) (5)	Shear force, S (lb) (6)	Shear stress, τ (lb/in.^{2}) (7)
14	0	0	0	0.31	0	0
14	0.01	+0.001	45	0.31	13.95	3.49
14	0.02	+0.002	76	0.31	23.56	5.89
14	0.03	+0.004	95	0.31	29.76	7.44
14	0.04	+0.006	112	0.31	34.72	8.68
14	0.05	+0.008	124	0.31	38.44	9.61
14	0.06	+0.009	129	0.31	39.99	10.00
14	0.07	+0.010	125	0.31	38.75	9.69
14	0.08	+0.010	119	0.31	36.89	9.22
14	0.09	+0.009	114	0.31	35.34	8.84
14	0.10	+0.008	109	0.31	33.79	8.45
14	0.11	+0.008	108	0.31	33.48	8.37
14	0.12	+0.008	105	0.31	32.55	8.14

* Plus (+) sign means expansion

Plot of shear stress and vertical displacement vs. horizontal displacement for the direct shear test reported in Tables 12-1 and 12-2.



Typical values of the drained angle of friction, ϕ, for sands are given below:

Round-grained sand	ϕ (deg)	Angular-grained sand	ϕ (deg)
Loose	28–32	Loose	30–36
Medium	30–35	Medium	34–40
Dense	34–38	Dense	40–45

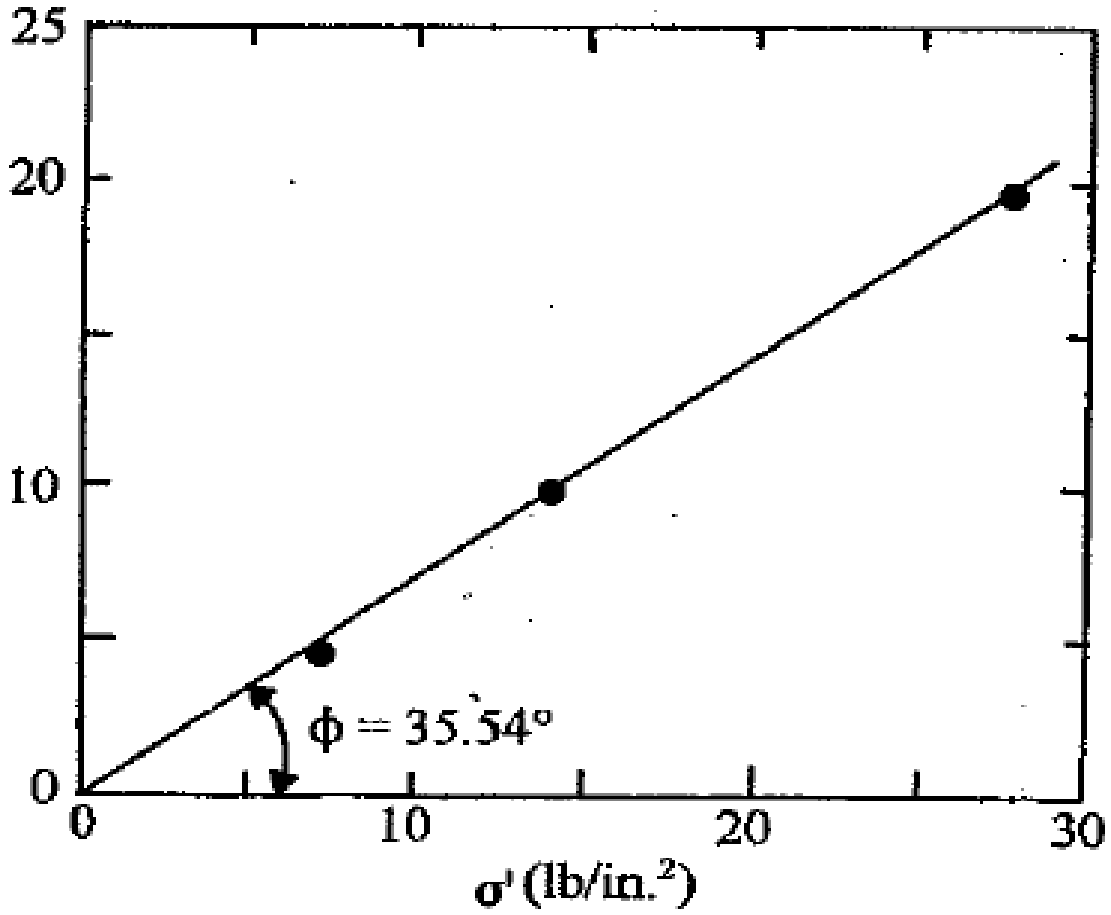


Fig. 12.5. Plot of *s* vs. σ' for the sand reported in Tables 12-1 and 12-2.

Note: The results for tests with σ' = 7 Ib/in.2 and 28 Ib/in.2 are not shown in Table 12-2.

13. PERFORM SOIL PENETRATION TEST

13.1. Identify main testing equipment with its accessories

13.2. Preparation of sample

13.3. Perform testing procedures

13.4. Record and analyze data

13.5. Prepare report

The “rule of thumb” is as follows: buried to the thumbnail means 1 MPa, to the first knuckle, 0.5 MPa, and to the second knuckle 0.25 MPa. Spring-loaded pocket penetrometers would add a bit more science. **Soil penetrability** is measured with a device called a *penetrometer* (Fig. 13.1 and 13.2). A penetrometer consists of a rod, or shaft, with a flat end, an enlarged cone tip, or an enlarged flat plate end. Penetrometers with a flat-end shaft are typically used to test soil surface strength or near-surface soil conditions. **An enlarged cone tip** is the most commonly used penetrometer for agricultural applications to investigate soil-profile conditions. Plate penetrometers are used to test the strength of exposed soil layers.

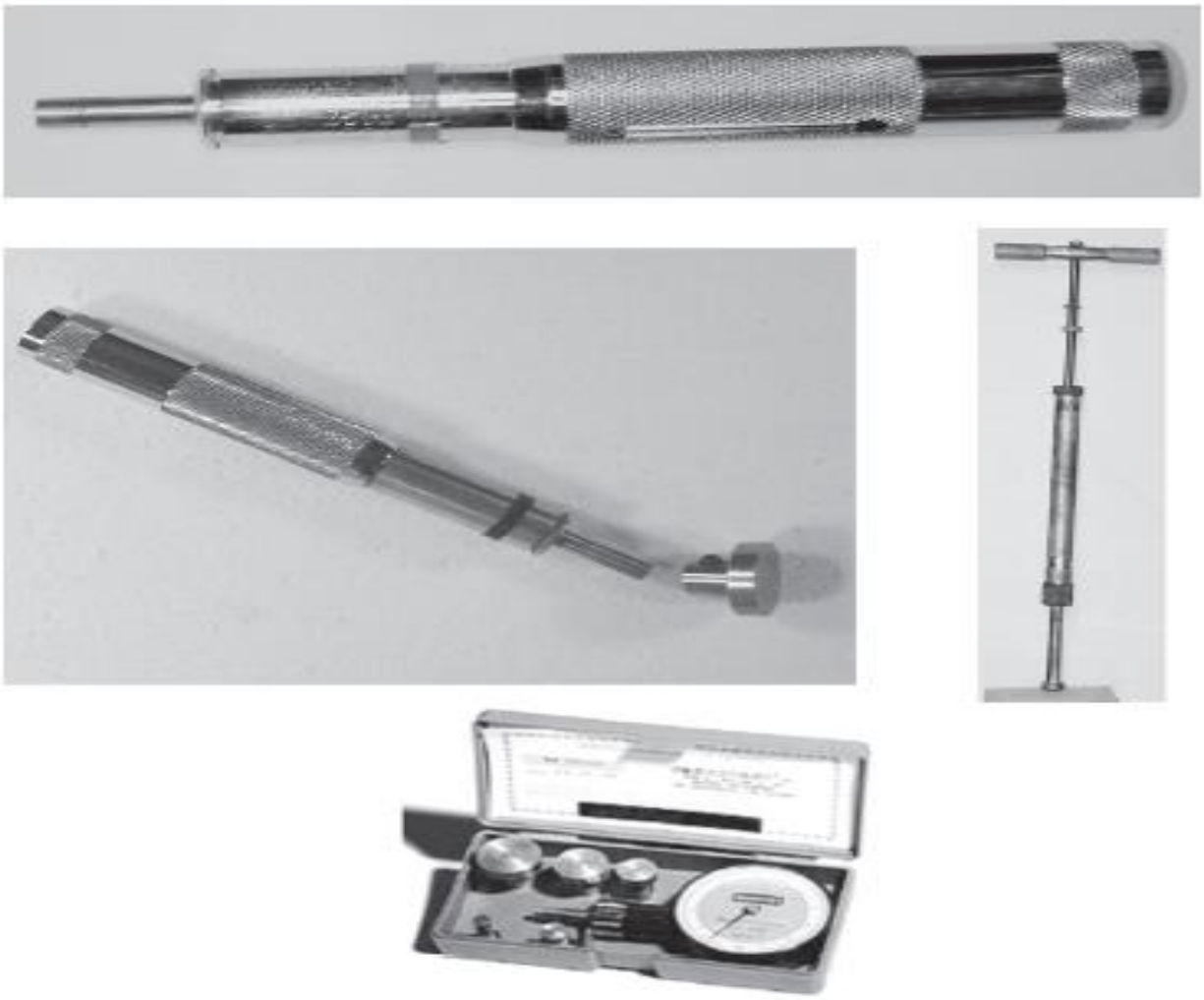


Fig. 13–1. Examples of pocket penetrometers

Penetrometer data are typically reported as the resistance to soil penetration in terms of penetration force per unit area, or resistance pressure. This resistance pressure has been described as the *cone index* (CI), expressed in pressure units of pascals, kilopascals, or megapascals (1 Pa = 1 N m−2).

Penetrometer technology has been advanced by civil engineers in search of methods to **survey subsoil conditions such as relative density, shear strength, bearing capacity, and settlement**. **For most agricultural purposes, penetrometer guidelines provided for civil engineering applications, for example, large-diameter drive-rods, do not readily apply.**

There are cone penetrometers that includes agricultural application (Perumpral, 1987). From its very early adoption, penetrometer use in agricultural research and investigations has traditionally involved the **measurement of penetration resistance to assess soil compaction for correlation with observed root growth, crop yields, and other soil physical properties related to agricultural crop production.**

Agricultural applications of soil penetrometers in general have not addressed the whole soil profile below the root zone. Civil engineering standards for penetrometers, on the other hand, are designed for penetrating to depths much greater than a meter. More recently, penetration resistance to depths below the root zone has been proposed for producing **three-dimensional maps of soil landscapes for assessing soil variability** (Fig. 13–3) (Grunwald et al., 2000, 2001).

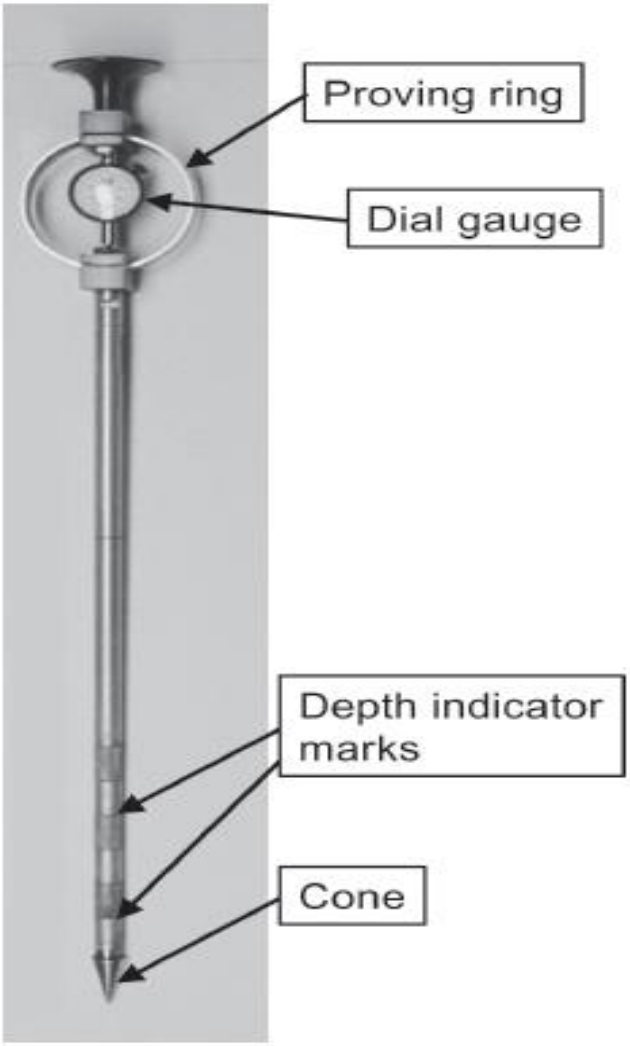


Fig.13.2. Commercially available version of the U.S. Army Corps of Engineers cone penetrometer

The objectives of a particular investigation, and to some extent soil conditions, including **maximum depth to be investigated**, will influence the **penetration method** to be used. Penetrometers and penetration methods can be **simple** or **highly mechanized** and **very sophisticated**.

There are several methods: both laboratory and field apparatus, ranging from the use of inexpensive devices to sophisticated digital-recording, power-driven penetrometers.

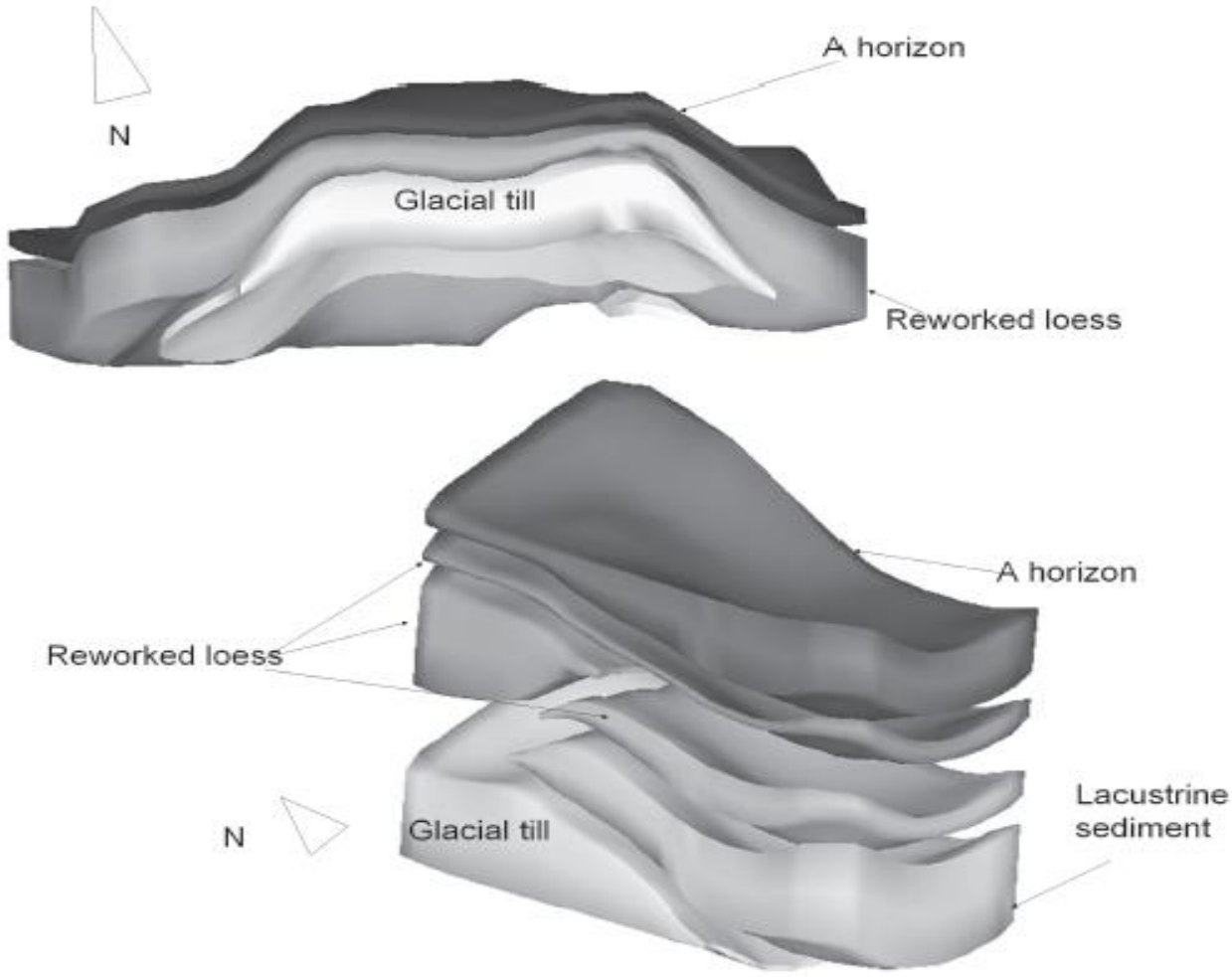


Fig.13.3. Three-dimensional maps of soil landscapes developed from penetration resistance measurements (Grunwald et al., 2000b).

Principles

Soil penetrometers are instruments used to investigate soil characteristics that cannot otherwise be observed without destructive invasion of the soil mass. The level of disturbance is minimal with penetrometers. There are two basic principles of soil penetrometer method, ***dynamic*** **and** ***static***.

Dynamic penetrometers are devices that are designed to be driven into the soil by the impact of a hammer or a falling weight. Dynamic penetrometers systems are mostly used for highway

pavement evaluations and few include modern, high-resolution automated data acquisition systems.

Static penetrometers are devices that are designed to be pushed into the soil at a slow, steady rate to avoid the inclusion of dynamic effects. Static penetrometers are typically a steel rod or shaft with one of several types of elements attached to the end. Because soil penetrometers interact with highly variable soil properties, they have been used for many different applications and conditions.

Soil Physical Factors Affecting Penetration

Soil factors influencing penetration resistance include **water content, bulk density, soil compressibility, soil strength parameters, soil structure, and clay and sand content,** among others. Numerous investigations have shown how water content, bulk density, pore size, and soil texture and structure influence soil strength–cone index (Taylor & Gardner, 1963; Taylor et al., 1966; Taylor & Bruce, 1968; Gerard, 1965; Byrd & Cassel, 1980). Vepraskas (1984) presented data showing that as water content increases, penetration resistance decreases. The impact of soil water content on soil penetration resistance is shown in Fig. 13–4. Lowery and Schuler (1994) and others have shown that **penetration resistance and bulk density** increased with **increasing levels of soil compaction**.

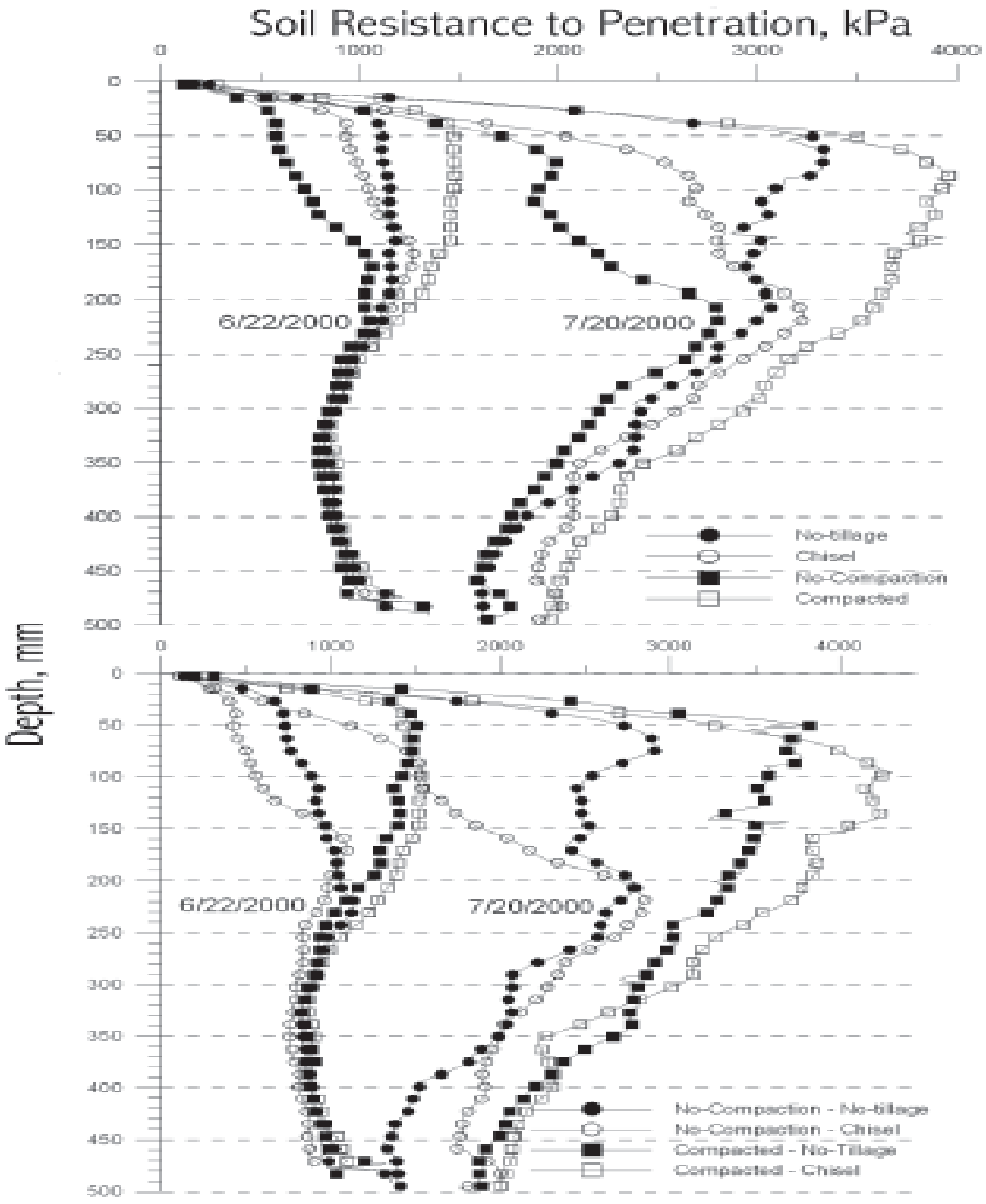


Fig. 13.4. Penetration-resistance profiles for a compacted silt-loam soil under relatively wet (0.36 m3 m−3 water content, 22 June 2000) and dry (0.27 m3m−3 water content, 20 July 2000) conditions (Reinert et al., 2001).

Penetrometer data are most usefully interpreted if the soil is at some reference water content such as field-water capacity, or if water-content and bulk density data are also collected for the same area. **Penetrability testing at in situ field-water capacity** is recommended because this water content is repeatable from season-to-season and from time-to-time within a given season. However, as noted previously, there are devices being developed that can measure water content and cone resistance simultaneously.

A. Pocket Penetrometer

The pocket penetrometer is a miniature hand-held penetrometer. It is hand operated and equipped with a calibrated spring. It was originally developed as an improvement on the rule-of-thumb technique for estimating the engineering consistency of cohesive, fine-grained soils (Fig. 13. 1).

The maximum deformation of the spring as the rod end is pushed into silty clay or clay soil has been correlated with the unconfined compressive strength of soil in tons per square foot or kilograms per square centimeter. The latter values are the scale on the piston barrel. Since correlations have been developed between root growth and point resistance, Bradford (1980) suggested converting the unconfined compressive-strength scale to read in units of total probe resistance by calibrating the penetrometer scale against a load cell or set of known weights. A flat-plate active element may be attached to the rod end for soft soils or soil-surface measurements, but the scale must be **converted to compensate for the changed base area**.

The pocket penetrometer can be operated on a range of soil samples of various sizes. It can be used to measure the surface resistance of agricultural fields, soil located in a sampling tube, an undisturbed soil block, soil in an open-pit excavation, or molded-soil specimens.

Similar to the cone penetrometer, the pocket penetrometer can be used for comparing relative strengths among similar soil types or in locating **hardpans, zones of compaction, or dense soil layers** of **excavated profiles**. However, the pocket penetrometer test is primarily supplemental and usually does not eliminate the need for more **precise field** or **laboratory testing**.

Method

Miniature Hand-Held Penetrometer

Direct-reading pocket penetrometers come in several different models and sizes and are commercially available (Fig.13–1). They weigh from 170 to 200 g and are from 160 to 180 mm in length with a diameter of 19.1 mm and a rod diameter of 6.4 mm.

Fig. 13–1. Examples of pocket penetrometers.

Commercial sources of penetrometers include the following: ELE/Soiltest, Internatioanl Inc., 2421 Highway 11, Pelham, AL, 35124; Ben Medows Co., 190 Etowah Industrial Court, Canton, GA, 30114; Hogentogler & Co., Inc., 9515 Gerwig Lane, Suite 109, Columbia, MD, 21046; Tecnotest, Via De Nicola, 31-41100, Modena, Italy.

Procedure

1) Move the sliding indicator to the lowest reading (zero) on the penetrometer scale.
2) Grip the handle and push the rod, with a steady rate of penetration, into the soil until the engraved line 6 mm from the blunt tip is flush with the surface of the soil.
3) Remove the penetrometer from the soil and read the scale.
4) Clean the rod and return the sliding indicator to its zero position.
5) Repeat the test several times in different areas to find an average value for unconfined compressive strength.

As is the case with any penetrometer, the readings can be converted to probe-resistance pressure by calibrating the penetrometer scale with a set of known weights.

- Calculate the pressure from the added weight (kilogram) per rodend area.
- Plot these calibration pressures against the corresponding sliding indicator readings.
- Convert subsequent data values to penetration resistance from the calibration plot.

B. Cone Penetrometer

A cone penetrometer was used by the U.S. Army Corps of Engineers at the Waterways Experiment Station for predicting the carrying capacity of cohesive, fine-grained soils for Army vehicles in off-road military operations. It has been used extensively in **agricultural soils research** to locate hardpans or traffic-induced compaction zones or areas, to correlate soil strength parameters with root growth and crop yield, to quantify the physical state of soil, and, recently, to map soils for these and other attributes.

The applied force required to push the cone penetrometer into a soil, divided by the area of the base of the cone, is an index of the shear resistance of the soil; this was called the ***cone index*** (Department of Army Staff, 1960).

C. Friction-Sleeve Cone Penetrometer

Cone penetrometers capable of measuring the rod- or sleeve-friction component of the total resistance are called friction-sleeve cone penetrometers or simply friction cone penetrometers (Fig. 13-5). Many types of friction cone penetrometers have been designed for engineering purposes (Sanglerat, 1972; Broms & Flodin, 1988). **Soil scientists and other agriculture-related researchers** have not widely adapted the use of friction-sleeve penetrometers to their studies.

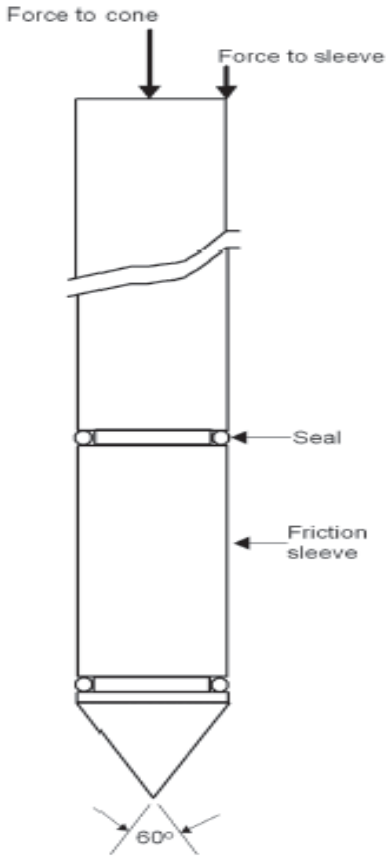


Fig. 13.5. Friction-sleeve cone penetrometer

Conversion Table (Rutajama S.S. & Overby C.,2000)

Example: to convert 10 miles to kilometres, find 1 mile in the 'length' table.
Numbers on that same horizontal are equal units to 1 mile, therefore 1 mile = 1.6094 km; 10 miles = 16.094 km.

Length

km	m	mm	mile	yard	ft	in	10^{-3} in
1	1000	10^{6}	0.6214	1094	3281	3.937×10^{4}	3.937×10^{7}
10^{-3}	1	1000	6.214×10^{-4}	1.0936	3.281	39.370	3.937×10^{4}
10^{-6}	10^{-3}	1	6.214×10^{-7}	1.094×10^{-3}	3.281×10^{-3}	3.937×10^{-2}	39.37
1.6094	1609.4	1.609×10^{6}	1	1760	5280	63360	6.336×10^{7}
9.144×10^{-4}	0.9144	914.41	5.682×10^{-4}	1	3	36	36000
3.048×10^{-4}	0.3048	304.8	1.894×10^{-4}	0.3333	1	12	12000
2.54×10^{-5}	0.0254	25.4	1.578×10^{-5}	2.778×10^{-2}	8.333×10^{-2}	1	1000
2.54×10^{-8}	2.54×10^{-5}	0.0254	1.578×10^{-8}	2.778×10^{-5}	8.333×10^{-5}	10^{-3}	1

Area

km^2	m^2	cm^2	mm^2	sq. mile	acre	yd^2	ft^2	in^2
1	10^{-6}	10^{10}	10^{12}	0.38612	247.11	1.196×10^{6}	1.076×10^{7}	1.550×10^{9}
10^{-6}	1	10^{4}	10^{6}	3.86×10^{-7}	2.471×10^{-4}	1.1960	10.764	1550
10^{-10}	10^{-4}	1	100	3.86×10^{-11}	2.471×10^{-8}	1.196×10^{-4}	1.076×10^{-3}	0.1550
10^{-12}	10^{-6}	10^{-2}	1	3.86×10^{-13}	2.47×10^{-10}	1.196×10^{-6}	1.076×10^{-5}	1.550×10^{-3}
2.590	2.59×10^{6}	2.59×10^{10}	2.59×10^{12}	1	639.96	3.097×10^{6}	2.788×10^{7}	4.01×10^{8}
4.047×10^{-3}	4047	4.047×10^{7}	4.047×10^{9}	1.563×10^{-3}	1	4840	43560	6.273×10^{6}
8.36×10^{-7}	0.8361	8361	8.36×10^{5}	3.228×10^{-7}	2.066×10^{-4}	1	9	1296
9.29×10^{-8}	9.29×10^{-2}	929	92900	3.587×10^{-8}	2.296×10^{-5}	0.1111	1	144
6.45×10^{-10}	6.45×10^{-4}	6.4516	645.16	2.491×10^{-10}	1.594×10^{-7}	7.716×10^{-4}	6.944×10^{-3}	1

Volume

m^3	dm^3 (litre)	cm^3 (ml)	yd^3	ft^3	in^3	UK gallon	US gallon
1	10^{-3}	10^6	1.3079	35.311	6102	219.97	264.17
10^{-3}	1	10^3	1.308×10^{-3}	3.531×10^{-2}	61.02	0.2200	0.2642
10^{-6}	10^{-3}	1	1.308×10^{-6}	3.531×10^{-5}	6.102×10^{-2}	2.199×10^{-4}	2.642×10^{-4}
0.7646	764.6	7.646×10^5	1	27	46650	168.19	201.99
2.832×10^{-2}	28.32	2.832×10^{-4}	3.704×10^{-2}	1	1728	6.229	7.481
1.639×10^{-5}	1.639×10^{-2}	16.387	2.144×10^{-5}	5.787×10^{-4}	1	3.605×10^{-3}	4.329×10^{-3}
4.546×10^{-3}	4.546	4.546×10^3	5.946×10^{-3}	0.1605	277.42	1	1.2008
3.785×10^{-3}	3.785	3.785×10^3	4.951×10^{-3}	0.1337	231	0.8327	1

Mass

Tonne (Mg)	kg	g	UK ton	US ton	cwt	lb	oz
1	1000	10^6	0.9842	1.1011	19.66	2.205×10^3	3.527×10^4
10^{-3}	1	1000	9.842×10^{-4}	1.101×10^{-3}	1.966×10^{-2}	2.2046	35.274
10^{-6}	10^{-3}	1	9.842×10^{-7}	1.101×10^{-6}	1.966×10^{-5}	2.204×10^{-3}	3.527×10^{-2}
1.016	1016	1.016×10^6	1	1.12	20	2240	35840
0.9081	908.1	9.081×10^5	0.8928	1	17.856	2000	32000
5.085×10^{-2}	50.85	5.085×10^4	0.05	0.0560	1	112	1792
4.536×10^{-4}	0.4536	453.6	4.46×10^{-4}	5×10^{-4}	8.92×10^{-3}	1	16
2.835×10^{-5}	2.835×10^{-2}	28.349	2.79×10^{-5}	3.125×10^{-5}	5.580×10^{-4}	6.25×10^{-2}	1

Density

Tonne/m^3 Mg/m^3 g/cm^3	kg/m^3	lb/in^3	UK ton/yd^3	US ton/yd^3	lb/ft^3
1	1000	0.03613	0.75247	0.8428	62.43
10^{-3}	1	3.613×10^{-5}	7.525×10^{-4}	8.428×10^{-4}	6.243×10^{-2}
27.680	27680	1	20.828	23.328	1.728×10^{3}
1.3289	1.328×10^{3}	4.801×10^{-2}	1	1.12	82.955
1.1865	1.186×10^{3}	4.287×10^{-2}	0.8929	1	74.074
1.602×10^{-2}	16.019	5.787×10^{-4}	1.205×10^{-2}	1.35×10^{-2}	1

Force and weight

MN	kN	N	kgf	tonf	lbf
1	1000	10^{6}	1.0196×10^{5}	100.4	2.248×10^{5}
10^{-3}	1	10^{3}	101.96	0.1004	224.82
10^{-6}	10^{-3}	1	0.10196	1.004×10^{-4}	0.2248
9.807×10^{-6}	9.807×10^{-3}	9.807	1	9.842×10^{-4}	2.2048
9.964×10^{-3}	9.964	9964	1016	1	2240
4.448×10^{-6}	4.448×10^{-3}	4.448	0.45455	4.464×10^{-4}	1

Pressure, stress and modulus of elasticity

MN/m^2 MPa	kN/m^2 kPa	kp kgf/cm^2	bar	atm	m H_2O	ft H_2O	mm Hg	Ton/ft^2	psi lbf/in^2	lbf/ft^2
1	1000	10.197	10	9.869	102.2	355.2	7500.6	9.320	145.04	20886
0.001	1	1.019×10^{-2}	0.0100	9.87×10^{-3}	0.1022	0.3352	7.5006	0.0093	0.14504	20.886
9.807×10^{-2}	98.07	1	0.9807	0.9678	10.017	32.866	735.56	0.9139	14.223	2048.1
0.100	100	1.0197	1	0.9869	10.215	33.515	750.06	0.9320	14.504	2088.6
0.1013	101.33	1.0332	1.0132	1	10.351	33.959	760.02	0.9444	14.696	2116.2
9.788×10^{-3}	9.7885	9.983×10^{-2}	9.789×10^{-2}	9.661×10^{-2}	1	3.2808	73.424	9.124×10^{-2}	1.4198	204.45
2.983×10^{-3}	2.9835	3.043×10^{-2}	2.984×10^{-2}	2.945×10^{-2}	0.3048	1	22.377	2.781×10^{-2}	0.43275	62.316
1.333×10^{-4}	0.1333	1.3595×10^{-3}	1.333×10^{-3}	1.315×10^{-3}	1.362×10^{-2}	4.469×10^{-2}	1	1.243×10^{-3}	1.934×10^{-2}	2.7846
0.1073	107.3	1.0942	1.0730	1.0589	10.960	35.960	804.78	1	15.562	2240
6.895×10^{-3}	6.895	7.031×10^{-2}	6.895×10^{-2}	6.805×10^{-2}	0.7043	2.3108	51.714	6.426×10^{-2}	1	144
4.788×10^{-5}	4.788×10^{-2}	4.883×10^{-4}	4.788×10^{-4}	4.725×10^{-4}	4.891×10^{-3}	1.605×10^{-2}	0.3591	4.464×10^{-4}	6.944×10^{-3}	1

Permeability

m/s	cm/s	m/year	Darcy	ft/yr	ft/day
1	100	3.156×10^{7}	1.04×10^{5}	1.035×10^{8}	2.835×10^{5}
0.01	1	3.156×10^{5}	1.04×10^{3}	1.035×10^{6}	2.834×10^{3}
3.169×10^{-8}	3.169×10^{-6}	1	3.28×10^{3}	3.281	8.982×10^{-3}
9.66×10^{-6}	9.66×10^{-4}	304	1	1000	2.74
9.658×10^{-9}	9.659×10^{-7}	0.3048	10^{-3}	1	2.738×10^{-3}
3.527×10^{-6}	3.527×10^{-4}	111.33	0.365	365.25	1

Densities (at 20 °C) g/cm³

Pure Water	0.99820	Kerosene (approx)	0.80
Sea Water	1.04	Paraffin wax (m.p. 52-52 °C)	0.912
Mercury	13.546	Microcrystalline wax (m.p. 60-63 °C)	0.915

Multiplying Prefixes

Prefix symbol	*Name*	*Multiplying factor*
G	giga	$1\,000\,000\,000 = 10^9$
M	mega	$1\,000\,000 = 10^6$
k	kilo	$1\,000 = 10^3$
h	hecto*	$100 = 10^2$
da	deca*	10
d	deci*	$10^{-1} = 0.1$
c	centi*	$10^{-2} = 0.01$
m	milli	$10^{-3} = 0.001$
µ	micro	$10^{-6} = 0.000\,001$
n	nano	$10^{-9} = 0.000\,000\,01$

** Not recommended in SI*

REFERENCES

Braja M. D.(2002).Soil Mechanics Laboratory Manual-Oxfor University Press. 6th Ed.

Birl L. & Morrison, J. J. E.(2002). Soil Penetrometers and Penetrability. In Campbell, G.S., Topp, G.C. & Dane, J.H., Eds. Methods of soil analysis. Part 4, Physical methods-Soil Science Society of America.pp.363-385

Day, P.R. 1965. Particle fractionation and particle size-analysis. In C.A. Black et al., Eds. Methods of Soil Analysis. Agronomy No. 9, Part 1. American Society of Agronomy, Madison, WI, pp. 545–567.

FAO. (n). Chapter 2 - Soil and Water. Retrieved from https://www.fao.org/3/r4082e/r4082e03.htm#:~:text=The%20soil%20moisture%20content%20indicates,of%20one%20metre%20of%20soil.

Flint., A.L. & Flint, L.E. 2022. Particle Density. In Campbell, G.S., Topp, G.C. & Dane, J.H., Eds. Methods of soil analysis. Part 4, Physical methods-Soil Science Society of America. pp.229-240

Gee, G.W. & Or, D. 2002. Particle-Size Analysis. In Campbell, G.S., Topp, G.C. & Dane, J.H., Eds. Methods of soil analysis. Part 4, Physical methods-Soil Science Society of America.pp.255-289

Gregorich, E.G. & Carter, M.R. 2007. Soil Sampling and Methods of Analysis, Second Edition-CRC Press

Grossman, R.B. & Reinsch, T.G.2002.Bulk Density and Linear Extensibility. In Campbell, G.S., Topp, G.C. & Dane, J.H., Eds. Methods of soil analysis. Part 4, Physical methods-Soil Science Society of America. pp. 201-225.

Hossain, s., Islam, A., Badhon, F. F., & Imtiaz, T. (2022). Chapter 1. Determination of Moisture Content. Mavs Open Press. Retrieved from https://uta.pressbooks.pub/soilmechanics/chapter/chapter-1/

Weil, R.R., & Brady, N. C. 2016. The Nature and Properties of Soils, Global Edition-Pearson Education Limited.

Rutajama S.S. & Overby C. (2000). Laboratory Testing manual 2000. Central Materials Laboratory (CML), The United Republic of Tanzania/Ministry of Works. ISBN 9987-8891-3-1

https://civilengineer.co.in/wp-content/uploads/2017/03/IS-2720-PART-28-1974-INDIAN-STANDARD-METHODS-OF-TEST-FOR-SOILS-DETERMINATION-OF-DRY-DENSITY-OF-SOILS-IN-PLACEBY-THE-SAND-REPLACEMENT-METHOD.pdf

Proctor compaction test: https://en.wikipedia.org/wiki/Proctor_compaction_test

VISUAL RESOURCES

Soil Moisture Content Test

- **Experiment 1_Determination of Moisture content | Soil Mechanics Laboratory Tests: https://www.youtube.com/watch?v=1Rb1kW_mWmA**
- **Moisture Content of Soil : https://www.youtube.com/watch?v=fobs0J9kK5I**

Bulk density test

- **Soil Bulk Density test: https://www.youtube.com/watch?v=bf9qTZQGNHs**
- **Soil bulk density determination by core method: https://www.youtube.com/watch?v=qcm1WTGlric**
- **Determination of Bulk Density from Soil by Clod Coating Method (Samarth Agriculture College D. Raja): https://www.youtube.com/watch?v=4r5_TtIunuI**

Sieve analysis test

- **Standard Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C136): https://www.youtube.com/watch?v=3Xqq1cxhD-s**
- **Sieve Analysis of Fine Aggregates | Fineness Modulus of Fine Aggregates | Particle Size Distribution: https://www.youtube.com/watch?v=rq5XTRRBU8g**
- **Particle Size Distribution Curve ,Sieve analysis test: https://www.youtube.com/watch?v=FI8DzS-63_M**

Specific gravity test

- **02 Specific Gravity of Soil Solids ASTM D854: https://www.youtube.com/watch?v=BwWUndnL__c**
- **Specific Gravity of Soil Solids by Water Pycnometer 1: https://www.youtube.com/watch?v=TzdjpZ-Inq8**
- **Measure density with a pycnometer: https://www.youtube.com/watch?v=5w3IKnovlng**

Hydrometer test

- **Soil Mechanics Laboratory Tests: Hydrometer: https://www.youtube.com/watch?v=78sKJKsaUvY**
- **Soil Texture Analysis: Hydrometer Method: https://www.youtube.com/watch?v=mySb2wMOYmQ**
- **Grain Size Analysis and Hydrometer: https://www.youtube.com/watch?v=w-70w5cMFSs**

Atterberg limits test

- **Atterberg Limit Tests (LL and PL): https://www.youtube.com/watch?v=EcXJ961qjGA**

- **Liquid Limit - Casagrande Method:**
  https://www.youtube.com/watch?v=OvrqyFYhhxQ
- **Plasticity and Plastic State & Plastic Limit of Soil and its Determination:**
  https://www.youtube.com/watch?v=c6Xcamy9CzU
- **A-Line Curve //U-Line Curve //Plasticity Chart//Classification of soil:**
  https://www.youtube.com/watch?v=KjFPgM6OgKM

Swelling test

- **Clay soils swelling on wetting at Cranfield University:**
  https://www.youtube.com/watch?v=ACpuYED9WkU
- **Swelling pressure test on soil { part 1} | black cotton soil |:**
  https://www.youtube.com/watch?v=JvHnDKB1BiU
- **Shrink Swell Tests: https://www.youtube.com/watch?v=r-oHZU37H3o**
- **Soil Shrink and Swell: https://www.youtube.com/watch?v=rDSaDwQ5Kbw**

Standard Proctor Test

- **Proctor 1: https://www.youtube.com/watch?v=Un4Qw3-3H54**
- **Proctor Compaction Test: https://www.youtube.com/watch?v=tqHNK67IgG4**
- **CEEN 341 - Lab 4 - Soil Compaction and Proctor Test:**
  https://www.youtube.com/watch?v=HQ5Fx4qhwZg
- **Proctor 1: https://www.youtube.com/watch?v=Un4Qw3-3H54**
- **Proctor Compaction Test: https://www.youtube.com/watch?v=tqHNK67IgG4**
- **CEEN 341 - Lab 4 - Soil Compaction and Proctor Test:**
  https://www.youtube.com/watch?v=HQ5Fx4qhwZg
- **AASHTO T 99 - A - Proctor Test:**
  https://www.youtube.com/watch?v=EELrzvSrfjM
- **Chapter 6 Soil Compaction - Example 1 (Standard Proctor Test):**
  https://www.youtube.com/watch?v=v_1tQfxBowQ

- **Standard/Modified Proctor Test Calculations | Geotech with Naqeeb: https://www.youtube.com/watch?v=YixF_Bw9VWU**
- **Standard Proctor Density: https://www.youtube.com/watch?v=6ZvmvPwlDSc**

Modified Proctor Test

- **Modified Proctor Compaction Test: https://www.youtube.com/watch?v=ZGCzJYQ1fGU**
- **MODIFIED PROCTOR TEST ASTM D1557: https://www.youtube.com/watch?v=kO5qkzRGek0**
- **Modified Proctor Test (AASHTO T-180 and ASTM D1557) in Urdu/Hindi with English Subtitles: https://www.youtube.com/watch?v=GswVYbaj55A**
- **Heavy Compaction Test (Modified Proctor Test), Soil Testing, IS 2720 part 8: https://www.youtube.com/watch?v=Tci8zxPQ4Fs**
- **Difference Between Standard Proctor Test and Modified Proctor Test: https://www.youtube.com/watch?v=ktjA2hG1vFg**
- **Standard and Modified Proctor: https://www.youtube.com/watch?v=ltmhN4SMueg**

Sand Replacement Test

- **Field Density Test by Sand Replacement Method: https://www.youtube.com/watch?v=WvTFgJBUum4**
- **Unit Weight Determination - Sand Replacement Method: https://www.youtube.com/watch?v=f5Z2l9RFumo**
- **Field Density Test Using Sand Replacement Method: https://www.youtube.com/watch?v=0YmesLUrREA**
- **Determination of dry density by sand replacement method: https://www.youtube.com/watch?v=1CWmqscWJ7M**
- **Soil Compaction Test | Sand Replacement method | LIVE: https://www.youtube.com/watch?v=l77ElSrEvd0**

- **Sand Replacement Test Live On site | Soil Test by Sand Replacement:** **https://www.youtube.com/watch?v=VhRaSsWCu0E**
- **Determination of Dry Density of Soil by Sand Replacement Method:** **https://www.youtube.com/watch?v=C10dklH12W0**
- **FIELD DRY DENSITY BY SAND REPLACEMENT METHOD:** **https://www.youtube.com/watch?v=pyyvTOExjrE**
- **In-Situ Density by Sand Replacement Method + Excel Sheet | Geotech with Naqeeb:** **https://www.youtube.com/watch?v=Y5Y1DgAajcc**
- **Soil Compaction test by sand Replacement method:** **https://www.youtube.com/watch?v=L8QYarkT_KA**
- **FDT Test by Sand Replacement Method - ASTM D1556/AASTHO T191:** **https://www.youtube.com/watch?v=m7oFjvXlfWQ**

Permeability Test

- **Constant Head Permeability Test:** **https://www.youtube.com/watch?v=B3gvVN29u8E**
- **Constant Head Permeability Test:** **https://www.youtube.com/watch?v=Eur_qpTKzrA**
- **Constant Head Permeability Test | Procedure and Data Analysis:** **https://www.youtube.com/watch?v=TaPjIvCsfFI**
- **How to Perform Constant Head Permeability Test in Lab | Geotech with Naqeeb:** **https://www.youtube.com/watch?v=BdhkP8l1ixU**
- **Falling Head - Variable Head Permeability Method:** **https://www.youtube.com/watch?v=SS7o6sKw2Xc**
- **Constant Head Permeability Test | Lecture 7 | Geotechnical Engineering:** **https://www.youtube.com/watch?v=X0zBKiONgXA**
- **Soil mechanics-3.5 | constant head permeability test | Shubham sarathe:** **https://www.youtube.com/watch?v=dtFUGkUlS5o**

Direct Shear Test

- **Direct Shear Test of Soil: https://www.youtube.com/watch?v=wSDPO7GhXXE**
- **Direct Shear test - geotechnical engineering - soil mechanics: https://www.youtube.com/watch?v=-sK01ZEd6ao**
- **Shear Strength of Soils - Direct Shear Test: https://www.youtube.com/watch?v=h6slcjiCgQ4**
- **Direct Shear Test Calculations | English | Geotech with Naqeeb: https://www.youtube.com/watch?v=qBjxRDNavnE**
- **LBYCVG2 Direct Shear Test Procedural Video: https://www.youtube.com/watch?v=vL6-2ytvMBQ**

Soil penetration test

- **How to conduct SPT | Standard Penetration Test | Soil Exploration Technique| Site Investigation: https://www.youtube.com/watch?v=DjWDOqQjsyQ**
- **Standard Penetration Test of Soil: https://www.youtube.com/watch?v=TSgiOpPTiJU**
- **Cone Penetration Test-2001: https://www.youtube.com/watch?v=EdKv4pZadX8**
- **Operation of the Dynamic Cone Penetrometer: https://www.youtube.com/watch?v=PUvjeYAU3Oc**

Determination of various soil physical parameters

- **Bulk Density, Water Content, Void Ratio, Porosity, Degree of Saturation: https://www.youtube.com/watch?v=MoAOCSsDXPM**
- **Soil bulk density & unit weight: https://www.youtube.com/watch?v=RXRbxvs0q8M**
- **Dry unit weight, Moisture unit weight and Degree of saturation: https://www.youtube.com/watch?v=qOZ8pLWeFas**

THANK YOU!

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