SUBJECT- SOIL AND FOUNDATION ENGINEERING

DEPARTMENT- CIVIL ENGG.

LEARNING OUTCOMES

- After undergoing the subject, students will be able to:
- Identify and classify various types of soils
- Select particular type of foundation according to loading of structure
- Determine shear strength of soil
- Carry out compaction of soils as per density
- Calculate bearing capacity of soil
- Calculate liquid limit and plastic limit of soil
- Calculate maximum dry density of soil and optimum moisture content of soil
- Perform various tests of the soil

1. Introduction:

Importance of soil studies in Civil Engineering

Soil has covered the surface of the earth like a blanket. As a result of this, it connects the rocks inside and lives on the earth systematically. It works like a medium for plants and animals for their existence. Soil is created from rocks. Different natural factors like earthquake, stream of water, wind, ice and organic materials cause the rocks to break. Big rocks turn into pretty pebbles. Pebbles turn into sand and finally we get clay from the sand. Sand, clay both and different organic materials create soil.

Here are some important reasons why soils are important to civil engineers:

- On the most basic level, infrastructure designed by civil engineers (e.g. roads, buildings, dams, bridges) is supported by earthen materials. Unless it floats on water or is shot into space, it most likely is supported by rock or soil.

- Civil engineers provide site design, which involves grading. Grading is basically moving soil around and can be very expensive. Ideally the engineer can make a site “balance” meaning there is no net import or export of soil, which is often even more expensive than moving soil around within a site.

- Some civil engineering infrastructure is actually constructed of soil, including earthen dams, levees and embankments.

- Civil infrastructure may be designed using a variety of materials: steel, concrete, wood, masonry, etc. The owner, engineer and architect have some freedom to choose materials based on a balance of performance, cost, and aesthetics. Soil fundamentally differs from other materials in that, due to financial constraints, the on-site soil is not chosen but is dictated by the site’s geology.

  Soil texture: depends on the proportion of sand, silt or clay it contains. For example, a soil described as a silt loam contains mainly silt but also will contain some sand and clay in smaller proportions. A close look at soil will clearly indicate that the makeup of the mineral portion is quite variable. Soil particles vary in size, shape and chemical composition. Some are so small they can be seen only with a microscope. Texture has good effect on management and productivity of soil. Sandy soils are of open character usually loose and friable. Sand facilitates drainage and aeration. Clay particles play a very important role in soil fertility. They are generally very fertile soils, in respect of plant nutrient content. Loam and Silt loam soils are highly desirable for cultivation.

Textural triangle: It is used to determine the soil textural name after the percentages of sand, silt, and clay are determined from a laboratory analysis. Since the soil's textural classification includes only mineral particles and those of less than 2mm diameter, the sand plus silt plus clay percentages equal 100 percent. The point at which the projections cross or intersect will identify the class name. Sometimes, the intersecting point exactly falls on the line between the textural classes.

Soil Profile: Vertical section of the matured soil shows several layers, with distinct characteristic physical and chemical properties, which are known as horizons or soil horizons. These layers or horizons from top to bottom together constitute soil profile. Each horizon has a specific thickness, structure, colour, texture, porosity, etc. The soil profile can be broadly divided into five horizons. From the surface to downwards, these may be named as O-horizon, A-horizon, B-horizon, C-horizon and R-horizon. The A and B zones together form the true soil or Solum.

Composition of Soil: The chief components of soil are Inorganic matter 40%, Organic matter 10%, Soil water 25% and Soil air 25% (approx.).

Soil Organism: These include the Protozoans, mites, nematodes, rotifiers, blue green or green, soil bacteria, fungi arthropods like mite, myriapods, spiders, insect larvae and collembola.

North Indian Soil: The Northern India plains are mostly formed of deep alluvial soil. The topsoil varies in texture from sand to clay, the greater part being light loam, porous in texture, easily worked and naturally fertile. The great depth of the alluvium keeps down the soil temperature. This soil is supposed to be naturally very rich in the plant-nourishing food, and is consequently very good for our Rabi and kharif crops. However, the most important advantage from the level character of the plains is that they facilitate a more even distribution of rainfall in Northern India, having no barriers to check the flow of the monsoon currents.

Soils of South India: The Southern India peninsular earth surface is made up of hills and river valleys. Hilly tracts are naturally unsuitable for cultivation. Some highlands are very hot. The river valleys, however, possess important attributes that make them very suitable for agriculture. The black cotton areas are included in them. In the rains, some of these tracts become sticky, in the dry weather hard and crumby, holding the moisture at lower levels. Thicker, dark-colored, and more fertile valleys are rich in chemical properties favorable for plant life.

Soil distribution: Soil is a valuable resource of India. Much of the Indian agriculture depends upon the extent and qualities of soil. Weathering prepares loose materials on the surface of the Earth and mixed with decayed organic matters it forms soil. The nature of soil in a place is largely influenced by such factors as climate, natural vegetation and rocks. The various types of soil found in India include.

Soil classification

Soil classification is the arrangement of soils into different groups such that the soils in a particular group have similar behavior. As there are a wide variety of soils covering earth, it is desirable to systematize or classify the soils into broad groups of similar behavior. Soils, in general, may be classified as cohesion less and cohesive or as coarse-grained and fine-grained. These terms, however, are too general and include a wide range. Natural soil deposits are never homogeneous in character; wide variations in properties and behavior are commonly observed. Through classification of soils one can obtain an appropriate, but fairly accurate, idea of the average properties of the soil group or a soil type, which is of great convenience in any routine type of soil. A soil is classified according to index properties, such as particle size and plasticity characteristics.

Preliminary Classification of Soil

Familiarity with common soil types is necessary for an understanding of the fundamentals of soil behavior. In this approach, soils are described by designation such as Boulders, Gravel, Sand, Silt, Clay, Rock flour, Peat, China Clay, Fill, Bentonite, Black Cotton soil, Boulder Clay, Caliche, Hardpan, Laterite, Loam, Loess, Marl, Moorum, Topsoil and Varved Clay. The following list gives the names and salient features of different types of soil, arranged in alphabetical order.

- Bentonite is a type of clay with a very high percentage of clay mineral – montmorillonite. It is

highly plastic clay

- Boulders are the rock fragments of large size, more than 300mm in size.
- Calcareous soil contains a large quantity of calcium carbonate. Such soils effervesce when tested

with weak hydrochloric acid.

- Caliche soil which contains gravel, sand and silt. The particles are cemented by calcium carbonate.
- Clay consists of microscopic and sub-microscopic particles derived from the chemical

decomposition of rocks. It contains a large quantity of clay mineral.

- Cobbles are large size particles in the range of 80mm to 300mm.
- Diatomaceous earth Diatoms are minute unicellular marine organisms. Diatomaceous earth is a

fine, light grey, soft sedimentary deposit of the silicious remains of skeletons of diatoms.

- Dispersive clays Such soils erode if exposed to low-velocity water. Susceptibility to dispersion

depends upon the cations in the soil pore water.

- Dune sands wind-transported soils. These are composed of relatively uniform particles of fine to

medium sand.

- Fills manmade deposits of soil and waste-materials are called fills. These are the soil embankments

raised above the ground surface.

- Gravel coarse-grained soil. The particle size ranges from 4.75mm to 80mm. It is cohesion-less

material.

- Humus dark brown, organic amorphous earth of the topsoil. It consists of partly decomposed

vegetal matter. It is not suitable for engineering works.

- Loess windblown deposit of silt. It is generally of uniform gradation. It consists of quartz and

feldspar particles, cemented with calcium carbonate or iron oxide.

- Marl is stiff, marine calcareous clay of greenish colour.
- Moorum the word moorum is derived from a Tamil word, meaning powdered rock.
- Muck it denotes a mixture of fine soil particles and highly decomposed organic matter.
- Peat organic soil having fibrous aggregates of macroscopic and microscopic particles.
- Sand is a coarse-grained soil, having particle size between 0.075 mm to 4.75 mm. The particles are visible to naked eye.
- Silt is a fine-grained soil; the particles are not visible to naked eyes. Organic silt contains an admixture of organic matter. It is a plastic soil and is cohesive.
- Till soil formed by unstratified deposit resulting from melting of a glacier.

- Top soils are the surface soils that support plants. They contain a large quantity of organic matter and are not suitable for foundations.
- Tuff is a fine-grained soil composed of very small particles ejected from volcanoes during its explosion and deposited by wind or water.
- Tundra is a mat of peat and shrubby vegetation that covers clayey subsoil in arctic regions.
- Varved clays: These are sedimentary deposits consisting of alternate thin layers of silt and clay.

2-Soil Classification And Identification Systems

In general soils may be classified by the following systems

 Particle size classification

 Textural classification

 Unified Soil Classification

 Indian Soil Classification

 Indian Standard Classification

As per Indian Soil Classification (IS: 1498-1970) the soil is divided into six groups.

(a) Boulders, particle size greater than 300 mm

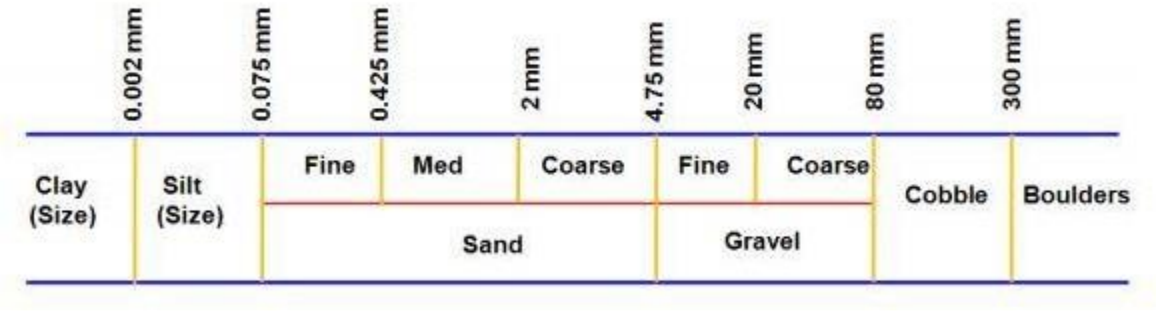
(b) Cobble, particle size between 80 to 300 mm

(c) Gravel, particle size between 4.75 to 80 mm

(d) Sand, particle size between 0.075 to 4.75 mm

(e) Silt (size), particle size between 0.002 to 0.075 mm

(f) Clay (size), particle size smaller than 0.002 mm (2 Um)



The Indian Council of Agricultural Research (ICAR) divided the Indian soils into eight major groups.

I. Alluvial Soils

II. Black Soils

III. Red Soils

IV. Laterite Soils

V. Forest and Mountain Soils

VI. Arid and Desert Soils

VII. Saline and Alkaline Soils

VIII. Peaty and Marshy Soils

Alluvial Soils These are formed by the deposition of sediments by rivers. They are rich in humus and very fertile. They are found in Great Northern plain, lower valleys of Narmada and Tapti and Northern Gujarat. These soils are renewed every year. Alluvial soils are by far the largest and the most important soil group of India. Covering about 15 lakh sq km or about 45.6 per cent of the total land area of the country, these soils contribute the largest share of our agricultural wealth and support the bulk of India's population . Materials deposited by rivers, winds, glaciers and sea waves are called alluvium and soils made up of alluvium are alluvial soils. The old alluviums are clayey and sticky, have a darker color, contain nodules of lime concretions and are found to lie on slightly elevated lands. The new alluviums are lighter in color and occur in the deltas and the flood plains

Black Soils The black soils are also called regur (from the Telugu word Reguda) and black cotton soils because cotton is the most important crop grown on these soils. Several theories have been put forward regarding the origin of this group of soils but most pedologist believe that these soils have been formed due to the solidification of lava spread over large areas during volcanic activity in the Deccan Plateau, thousands of years ago. Geographically, black soils are spread over 5.46 lakh sq km (i.e. 16.6 per cent of the total geographical area of the country). The black colour of these soils has been attributed by some scientists to the presence of a small proportion of titaniferous magnetite or even to iron and black constituents of the parent rock (Fig. 4). A typical black soil is highly argillaceous with a large clay factor, 62 per cent or more. It also contains 10 per cent of alumina, 9-10 per cent of iron oxide and 6-8 percent of lime and magnesium carbonates. Potash is variable (less than 0.5 per cent) and phosphates, nitrogen and humus are low.

Red Soil This comprehensive term designates the largest soil group of India, comprising several minor types. Most of the red soils have come into existence due to weathering of ancient crystalline and metamorphic rocks. The colour of these soils is generally red, often grading into brown, chocolate, yellow, grey or even black. The red colour is due more to the wide diffusion rather than to high percentage of iron content. The red soils occupy a vast area of about 3.5 lakh sq km which is about 10.6 per cent of the total geographical area of the country. In the north the red soil area extends in large parts of south Bihar; the Birbhum and Bankura districts of West Bengal; Mirzapur, Jhansi, Banda and Hamirpur districts of Uttar Pradesh; Aravallis and the eastern half of Rajasthan, parts of Assam, Nagaland, Manipur, Mizoram, Tripura and Meghalaya.

Laterite Soils The word 'laterite' (from Latin letter meaning brick) was first applied by Buchanan in 1810 to a clayey rock, hardening on exposure, observed in Malabar. But many authors agree with Fermor's restriction of this term to soils formed as to 90-100 per cent of iron, aluminium, titanium and manganese oxides. Laterite is a kind of clayey rock or soil formed under high temperature and high rainfall. Laterite soils are found in South Maharashtra, the Western Ghats in Kerala and Karnataka, at places on the Eastern Ghat, in some parts of Assam, Tamil Nadu, Karnataka, and in western West Bengal (particularly in Birbhum district). These soils are generally infertile.

Forest and Mountain Soils are mainly found on the hill slopes covered by forests. These soils occupy about 2.85 lakh sq km which is about 8.67 per cent of the total land area of India. The formation of these soils is mainly governed by the characteristic deposition of organic matter derived from forest growth these soils are heterogeneous in nature and their character changes with parent rocks, ground-configuration and climate. In the Himalayan region, such soils are mainly found in valley basins, depressions, and less steeply inclined slopes (Fig. 5). Generally, it is the north facing slopes which support soil cover; the southern slopes being too precipitous and exposed to denudation to be covered with soil. The forest soils are very rich in humus but are deficient in potash, phosphorus and lime. This soil distributed around Karnataka, Tamil Nadu and Kerala and wheat, maize, barley and temperate fruits in Jammu and Kashmir, Himachal Pradesh and Uttaranchal.

Desert soil The soils of Rajasthan, Haryana and the South Punjab are sandy. In the absence of sufficient wash by rain water soils have become saline and rather unfit for cultivation. In spite of that cultivation can be carried on with the help of modern irrigation. Indus and the Aravallis, covering an area of 1.42 lakh sq km (or 4.32% of total area). Some of these soils contain high percentages of soluble salts, are alkaline with varying degree of calcium carbonate and are poor in organic matter. Over large parts, the calcium content increases downwards and in certain areas the subsoil has ten times calcium as compared to that of the top soil. However, in large areas of desert soils, only the drought resistant and salt tolerant crops such as barley, rape, cotton, wheat, millets, maize and pulses are grown.

Saline and Alkaline Soils are found in Andhra Pradesh and Karnataka. In the drier parts of Bihar, Uttar Pradesh, Haryana, Punjab, Rajasthan and Maharashtra, there are salt-impregnated or alkaline soils occupying 68,000 sq km of area. These soils are liable to saline and alkaline efflorescence and are known by different names such as reh, kallar, usar, thur, rakar, karl and chopan. There are many undecomposed rock and mineral fragments which on weathering liberate sodium, magnesium and calcium salts and sulphurous acid (Fig. 6). The accumulation of these salts makes the soil infertile and renders it unfit for agriculture. It has been estimated that about 1.25 million hectares of land in Uttar Pradesh and 1.21 million hectares in Punjab has been affected by Usar. In Gujarat, the area round the Gulf of Khambhat is affected by the sea tides carrying saltladen deposits.

Peaty and Marshy Soils Originate in humid regions as a result of accumulation of large amounts of organic matter in the soils. These soils contain considerable amount of soluble salts and 10-40 per cent of organic matter. Soils belonging to this group are found in Kottayam and Alappuzha districts of Kerala where it is called Kari. Marshy soils with a high proportion of vegetable matter also occur in the coastal areas of Orissa and Tamil Nadu, Sunderbans of West Bengal, in Bihar and Almora district of Uttaranchal. The peaty soils are black, heavy and highly acidic. Most of the peaty soils are under water during the rainy season but as soon the rains cease, they are put under paddy cultivation.

Sandy: The sand group includes all soils in which the sand separates make up at least 70% and the clay separate 15% or less of the material by weight. The properties of such soils are therefore characteristically those of sand in contrast to the stickier nature of clays. Two specific textural classes are recognized in this group sandy and loamy sand.

Silt: The silt group includes soils with at least 80% silt and 12% or less clay. Naturally the properties of this group are dominated by those of silt. Only one textural class - Silt is included in this group.

Clays: To be designated clay a soi1 must contain at least 35% of the clay separate and in most cases not less than 40%. In such soils the characteristics of the clay separates are distinctly dominant, and the class names are clay, sandy clay and silty clay. Sandy clays may contain more sand than clay. Likewise, the silt content of silty clays usually exceeds clay fraction.

Loams: The loam group, which contains many subdivisions, is a more complicated soil textural class. An ideal loam may be defined as a mixture of sand, silt and day particles that exhibits the properties of those separates in about equal proportions. Loam soils do not exhibit dominant physical properties of sand, silt or clay. Loam does not contain equal percentage of sand, silt and clay. However, exhibit approximately equal properties of sand, silt and clay.

3. Physical Properties of Soils:

Here is a list of seven physical properties of soil: 1. Soil Texture 2. Soil Structure 3. Density of Soil 4. Pore Space 5. Soil Consistence 6. Soil Colour.

1. Soil Texture:

The relative size of soil particles is expressed by the term texture; more specially the texture is the relative proportions of different size, groups or separates.

Classification of Soil Separates:

There are a number of system for classification of soil separates namely United States Department of Agriculture (USDA) System. International system, British system and The European system. Out of these systems, the International System is commonly followed in India.

The soil separates are classified into Sand, Silt and Clay according to their size. According to the size of soil particles, the texture may be coarse and fine. The average size of the soil particles increases when the proportion of sand in the soil is increased and the resultant soil becomes coarser in texture. On the other hand, the average size of the soil particles decreases when the proportion of clay in the soil is increased and the resultant soil becomes finer in texture.

Soil Textural Classes:

Textural classification of soil means classification of soils on the basis of their texture into different groups or classes such as Sand, Sandy-loam and Silty loam. The broad and fundamental groups of soil textural classes are recognized as Sands, Silt and Clays.

2. Soil Structure:

The arrangement of particles in the soil mass is called soil structure. Soil structure also be defined as aggregates into which soil breaks up.

Structure is strictly a field term descriptive of the gross, overall aggregation and arrangement of primary soil separates. The primary soil particles such as sand, silt and clay usually occur grouped together in the form of aggregates. Natural aggregates are called peds whereas artificial aggregates are called clods. Clods are formed due to disturbance of the field by ploughing or digging. The words fragmentation and concretions are often used in connection with the structure of soil.

Fragment is a broken peds whereas when salts dissolved in percolating water precipitate, it results in the formation of concretions. The soil conditions and characteristics such as water movement, heat transfer, aeration, bulk density and porosity will be much more influenced by structure. In fact, the important physical changes imposed by the farmer is ploughing, cultivating, draining, liming and manuring his land are structural rather than textural.

3. Density of Soil:

Density represent the mass (or weight) of a unit volume of soil. One means of expressing soil weight is in the terms of density of the soil particles making up the soil.

The soil density is expressed in two manners as follows:

i. Particle Density:

The density of soil solid is known as the particle density of soil. The weight per unit volume of the solid portion of soil is called particle density. It is concerned with solid particles only. The weight of the soil solid has often been expressed in terms of the specific gravity. Specific gravity is the ratio of the weight of soil solid to the weight of an equal volume of water. In metric system, particle density is usually expressed in terms of grams per cubic centimeter.

Thus, if one cubic centimeter of soil solids weighs 2.6 grams, the particle density is 2.6 grams per cubic centimeter. Generally the particle density of normal soil usually vary between the narrow limits of 2.60 and 2.75 grams per cubic centimeter. The particle density will be higher if large amount of heavy minerals such as magnetite, limonite and hematite are present in the soil. The particle density decreases with the increase of organic matter in the soil. Particle density is also termed as 'True density'. (T)

ii. Bulk Density:

Bulk density is defined as the mass (weight) of soil solid per unit volume of dry soil. It is also called as apparent (A) density. This volume includes both solid and pore space (voids).

The relationship between apparent density (A), True density (T) and the pore space (P) is as follows –

$$P = [(T - A)/T] \times 100$$

It is expressed in percentage.

In this case, the total soil space (space occupied by solid and pore-spaces combined) is taken into consideration. Bulk density is determined by the quantity of pore-space as well as soil solids. The bulk density of a soil is always smaller than its particle density. In metric system (c.g.s), it is expressed in gram per cubic centimeter (gm/c.c.). Bulk density of sand is about 1.6 grams per cubic centrimeter.

Calculation of Density of Soil:

Factors Affecting Bulk Density:

(i) Soil Texture:

Bulk density normally decreases as minor soils become finer in texture. The sandy soils have high bulk density as the particles of that soil lie in close contact with each other. The low organic matter content of such soil increases the bulk density further. The particles of finer textured surface soil such as clays, clay loams and silt loams do not lie close together and hence have more pore space and well granulated.

Granulation encourages a fluffy, porous condition which results in low bulk density values. But sand and sandy loam show high bulk density.

(ii) Soil Structure:

Soil structure affects bulk density by influencing the Porosity of soil. The crumb soil structure shows low bulks density than that of platy soil structure.

(iii) Depth of the Soil:

Bulk density varies with the depth of soil. Surface soils usually have low bulk density. Because surface soils contain more humus than sub-soil. On the other hand, the underlying lower horizon of soil has higher bulk density due to lower content of organic matter, less aggregation and root penetration and a compaction caused by the weight of overlying layers of the soil.

(iv) Humus:

When organic matter decomposed to form humus, some organic compounds are formed. This organic compound binds the primary soil particles such as sand, silt and clay to form the soil aggregates. Pore space occurs within and between soils aggregate. As a result, the weight of unit volume of soil decreases. When the percentage of humus increases, the bulk density decreases. The addition of farm manures in huge quantities lower the bulk density value.

(v) Nature of the Crop:

The bulk density of grass land decreases as the grass roots bind the soil particles to form soil aggregates and humus is formed due to decomposition of grass roots and other materials. The intensive cultivation increases the bulk density value.

4. Pore Space:

The pore space of a soil is that portion which is occupied by air and water.

The pore space is not occupied by soil particles. The amount of pore space depends on the arrangement of solid particles. The total porosity of sands and compact sub-soil is low as the soil particles of such soil lies in close together. On the other hand, medium texture soil rich in organic matter has high pore space per unit volume of soil. Pore space is necessary for retention of soil moisture, aeration of plant root and for proper drainage.

Kinds of Pore Space:

The size and shapes of pores and pore spaces vary considerably.

In general, pore spaces are of two types as follows:

(i) Macropores or Non-Capillary Pores:

Macropores are those pores through which water and air movement can take place easily. Macropore do not hold much water under normal condition. Light soil such as sands and sandy loam soil has macropore or non-capillary pore. Macropore is necessary for proper drainage and aeration of plant root. The average diameter of macropore is greater than 60 microns.

(ii) Micropores or Capillary Pores:

Micropores are those pore through which movement of air is difficult and movement of water is restricted largely to slow the capillary movement. Heavy soil such as clay, and clayey loam soil have micropore or capillary pore. Micropore is necessary for the retention of moisture which is necessary for the plant. The average diameter of micropore is less than 30 microns.

Porosity refers to the percentage of soil volume occupied by pore space. The existence of approximately equal amount macro and micropores or suitable for the growth of the plant which influence aeration drainage. Permeability and water retention favourably.

The derivation of the formula used to calculate the percentage of total pore space of soil is as follows –

Example:

Factors influencing total pore space of a soil are as follows:

(i) Soil Texture:

In sandy soil, total pore space is less as the pore of such soil is quite large. On the other hand, in clayey soil, the total pore space and micropores are high, because clay particles unite to form soil aggregates within which micropore space occurs.

(ii) Soil Structure:

A soil having compound structure has greater pore space than the single grain soil. Granular or crumb structure has more pore space than plate like structure.

(iii) Organic Matter:

Soil rich in organic matter having good granulation and aggregation has more total pore space and micropore space.

(iv) Depth of Soil:

The pore space of the surface soil is usually much more than that of the sub-soil, because plant roots and organic matter occurs more in surface soil than in sub•soil.

(v) Soil Organism:

Soil organism such as earthworm and insect increases the macropore in the soil.

(vi) Nature of Crops and Cultivation:

Intensive Cropping tends to lower the total pore space in comparison to virgin soil. Continuous cropping and cultivation reduces the total pore space and the size of the macropores as the organic matter content of a soil decreases.

5. Soil Consistence:

Soil consistence is defined as a term to designate the manifestation of physical forces of cohesion and adhesion acting within the various level of moisture content. Soil consistence is defined, another way, as the physical condition of the soil at various moisture content as evidenced by the behaviour of that soil toward mechanical stresses or manipulation.

The two forces responsible for soil consistence are cohesion and adhesion which act within the soil. Adhesion is the attraction between soil particles and water molecules. Cohesion is the attraction between soil particles or between water molecules.

The manifestation as stated in the definition includes as follows:

(i) Behaviour of the soil towards gravity, pressure, thrust and pull.

(ii) Tendency of the soil mass to adhere to foreign bodies.

(iii) Tactile quality of soil on rubbing between the fingers.

Soil Tillage:

Tillage is the physical manipulation of soil with tools and implements to result in good tilth for better germination of seeds and subsequent growth of crops. Tillage is tilling of land for bringing about conditions that are favourable for the cultivation of crops. Tilth implies to the physical condition of soil in its relation to plant growth. Tilth is brought out by tillage. Tillage is the primary function of cultivation and it is a laborious and expensive cultural practice.

Tillage helps to replace natural vegetation with useful crop and is necessary to provide a favourable edaphic environment for establishment, growth and yield of crop plants. Tillage helps to improve the physical condition of soil, control of weeds, insect-pests and diseases and also bring the nutrient available to plant. The cultivation is not possible without tillage operation. The crop production depends on good tillage operations.

The word manure has originated from the French word “Manoevrer”, which refers to ‘Work with soil’, that is why the word tillage and manure which synonyms as it clear by the statement of Jethro Jull (1700 BC) “Tillage is manure”. There must be sufficient moisture in the soil for good tillage.

Tillage is quite impossible in fully dry soil. On the other hand, tillage in wet land results in puddling of soil. Tillage in wet soil having sufficient water brings puddling condition of soil which is favourable for cultivation of transplanted paddy, onion etc. Tillage practices must be carried out at optimum soil moisture content to maintain a good soil structure.

Soil Compaction:

Soil compaction is the process of increasing dry bulk density of soil, reducing the pore space by expulsion of air through applied pressure on a soil body. Under very high pressure, the soil particles may themselves be compressed but only slightly. Compaction due to the machines used for tillage of land, inter-cultivation, harvesting and threshing of crops has adverse effects on the normal growth of plants due to reduced aeration and increased bulk density of the soil. Compaction of the soil may also be due to grazing of animals, human activities in the field and intense rainfall as well as irrigation.

6. Soil Colour:

The colour of soil is probably the first soil property for the human perception and it is one of its obvious property. The colour of a soil is an indication of the nature of an individual soil. The colour of soils is due to the colour of their constituents. The colour of a soil is inherited from its parent rock material. As for example, red soil developed from red sand stone and sand developed from quartz.

Black coloured soils are rich in organic matter and therefore fertile. Red coloured soils are rich in ferric oxide, highly weathered and of poor fertility. When superphosphate is applied in red soil (pH 5.3-6.0); the phosphorus is converted to iron and aluminium phosphate. The phenomenon is called ‘Phosphate fixation’, soil colour influences greatly the soil temperature. The dark coloured soil absorbs heat more readily than light coloured soils.

Factors for Soil Colour:

There are many factors which are responsible for soil colour as follows:

(i) Organic Matter:

Organic matter is black in colour. A soil, which contains high organic matter and if it is alkaline, will be black or brown in colour. Colour indicates, approximately, the organic matter content of the soil.

(ii) Free Oxides of Iron:

A soil which contains high percentage of free oxides of iron ($2Fe_2O_3 . 3H_2O$) will be yellow red in colour as the ferric oxide is red in colour. When the oxides of iron are dehydrated, the colour of the soil will be yellow. On the other hand, the colour of the soil will be red when the oxides of iron are highly hydrated.

(iii) Texture of the Soil:

The intensity of colour of the soil depends on the texture of soil. The fine textured soils are dark in colour and more fertile than coarse texture soil (i.e. sandy soil). Because, in fine textured soil (i.e. clay soil), the total surface area will be more than sandy soil. The effect of soil colour can be seen by the fact that black vertisols in dry state are heated stronger than all other soils.

(iv) Moisture Content of Soil:

The wet soils are darker in colour than dry soil. This is due to the interaction of organic matter and water. The water logging condition has also influence on the colour development of soil. Soils which are imperfectly and poorly drained are nearly always mottle with various shades of grey, brown and yellow, specially within the zone of fluctuation of water table.

Soils are generally described by its colour. Such as black, red, yellow, etc.

The three variables which combine to give colour as follows:

(i) Hue – It refers to the dominates spectral colour (rainbow, such as red, yellow, etc., It is related to dominant wavelength of light.

(ii) Value – It refers to the relative lightness of colour and it is a function of total amount of light.

(iii) Chroma – It refers to the relative purity of the spectral colour.

Significance of Soil Colour:

Soil colour indicates the nature and properties of soil.

By knowing the colour, one can get some idea about the type of soil as follows:

(i) Dark in Colour:

It indicates that the soil contains high percentage of organic matter. Black coloured soil is richer in clay. As a result, the water holding, nutrient retention capacity of this soil will be more and soil will be granular in structure and therefore will be more fertile than lighter colour soil. Dark colour soil absorbs much temperature than light colour soil. For this, dark colour soil is warmer.

(ii) Red or Yellow in Colour:

It indicates that the soil contains high percentage of oxides of iron ($2Fe_2O_3. 3H_2O$) and this soil is low in water holding capacity, nutrient retention capacity. Super phosphate, if applied in this soil, will be fixed as iron phosphate, which is not available to plant. Rock phosphate, bone-meal etc. are the safe fertilizer for this soil.

7. Soil Temperature:

The temperature of soil is very important, because plant growth as well as the chemical and biological weathering are greatly influenced by the soil temperature.

Sources of Soil Temperature:

(i) Solar Radiation:

The main source of heat is the sun. The temperature of the soil is primarily dependent upon the amount of radiant energy received from the sun. The sun rays reach the earth after they pass through the atmosphere and warms the surface of the soil on which they fall. A moist or cloudy atmosphere prevent much of the sun's radiation from reaching the earth. A part of soil temperature is lost to the air by radiation.

(ii) Conduction:

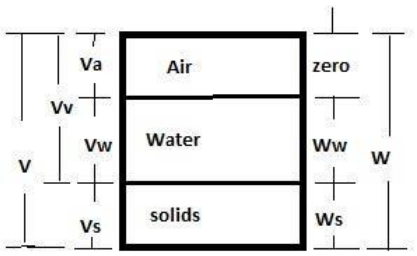
The heat is absorbed from solar radiation by surface soil and is conducted down the depth of the soil. The interior of the earth is very hot, the conduction of this heat to the soil is very slow.

(iii) Biological and Chemical Reaction:

In a soil, various biological and chemical reaction occurs. As a result, some amount of heat is liberated in the soil due to biological and chemical reaction.

Three Phase Diagram:

A soil mass consist of the solid particles and the voids in between them. These voids are filled with air or/and water. So there is a three phase system, but when the voids are only filled with air, or only filled with water then soil becomes a two phase system. Three phase system can be represented with a diagram as shown below. When the voids are only filled with water, it is said to be saturated.



Total volume of the soil mass, V = (Va+Vw) +Vs

Where, V = Total Volume

Va= Volume of air mass

Vw = Volume of water mass

Vs = Volume of solids

But, Va+Vw = Vv

So,

V = Vv+ Vs

Where Vv= Total volume of voids.

Void Ratio(e):

Void ratio is the ratio of the volume of the voids to the volume of the solid in the soil.

It is denoted by 'e'.

e= Vv/Vs = n/(1-n)

Porosity (n):

Porosity is defined as the ratio of the volume of the total voids to the total volume of the soil mass.

It is denoted by 'n'

So $n = V_v/V = e/(1+e)$

Degree of Saturation(S_r):

Degree of saturation is defined as the ratio of the volume of the water to the total volume of the voids present in the soil mass.

$S_r = V_w/V_v$, For fully saturated soil mass $V_w=V_v$, So $S_r=1$

For fully dry soil mass, $V_w= 0$, So $S_r=0$

Water content(w):

It is the ratio of the weight of the water to the weight of the solids in the given soil mass. Weight of solids can be found by weighing the soil mass after drying it completely.

$w = W_w/W_s$

Air Content(n_a):

It is the ratio of the volume of air(V_a) to the total volume of the voids(V).

$n_a= V_a/V*100$

4. Flow of Water Through Soils:

Flow of water in the soil is complex because of various states and direction in which water flows and because of the forces that cause it to flow. Water flows downwards due to gravity. It moves in small pores due to capillarity because of adhesive and cohesive forces. Because of heat, it vapourises and diffuses through soil air.

The rate at which gravitational water moves through soil is determined by the size and continuity of pores. In coarse textured soils, it moves rapidly through large pores. It moves less rapidly through fine textured soils because of resistance to flow in micro pores. Movement is retarded by clay pan or plough pan. A sandy layer temporarily halts percolation, but once water penetrates such layer, it continues to move downwards.

Irrigation water moves as a front from saturated soil layer to an unsaturated layer and movement of the front is unsteady. Movement of water is more uniform in moist soil than in dry soil. Heat vapourises the soil- water, which diffuses through soil air. As soil- water is evaporated from the soil surface, capillary water rises and replaces part of the evaporated water.

Darcy’s Law:

shows a horizontal column of soil, through which a steady flow of water is occurring from left to right, from an upper reservoir to a lower one, in each of which the water level is maintained constant.

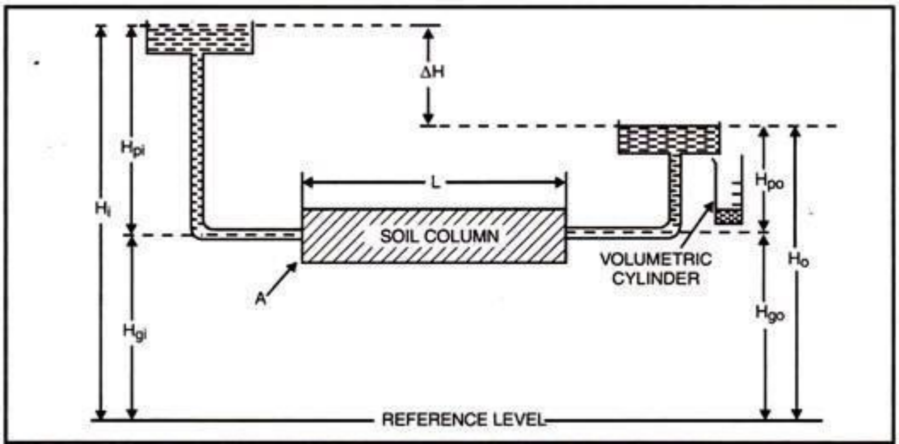


Fig 4.40 Flow in horizontal saturated column.

Flow in Horizontal Saturated Column

Experience shows that the discharge rate Q, being the volume V, flowing through the column per unit time, is directly proportional to the cross-sectional area and to the hydraulic head drop ΔH, and inversely proportional to the length of the column L ;

$$Q = \frac{V}{t} \alpha \frac{A\Delta H}{L}$$

Hydraulic head drop across the system is usually determined by measuring the head at the inflow boundary (Hi) and at the outflow boundary (Ho), relative to some reference level.

Difference between the two heads is ΔH:

$\Delta H = Hi - Ho$

Obviously, no flow occurs in the absence of a hydraulic head difference, i.e., when $\Delta H = 0$.

The head drop per unit distance in the direction of flow (ΔH/L) is the hydraulic gradient, which is in fact the driving force. Simply, hydraulic gradient is the rate of change of hydraulic head with distance. The specific discharge rate, Q/A (i.e. the volume of water flowing through a cross-sectional area A per time t) is called flux density (simply flux) and indicated by q.

Thus, the flux is proportional to the hydraulic gradient:

$$q = \frac{Q}{A} = \frac{V}{At} \alpha \frac{\Delta H}{L}$$

The proportionality factor K is, generally, designated as the hydraulic conductivity.

$$q = K \frac{\Delta H}{L}$$

This equation is known as Darcy's law. In other words, hydraulic conductivity is the proportionality factor K in Darcy's law. The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient.

Where flow is unsteady or the soil is non-uniform; the hydraulic head may not decrease linearly along the direction of the flow. Where the hydraulic head gradient or the conductivity is variable, we must consider the localised gradient, flux and conductivity values rather than overall values for the soil system as a whole. A more generalised expression of Darcy's law is, therefore, in differential form.

A more exact and generalised expression of Darcy's law for saturated porous media into a three-dimensional macroscopic system is:

q = -K□H

Stated verbally, this law indicates that the flow of a liquid through a porous medium is in the direction of, and at a rate proportional to, the driving force (hydraulic gradient) acting on the liquid and also proportional to the property of the conducting medium (conductivity) to transmit the liquid.

In one-dimensional system, the above equation takes the form:

$$q = -K\frac{dH}{dx}$$

Hydraulic conductivity is one of the hydraulic properties of the soil. These properties determine the behavior of the soil fluid within the soil system under specified conditions. More specifically, the hydraulic conductivity determines the ability of the soil fluid to flow through the soil matrix system under a specified hydraulic gradient; the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition.

Hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, the type of soil fluid and the relative amount of soil fluid (saturation) present in the soil matrix. Important properties relevant to the solid matrix of the soil include pore size distribution, pore shape, tortuosity, specific surface and porosity. In relation to the soil fluid, the important properties include fluid density and fluid viscosity.

Limitations of Darcy' Law:

1. It applies only when the flow is laminar and where soil-water interactions do not result in a change of permeability with a change in gradient

2. Since the saturated flow depends on size of pores, management practices like tillage may affect the porosity and hence the flow and hydraulic conductivity of the soil

3. Pore spaces may be entrapped by gases, especially when the soil is under submergence for long time

4. In coarse sands and gravels, hydraulic gradients in excess of unity may result in non-laminar flow conditions where Darcy' law may not always be applicable.

Measurement of Saturated Hydraulic Conductivity:

The saturated hydraulic conductivity of water in soil (or the intrinsic permeability of the soil) can be measured by both field and laboratory experiments. Either way, the experimental measurement of K (or k) consists in determining the numerical value for the coefficient in Darcy's equation

Laboratory Methods:

In the laboratory, the value of K can be determined by several different instruments and methods such as the permeameter, pressure chamber and consolidometer. A common feature of all these methods is that a soil sample is placed in a small cylindrical receptacle representing a one-dimensional soil configuration through which the circulating liquid is forced to flow.

Depending on the flow pattern imposed through the soil sample, the laboratory methods for measuring hydraulic conductivity are classified as either a constant head test with a steady-state flow regimen or a falling head test with an unsteady state flow regimen.

Constant head methods are primarily used in samples of soil materials with an estimated K above 1.0 x 102 m yr-1, which corresponds to coarse-grained soils such as clean sands and gravels. Falling head methods, on the other hand, are used in soil samples with estimated values of K below 1.0 x 102 m yr-1.

Constant Head method:

The constant head test with the permeameter is one of the most commonly used methods for determining the saturated hydraulic conductivity of coarse grained soils in the laboratory. The test operates in accordance with the direct application of Darcy's law to a soil liquid configuration representing a one-dimensional, steady flow of a percolating liquid through a saturated column of soil from a uniform cross- sectional area.

In this method, a cylindrical soil sample of cross-sectional area A and length L is placed between two porous plates that do not provide any extra hydraulic resistance to the flow (Fig 4.41).

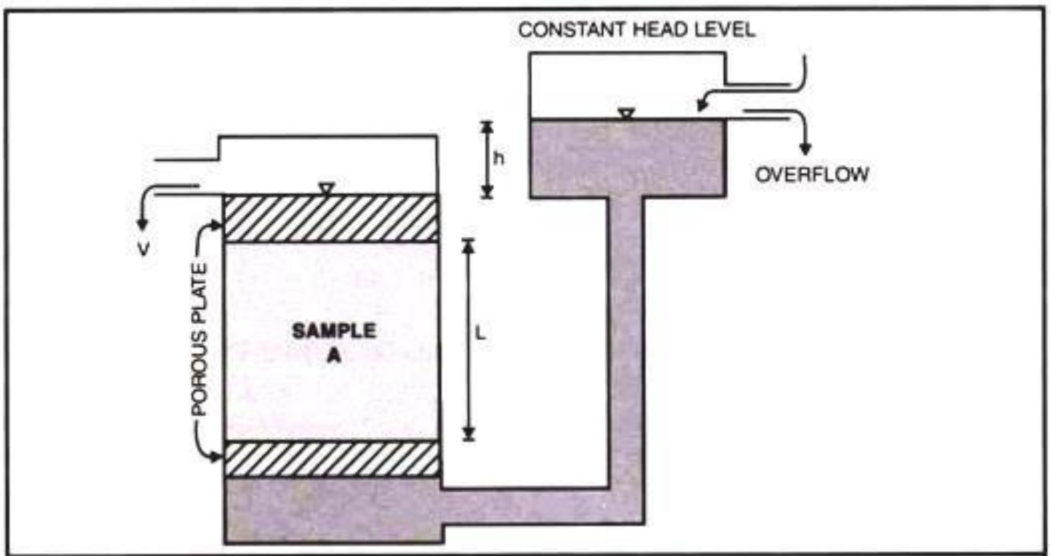


Fig 4.41 Constant head method.

A constant head difference, H2 – H1, is then applied across the test sample.

By measuring the volume V of the test fluid that flows through the system during time t, the saturated hydraulic conductivity K of the soil can be determined directly from Darcy's equation:

$$K = \frac{VL}{[At(H_2 - H_1)]} \qquad \text{or } K = \frac{VL}{Ath}$$

Falling Head methods:

The falling head test with the permeameter is primarily used for determining the K (or k) value of fine grained soils in the laboratory. Like the constant head method, the falling head test also operates in accordance with direct application of Darcy's law to a one-dimensional, saturated column of soil with a uniform cross sectional area.

The falling head method differs from the constant head method in that the liquid that percolates through the saturated column is kept at an unsteady state flow regimen in which both the head and the discharged volume vary during the test (Fig 4.42).

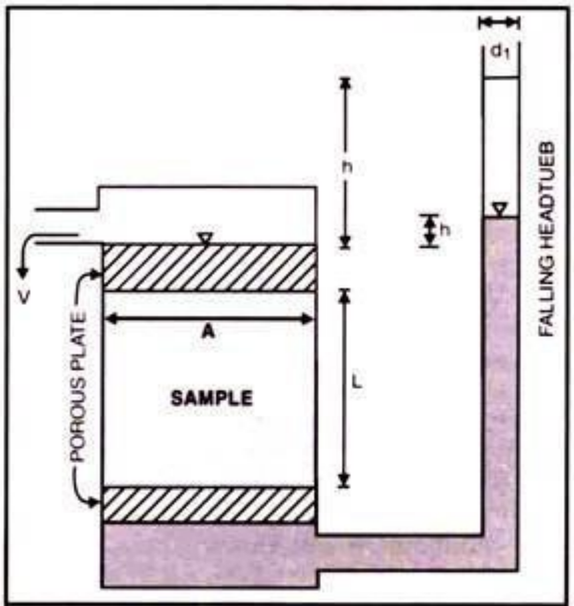


Fig 4.42 Falling-head method.

In the falling head test method, a cylindrical soil sample of cross-sectional area A and length L is placed between two highly conductive plates. The soil sample column is connected to a standpipe of cross-sectional area a, in which the percolating fluid is introduced into the system.

Thus, by measuring the change in head in the standpipe from H1 to H2 during a specified interval of time t, the saturated hydraulic conductivity can be determined as follows:

$$K = \left(\frac{aL}{At}\right) ln\left(\frac{H_1}{H_2}\right)$$

The lower limit of K, which can be measured in a falling head permeameter, is about 1 x 10-2 m yr-1. This value corresponds approximately to the lower limit of conductivity of silts and coarse clays.

A common problem encountered in using either the constant head or falling head test with the permeameter is related to the degree of saturation achieved within the soil samples during the test. Air bubbles are usually trapped within the pore space and although they tend to disappear slowly by dissolving into the de-aerated water, their presence in the system may alter the measured results.

Therefore, after using these instruments to measure K, it is always recommended that the degree of saturation of the sample be verified by measuring the sample's volumetric water content and comparing the result with the total porosity calculated from the particle density.

Ranges of hydraulic conductivity for different soils are given in Table 4.7:

TABLE 4.7: Ranges of hydraulic conductivity for different soils.

Material	Intrinsic Permeability (arcy)	Hydraulic Conductivity (cm s^{-1})
Clay	$10^{-6} - 10^{-3}$	$10^{-9} - 10^{-6}$
Silt, sandy silts, clayey sands, fine sands	$10^{-3} - 10^{-1}$	$10^{-6} - 10^{-4}$
Silty sands, fine sands	$10^{-2} - 1$	$10^{-5} - 10^{-3}$
Well sorted sands, glacial outwash	$1 - 10^{2}$	$10^{-3} - 10^{-1}$
Well sorted gravel	$10 - 10^{3}$	$10^{-2} - 1$

Field Methods:

Many in situ methods have been developed for determining the saturated hydraulic conductivity of soils within a groundwater formation under unconfined and confined conditions.

Auger-hole method or Hooghoudt's method:

Auger-hole method is the field procedure most commonly used for in situ determination of saturated hydraulic conductivity of soils. In its simplest form, it consists of the preparation of a cavity partially penetrating the aquifer, with minimal disturbance of the soil. After preparation of the cavity, water in the hole is allowed to equilibrate with the groundwater; that is, the level in the hole becomes coincident with the water table level. Actual test starts by removing the entire amount of water from the hole and by measuring the rate of rise of water level within the cavity

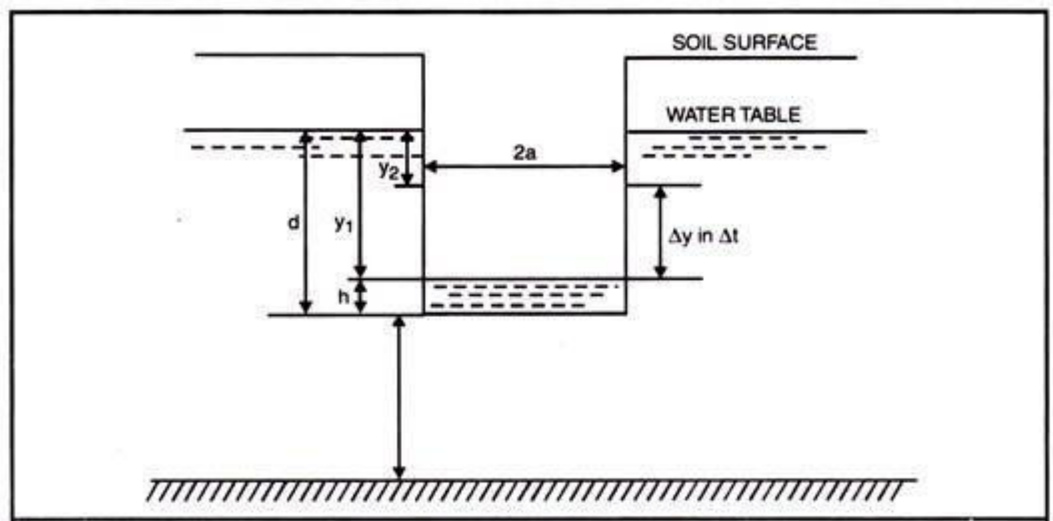


Fig 4.43 Auger-hole method.

Because of the three-dimensional aspect of the flow pattern of the water near the cavity, there is no simple equation for accurately determining the conductivity. Numerous available semi-empirical expressions, however, can be used for approximating the saturated hydraulic conductivity for different soil configurations.

The formula to use in the case where the auger-hole does not terminate on a impermeable layer is:

$$K = \left[\left(\frac{2.3\ aS}{(2d + a)t}\right)\right] log_{10}\left(\frac{y_1}{y_2}\right)$$

When the auger-hole terminates on an impermeable layer:

$$K = \left[\left(\frac{2.3\ aS}{2dt}\right)\right] log_{10}\left(\frac{y_1}{y_2}\right)$$

In both equations, S is given by the relation:

S = 0.19 a x d

where, y1 = Water level in the auger-hole (cm) below groundwater level at the start of measurement

y2 = Water level in the auger-hole (cm) at the end of measurement

Δt = Rise of water level in the auger-hole between t2 and t1

2R = Auger-hole diameter

d = Depth of auger-hole (cm) below groundware level

S = Depth of impermeable layer (cm) below auger-hole.

Hoodghoudt determined that the constant S is dependent of a, d and s expressed with the above equation.

Advantages:

1. Use the soil-water for the measurement

2. Sample used for the measurement is large

3. Measurement is not greatly affected by the presence of rocks, and or root holes adjacent to the hole

4. Measurement reflects the horizontal component of Ksat.

Auger-hole method is applicable to an unconfined aquifer with homogeneous soil properties and a shallow water table. In its simplest form, this method provides an estimate of the average horizontal component of the saturated hydraulic conductivity of the soil within the aquifer.

Enhanced variations of the method have been developed to account for layered soils and for the determination of either horizontal or vertical components of saturated hydraulic conductivity.

Results obtained by the auger-hole method are not reliable for cases in which:

1. The water table is above the soil surface

2. Artesian conditions exist

3. Soil structure is extensively layered

4. Occurrence of highly permeable small strata.

Piezometer Method:

Kirkham (1946) proposed a method in which a tube is inserted into the auger hole below a water table with or without a cavity at the end of the tube.

Pipes or tubes are driven in to the soil below the water table either with or without a cavity at the end. Soil is removed from the pipe or tube. Water table is allowed to get its level and then water is pumped out. Rise of water level in the pump is recorded with time (Fig 4.44).

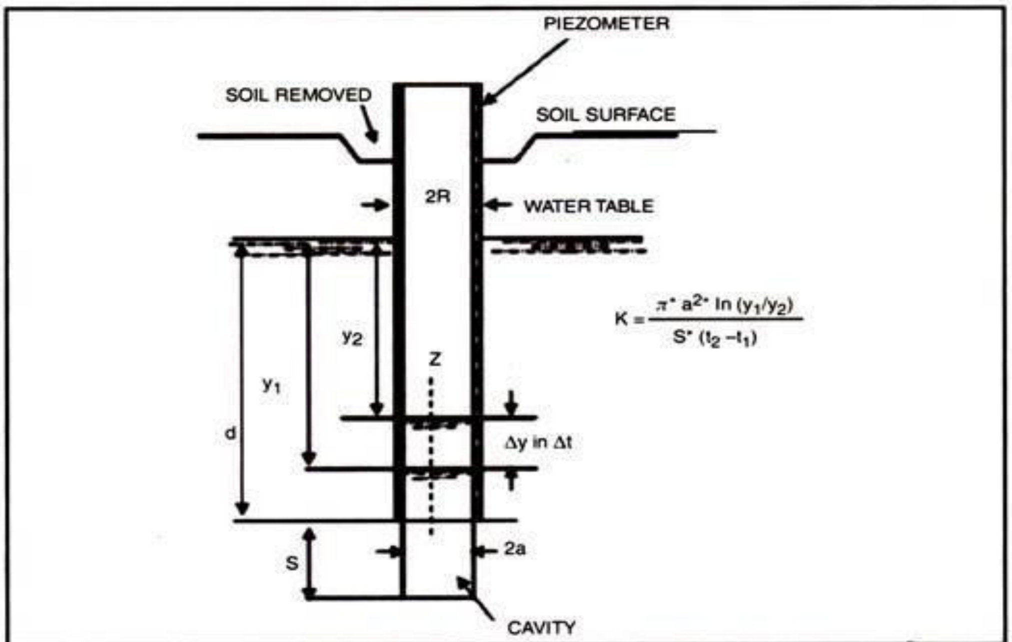


Fig 4.44. Piezometer method.

Movement of Water in the Soil:

Water movement in soils is quite simple and easy to understand in some ways and quite complex and difficult to grasp in others. An object that is free to move tends to move spontaneously from a state of higher potential energy to one of lower potential energy. So it is with water. A unit volume or mass of water tends to move from an area of higher potential energy to one of lower potential energy (Fig 4.45).

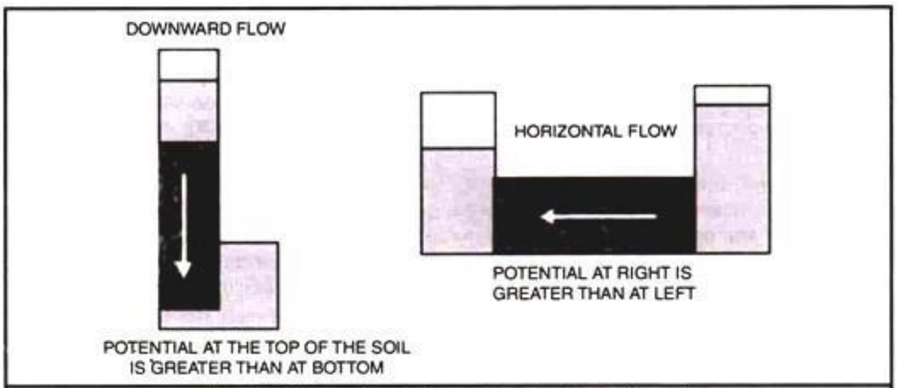


Fig 4.45 Absorption and movement of water in soil.

Movement of Water under Saturated Conditions:

Poiseuille's law forms the basis for a number of different equations which have been developed for determining the hydraulic conductivity of the soil for knowledge of its pore size distribution. Pore size is of outstanding significance, as its fourth power is proportional to the rate of saturated flow. This indicates that saturated flow under otherwise identical conditions decreases as the pore size decreases.

Generally, the rate of flow in soils of various textures is in the following sequence:

Sand > loam > clay

Saturated flow occurs when the soil pores are completely filled with water. This water moves at water potentials larger than – 33 kPa. Saturated flow is water flow caused by gravity's pull. It begins with infiltration, which is water movement into soil when rain or irrigation water is on the soil surface. When the soil profile is wetted, the movement of more water flowing through the wetted soil is termed percolation.

Factors affecting movement of water include:

1. Texture

2. Structure

3. Amount of organic matter

4. Depth of soil to hard pan

5. Amount of water in the soil

6. Temperature

7. Pressure.

Moisture Movement under Unsaturated Conditions:

It is flow of water held with water potentials lower than -1/3 bar. Water will move toward the region of lower potential (towards the greater "pulling" force). In a uniform soil this means that water moves from wetter to drier areas. The water movement may be in any direction.

The rate of flow is greater as the water potential gradient (the difference in potential between wet and dry) increases and as the size of water filled pores also increases. The two forces responsible for this movement are the attraction of soil solids for water (adhesion) and capillarity. Under field conditions this movement occurs when the soil macro pores (non-capillary) are filled with air and the micro-pores (capillary) pores with water and partly with air.

As drainage proceeds in a soil and the larger pores are emptied of water, the contribution of the hydraulic head or the gravitational component to total potential becomes progressively less important and the contribution of the matric potential ψm becomes more important

The effect of pressure is, generally, negligible because of the continuous nature of the air space. The solute potential (osmotic potential) ψs does not affect the potential gradient unless there is unusual concentration of salt at some point in the soil. The negligible effect of solute potential is due to the fact that both solutes and water are moving. Thus, in moisture moment under unsaturated conditions, the potential ψ is the sum of the matric potential (ψm) and to some extent the gravitational potential (ψg). In horizontal movement, only ψm applies. Under conditions of downward movement, capillary and gravitational potentials act together. In upward capillary movement ψm and ψg oppose one another.

For unsaturated flow the equation can be rewritten as:

$$V = -K\frac{\Delta(\psi_m + \psi_g)}{\Delta I}$$

The direction of I is the path of greatest change in (ψm + ψg).

Under unsaturated conditions, Darcy's is still applied but with some modifications. It is applicable to unsaturated flow if K is regarded as a function of water content, i.e K (θ) in which θ is the soil moisture content.

As the soil moisture content and soil moisture potential decreases, the hydraulic conductivity decreases very rapidly, so that ψsoil is – 15 bars, K is only 10-3 of the value at saturation. Rapid decrease in conductivity occurs because the larger pores are emptied first, which greatly decreases the cross-section available for liquid flow. When the continuity of the films is broken, liquid flow no longer occurs.

In unsaturated soil moisture movement, also called capillary movement, k is often termed as capillary conductivity, though the term hydraulic conductivity is also frequently used. The unsaturated conductivity is a function of soil moisture content as well as number, size and continuity of soil pores.

At moisture contents below field capacity, the capillary conductivity is so low that capillary movement is of little or no significance in relation to plant growth. Many investigations have shown that capillary rise from a free water table can be an important source of moisture for plants only when free water is within 60 or 90 cm of the root zone.

Movement of unsaturated flow ceases in sand at a lower tension than in finer textured soils, as the water films lose continuity sooner between the larger particles. The wetter the soil, the greater is the conductivity for water.

In the 'moist range', the range of unsaturated flow in soils of various textures is in the following order:

Sand < loam < clay

It may be noticed that this is the reverse of the order encountered in saturated flow. However, in the 'wet range' the unsaturated conductivity occurs in the same or similar order as saturated conductivity.

Water Vapour Movement:

The movement of water vapour from soils takes place in two ways:

1. Internal movement — the change from the liquid to the vapour state takes place within the soil, that is, in the soil pores and

2. External movement — the phenomenon occurs at the land surface and the resulting vapour is lost to the atmosphere by diffusion and convection.

Movement of water vapour through the diffusion mechanism takes place from one area to other soil area depending on the vapour pressure gradient (moving force). This gradient is simply the difference in vapour pressure of two points, a unit distance apart. The greater this difference, the more rapid the diffusion and the greater is the transfer of water vapour during a unit period.

Movement of soil-water in unsaturated soils involves both liquid and vapour phases. Although, vapour transfer is insignificant in high soil-water contents, it increases as void space increases. At a soil moisture potential of about -15 bars, the continuity of the liquid films is broken and water moves only in the form of vapour.

Diffusion of water vapour is caused by a vapour pressure gradient as the driving force. The vapour pressure of soil moisture increases with the increase in soil moisture content and temperature, it decreases with the increase in soluble salt content.

Water vapour movement is significant only in the 'moist range'. In the 'wet range' vapour movement is negligible because there are few continuous open pores. In the 'dry range' water movement exists, but there is so little water in the soil that the rate of movement is very small.

Water vapour movement goes on within the soil and also between soil and atmosphere, for example, evaporation, condensation and adsorption. The rate of diffusion of water vapour through the soil is proportional to the square of the effective porosity, regardless of pore sizes. The finer the soil pores, the higher is the moisture tension under which maximum water vapour movement occurs.

In a coarse textured soil, pores become free of liquid water at relatively low tensions and when the soil dries out there is little moisture left for vapour transfer. But a fine textured soil retains substantial amounts of moisture even at high tensions, thus permitting vapour transfer. It is interesting to note that maximum water vapour movement in soils is of greatest importance for the growth and survival of plants.

5-Effective Stress: (Concept only)

Effective Stress in Soil: Development, Importance and Principles

When a building is constructed, its weight is transmitted to the ground through its foundation, thus inducing stresses in the underlying strata. These induced stresses might cause problems such as excessive settlement or shear failure and thus are important to geotechnical engineers.

Stresses in Sub-Soil:

Stresses in sub-soil are caused by:

(i) Self weight of soil

(ii) Structural load on the soil

Stresses developed in saturated soil are:

(i) Effective stresses

(ii) Neutral stresses

(iii) Total stresses.

Effective Stress:

Karl Terzaghi was the first to recognize the importance of effective stress. It is the stress transmitted through grain to grain at the point of contact through soil mass. It is also known as inter-granular stress. It is denoted by σ'. When soil mass is loaded. The load is transferred to the soil gains through their point of contact. If at the point of contact, the applied load is greater than the resistance of the grains, then there will be compression in the soil mass.

This compression is partly due to the elastic compression of the grains at the points of contact and partly due to relative sliding between particles. This load per unit area of soil mass responsible for deformation of the soil mass is termed as effective stress.

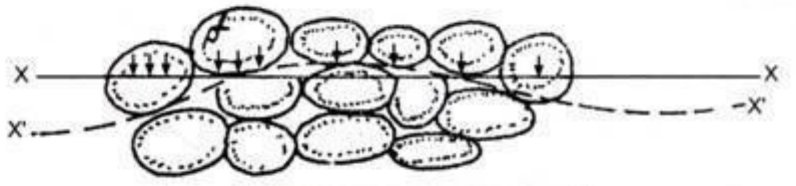


FIG. 5.1 Load transmission

Neutral Stress:

It is the stress or pressure transmitted through the pore fluid. It is also termed as pore pressure and is denoted by u. In saturated soil, pores of the soil mass are filled with water. When the saturated soil mass is loaded, the load is not transmitted through the grains. The load is transferred to the pore water. As water is incompressible, a pressure is developed in the pore water.This pressure is called pore pressure or pore water pressure. Pore pressure does not have any measurable influence on the mechanical property of the soil like void ratio, shear strength etc. This pressure or stress is called neutral stress.

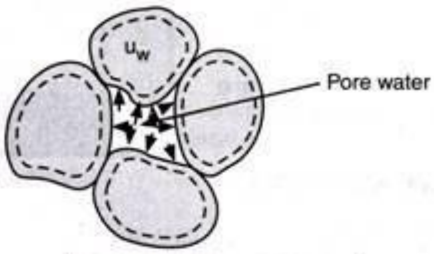


FIG. 5.2 Neutral stress

Total Stress:

Total stress is equal to the sum of the effective stress and the neutral stress. It is denoted by σ.

σ = σ + u

Effective stress cannot be measured in the field by any instrument. It can only be calculated after measuring total stress and pore pressure. Thus effective stress is not a physical parameter, but is only very useful mathematical concept for determination of engineering behaviour of soil.

Importance of Effective Stress in Engineering Problems:

The effective stress plays an important role in:

(i) Settlement of soil

(ii) Shear strength of soil

Settlement of Soil:

The phenomenon of gradual reduction in volume of soil due to expulsion of water from soil pores is called consolidation or compression or settlement of soil. Figure 5.3 shows a compression curve of clay. It is a curve between effective stress σ and void ratio e. It is clear from the graph that when σ increases e decreases i.e., due to increase in the effective stress the compression of soil will increase.

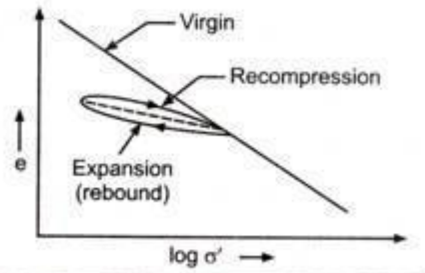


FIG. 5.3 Compression curve for clay

The final consolidation settlement may be calculated by using the formula

S = mV H clip_image007

where mV is the coefficient of volume compressibility

H is the thickness of compressible layer

Δσ is the average increase in effective pressure.

From the above equation it is clear that settlement of soil is directly proportional to the effective pressure. So the settlement of soil depends upon the effective stress or effective pressure. As the effective stress increases, the settlement of the soil also increases.

Shear Strength of Soil:

Many geotechnical engineering problems require an assessment of shear strength including:

(a) Structural foundations:

Load from a structure is transferred to ground through foundation. This produces shear stress and compressive stress. If shear stress produced is more than the shear strength of soil, shear failure occurs which cause the structure to collapse.

(b) Earth slopes:

On a sloping ground, gravity produces shear stresses in the soil. If these stresses exceed the shear strength, a landside occurs.

(c) Highway pavements:

Wheel loads, from vehicles are transferred through pavement to the ground. These loads produce shear stress which causes shear failure.

The value of K in x-direction is equal to that in y-direction for a level ground surface.

Shear strength of soil is calculated by using the formula

S = σ tan ϕ

Where σ = Effective stress

ϕ= Effective friction angle

For a given soil, f is constant. Shear strength is then directly proportional to effective stress. So with increase in effective stress the strength increases. If shear strength of soil is more, shear failure will be less.

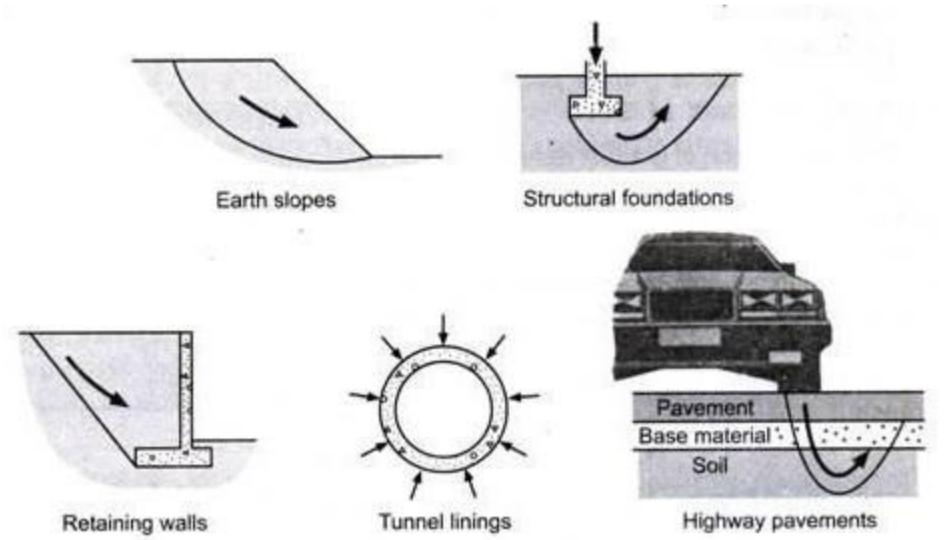


FIG. 5.4 Typical applications of strength analysis in soils

Principle of Effective Stress:

If the saturated soil mass is loaded, the load is transferred to the pore water. After expulsion of pore water it is transferred to the soil grains. Let YY be the wavy plane passing through the points of contact of the soil grains. Let A be the area of the wavy plane YY. This area A is the sum of area of grains contact (Ag) and area of the pore water (Aw) as shown in figure 5.5. It is evident from figure 5.6 that area of grains contact (Ag) is much less than the area of pore water (Aw) i.e., Aw = A.

Let F be the total load on area A.

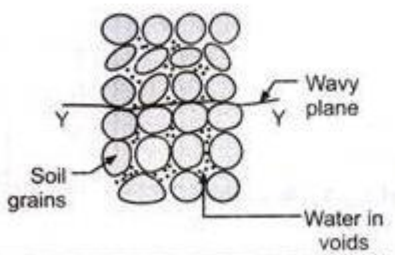


FIG. 5.5 Concept of effective stress

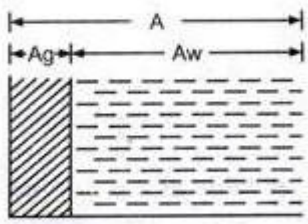


FIG. 5.6 Grain contact area and water area in YY.

Then $F = F_g + F_w$ ...(*i*)

where F_g = Total load transmitted through soil grains

F_w = Total load transmitted through pore water.

If the pore pressure develope is water is u then

$F_w = uA_w$ ...(*ii*)

The total stress on YY-plane is then

$$\frac{F}{A} = \frac{F_g}{A} + \frac{uA_w}{A} \quad \text{[using eqns. (i) and (ii)]}$$

$$\frac{F}{A} = \frac{F_g}{A} + u \quad [\because A_w = A]$$

or, $\sigma = \sigma' + u$

$\therefore$ $\sigma' = \sigma - u$

where σ = Total stress = $\frac{F}{A}$

σ' = Effective stress $\frac{F_g}{A}$

u = Pore pressure

The principle of effective stress in its simplest from can be stated as

(i) The effective stress is equal to the total stress minus the pore pressure for a saturated soil

$\sigma = \sigma - u$

(ii) The effective stress controls certain aspects of soil behaviour like strength, deformation etc.

Shear Strength Characteristics of Soils:

The strength of a material is defined as the greatest stress it can sustain. If the stress exceeds strength, failure occurs. Strength analysis can be performed for tensile. Compressive and shear stresses. Because soil has very little or negligible tensile strength geotechnical engineers rarely perform tensile strength analysis.

The geometry of most geotechnical problems is such that the soil mass is in compression, but do not fail in compression. Although the introduction of large compressive stresses may result in soil failure, the soil is actually failing in shear, not in compression. Therefore, nearly all geotechnical strength analysis is performed for shear stresses.

Shear Strength:

The shear strength of a soil in any direction is the maximum shear stress that can be applied to the soil in that direction. It can also be defined as the resistance to deformation by continuous shear displacement of soil particles.

The shear strength of soil is basically made up of the following components:

(i) Frictional component:

It is mainly due to interlocking of soil particles and the friction between them.

(ii) Cohesion component:

It is due to mutual attraction that exists between the fine particles of some soils. The shear strength of cohesive soil results both from friction as well as cohesion whereas for cohesion-less soil it results from friction alone.

The Coulomb Equation:

The shear strength equation was first proposed by French engineer Coulomb. He expressed the shear strength's' as a linear function of total normal stress 'σ' on the potential surface of sliding

$s = c + \sigma \tan(\phi)$

Where s == shear strength

c = apparent cohesion

α = total normal stress

φ= angle of internal friction

The coulomb strength envelope is shown in the figure 7.1. It is clear from the plot that the frictional component (tan φ) of shear strength increases with normal stress whereas the cohesion component (c) remains constant.Experiments have shown that the shear strength in a soil is developed only by solid particles, because the water and air phases have no shear strength.

Inaccordance with Terzaghi's early concept that shear stress in a soil can be resisted only by soil solids, the shear strength is expressed as a function of effective normal stress, σ' and is given by

$$s = c' + \sigma' \tan \phi'$$

or $$s = c' + (\sigma - u) \tan \phi'$$

where c' = effective cohesion

σ' = effective normal stress

u = pore water pressure

ϕ' = effective angle of internal friction

The above equation is known as coulomb Terzaghi shear strength equation.

Based on total strength properties soils may be classified into the followings :

(i) Cohesionless soil : Purely granular soils possess no cohesion ($c = 0$). The shear strength of such soils are given by

$$s = \sigma \tan \phi$$

and the strength envelope is shown in figure 7.2

(ii) Cohesive soil : Fine soils possess cohesion and no friction ($\phi = 0$). The shear strength is given by

$$s = c$$

and the strength envelope is horizontal as shown in figure 7.3.

(iii) Cohesive frictional soil : Soil which possesses both cohesion and friction is called $c - \phi$ soil. The shear strength of such soils is given by

$$s = c + \sigma \tan \phi$$

The strength envelope is shown in figure 7.4.

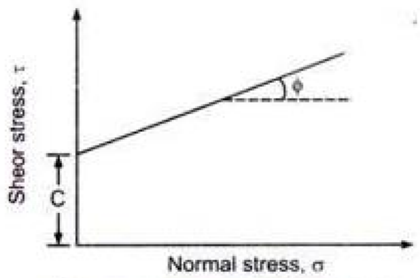


FIG. 7.1 Coulomb strength envelope

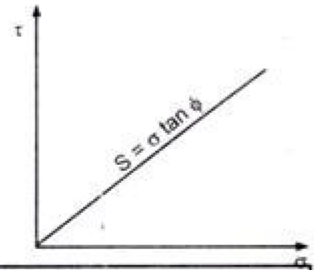


FIG. 7.2 Strength envelope of cohesionless soil.

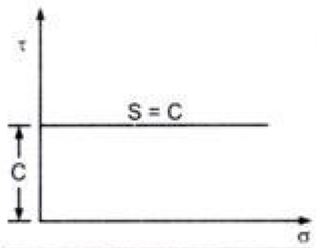


FIG. 7.3 Strength envelope of cohesive soil.

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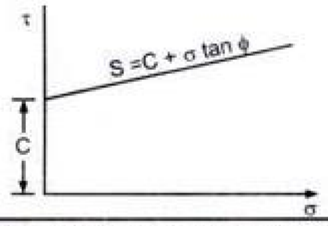


FIG. 7.4 Strength envelope of c – φ soil

Factors Affecting Angle of Internal Friction:

The angle of internal friction of cohesion less soils is affected by the following factors:

(i) Mineralogy:

Soil contains many different minerals. Some of the minerals slide more easily than others. As for example, sands having pure quartz has φ value of 30-36°. Sands having significant quantities of mica have a smaller φ value. Clay minerals like montmorillonite have 6 value of 4°.

(ii) Organic materials:

Presence of organic materials in soil reduces the value.

(iii) Shape:

Soils having angular particles have higher (t)-value then those having rounded particles.

(iv) Gradation:

The interlocking between the particles are more in well graded soils than that of poorty grade soil and hence well graded soils have more φ value.

(v) Void ratio:

Void ratio is perhaps the most important factor influencing the shear strength. Soils having lower void ratio have higher value of φ.

Table 7.1. Effect of angularity and grading on φ′ of cohesionless soil

S. No.	Shape and grading	φ′ (in degrees)	
		Loose	Dense
1.	Rounded, Uniform	30	37
2.	Rounded, well graded	34	40
3.	Angular, Uniform	35	43
4.	Angular, well graded	39	45

Principal Stresses:

For any system of forces acting at a point there exist three mutually perpendicular planes on which there are zero shear stresses and the stresses are wholly normal. These planes are called ‘Principal planes’. The normal stresses acting on them are called the ‘Principal stresses’. The largest of these three stresses is called the “major principal stress “σ_1”, the smallest is called the minor principal stress σ_3”, and the third one is the intermediate principal stress σ_2”, .The directions of the principal stresses are called the “Principal axes”.

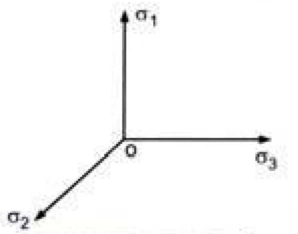


FIG. 7.5 Principal axes.

Cohesion:

It is the property of soil which holds the particles together in soil mass mainly due to inter-particle molecular attraction and bonds. The exact nature of the surface forces helpful in causing cohesion is not known. It is not a constant soil property but is a function of the load carried by the soil structure or inter-particle load.

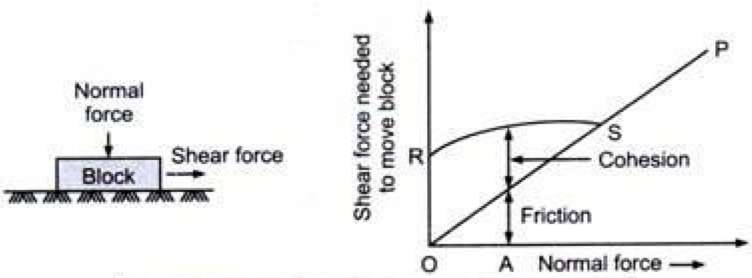


FIG. 7.6 Plot of shear force vs normal force

In the figure 7.6 shown above, a block is shown which will move under the effect of a shear and normal force of different magnitudes. The line OP represents the relationship between shear and normal forces required for moving the block. Now if the block is struck to the surface with some

adhesive, then line RSP represents the relationship between shear and normal forces required for moving the block.

At any normal force say at A, the resistance to movement is due to friction between the block and surface plus the strength of adhesive. In actual soil mass, the resistance will be provided due to friction between soil particles plus cohesion in soil. At the point S, there is no adhesive between the block and surface. It means that in actual soil mass, cohesion can be reduced to zero at large normal pressures.

Angle of Repose:

Angle of repose is the angle between the horizontal and maximum slope at which a given dry material is stable. For a granular material at its loosest state, angle of repose is equal to the angle of friction.

Mohr's Stress Circle:

Consider a soil element in a two dimensional state of stress with σ_1 and σ_3 acting on the principal planes. The normal and shear stresses (σ and on any plane AB inclined at an angle a to the major principal plane can be obtained easily by constructing a circle with a radius $(\sigma_1, - \sigma_3)/2$ and its centre at $[(\sigma_1 + \sigma_3)/2$ in the σ- plane. It is known as "Mohr circle of stress". It represents the state of stress at a point at equilibrium and it applies to any material, not just soil.

The stresses σ and on the plane AB are obtained by drawing a line through the point P on the circle, parallel to AB, to intersect the circle at point C whose coordinates yield the values of σ and τ as:

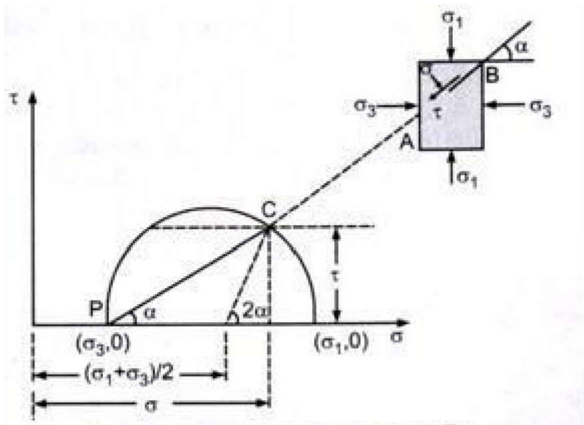


FIG. 7.7 Mohr circle of stress

$$\sigma = \frac{(\sigma_1 + \sigma_3)}{2} + \left\{\frac{(\sigma_1 - \sigma_3)}{2}\right\} \cos 2\alpha \quad ...(1)$$

$$\tau = \frac{(\sigma_1 - \sigma_3)}{2} \sin 2\alpha \quad ...(2)$$

The point P on the circle is a unique point called the "pole" or the "origin of planes". It has a very useful property: any straight line drawn through the pole intersects the Mohr circle at a point which represents the state of stress.

Mohr's circle for c-soil, φ-soil and c- ϕ soils C-soils:

For purely cohesive soil, $\phi = 0$

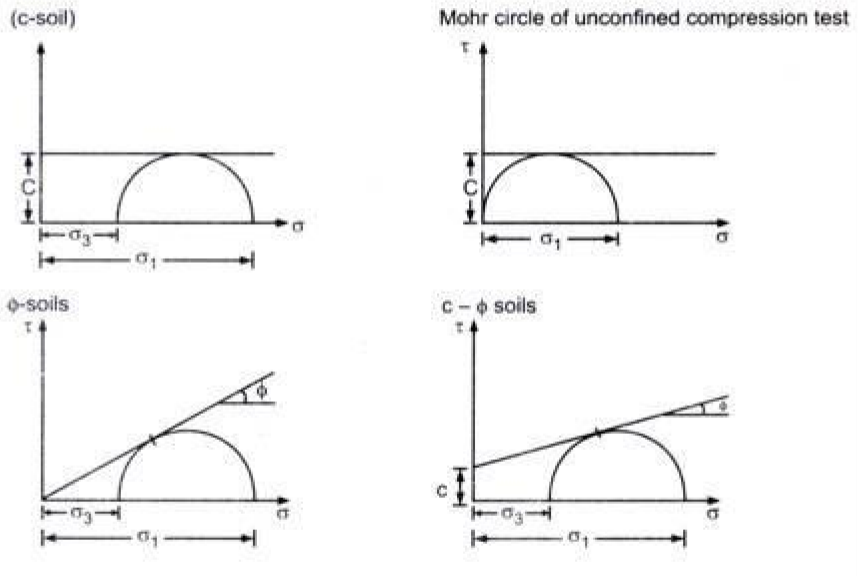


FIG. 7.8 Mohr circle for different soils

Mohr Coulomb Failure Theory:

The theory was first given by coulomb (1776) and later generalized by Mohr (1900). According to Mohr coulomb failure theory, the failure occurs when shear stress on the failure plane reaches some unique function of the normal stress on that plane and can be expressed algebraically by the equation

$\tau_f = S = f(\sigma_f)$

The shear stress at failure, τ_f is called the shear strength. If the shear stress and normal stress at failure are plotted then a curve is obtained. This curve is called failure envelope or strength envelope. The failure envelope suggested by coulomb is a straight line as shown in figure 7.9. The failure envelope given by Mohr is a curved line as shown in figure 7.10.

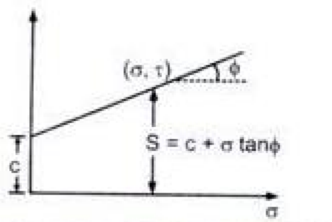


FIG. 7.9 Coulomb envelope

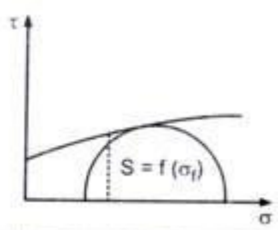


FIG. 7.10 Mohr envelope

In practice, Mohr envelope for a soil is commonly found to be approximately straight over a considerable range of normal stress and as a fairly close approximation Mohr envelope is assumed to be identical with the coulomb envelop. The combination of coulomb theory of linear relationship between normal stress and shear stress at failure and Mohr's condition of

tangency between Mohr's circle and failure envelope at the time of failure is known as the "Mohr-coulomb failure theory". Thus Mohr-coulomb failure envelope is a straight line tangential to the Mohr circle at failure, as shown in figure 7.11.

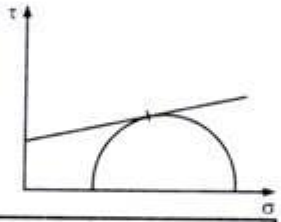


FIG. 7.11 Mohr coulomb failure envelope.

Stress-Strains Behaviour of Sands:

Figure 7.12 shows stress-strains behaviour of coarse grained soils. There is definite peak with stress-strain curve for dense or medium dense sand. The shear stress at the peak is known as peak shear strength. After reaching the peak value both the curve show a decrease in shear stress and reach the same constant ultimate shear stress. This is known as residual strength or ultimate shear strength. The sand in loose condition also tends to reach the same ultimate shear strength.

Peak strength = $s_P = \sigma \tan \varphi$ and residual strength = $s_r = \sigma \tan \varphi'_r$

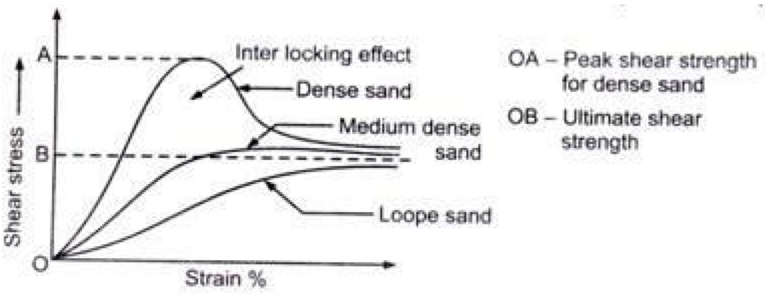


FIG. 7.12 Stress-strain curve of sand

Stress-Strain Behaviour of Clays:

Figure. 7. 13 shows the stress-strain behaviour of fine grained soil. From the figure it is clear that the stress-strain behaviour of over consolidated clay is similar to dense sand and that of normally consolidated clay is similar to lose sand.

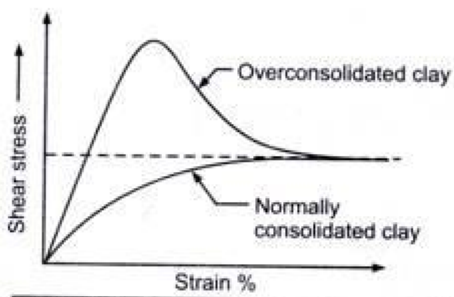


FIG. 7.13 Stress-strain curve of clay

Concept of Failure:

Failure of dense sand may be defined either by the peak stress point A or the ultimate stress point B. The failure envelope is shown in the figure 7.14. The choice of failure criteria is based on the field conditions. In most of applications, peak stress criteria are used. In case of loose sand which does not exhibit a peak stress point, failure is generally defined as the stress condition corresponding to a given strain condition, such as 20%.

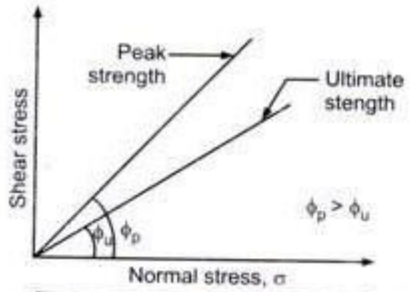


FIG. 7.14 Failure envelope

Sensitivity:

Some clays have a property due to which their strength in a remoulded or highly disturbed state is less than that in an undisturbed state at the same moisture content. This property is called sensitivity. It is defined as the ratio of undrained shear strength, S_u of undisturbed soil to undrained shear strength of remoulded soil.

S_t = Su (undisturbed)/Su (remoulded)

Sensitivity of natural deposits ranges from 1.0 to as high as 500. High sensitivity is observed in clays knows as "Quick clays" and rare found in certain areas of Eastern Canada.

Table 7.2. Typical classification of sensitivity.

S. No.	Classification	Sensitivity
1.	Low sensitivity	2–4
2.	Medium sensitivity	4–8
3.	High sensitivity	8–16
4.	Quick	> 16

Drainage Conditions in Shear Testing:

Fine grained soils are tested for shear strength when they are fully saturated. Shear tests for saturated soils are designed for three types of drainage conditions. The choice of a particular type of drainage condition depends upon the field conditions. The drainage conditions are generally designated by two letter symbol. The first letter refers to what happens before shear (i.e., whether the sample is consolidated) and second letter refers to the drainage conditions during shear.

Table 7.3. Types of drainage conditions

S. No.	Designation (Before shear-During shear)	Symbol	Also known as
1.	Unconsolidated-undrained	UU	Undrained or quick test
2.	Consolidated-undrained	CU	Consolidated-quick test
3.	Consolidated-drained	CD	Drained or slow test

(i) Unconsolidated-untrained test (UU test):

In UU test, drainage is not permitted at any state of shear test. If direct shear test is to be performed under UU condition then drainage is prevented both during application of normal as well as shear stress. The sample is subjected to initial stress and without waiting for consolidation shearing process is started without permitting any drainage.

Such test can be used for field condition where critical stresses develop in a saturated soil mass too rapidly for any moisture content to change appreciably The shear strength parameters obtained from this test are written as Cu and ϕ_u represents total stress.

Cu = C and $\phi_u = \phi$

Example:

Earth pressure against bracings in temporary excavation, bearing capacity of foundations on saturated homogeneous clays immediately after construction.

(ii) Consolidated undrained test (C-U test):

In C_u test complete drainage is allowed during applications of normal stress i.e., consolidation of the sample is permitted prior to actual shearing process under a specified initial stress. Sample is then sheared allowing no drainage. The test results are applicable to field conditions where the soil has consolidated under the foundation pressure during construction and which is then followed by sudden increase in loads resulting in rapid change of critical stresses during which change of water content can take place.

Example:

Stability of consolidated earth dams under conditions of rapid drawdown of water.

(iii) Consolidated drained test (C-D test):

In C-D test, complete drainage is permitted throughout the test so that no pore pressure is developed at any stage of the test. The test results are applied to field problems where the stresses developed within the soil mass sufficiently slowly so that full change in water content to take place. The stresses are effective stresses at all times. Effective stress parameters obtained from this test are written as C_d and φ d.C_d= c' and φ d = φ'

Example:

Final bearing capacity of soil where the foundation is constructed more slowly than the soil consolidates.

Drained and Un-drained Shear Strength:

Drained shear strength of a soil is the shear strength w.r.t. the effective stresses produced in the soil mass and is given by

$S_d = C_d + \sigma \tan = \varphi_d$

c' +σ' tan φ'

Drained shear strength is computed for solving all field problems in sandy soils. It is also required for clay soil to evaluate the long term stability. Un-drained shear strength of a soil is the shear strength w.r.t. total stresses produced in the soil mass and is given by

$Su – Cu + o \tan = \varphi_u$

$= c + o' \tan \varphi$

Un-drained shear strength is computed and used for those field problems, where the change in the total stress is immediately compensated by a change in the pore water pressure.

Table 7.4: Relationship between unconfined compressive strength (q_u) and consistency of clays:

S. No.	Soil consistency	q_u (kg/cm^2)
1.	Very soft	0–0.25
2.	Soft	0.25–0.5
3.	Medium	0.5–1.0
4.	Stiff	1.0–2.0
5.	Very stiff	2.0–4.0
6.	Hard	> 4.0

Different Kinds of Shear Tests:

(i) Laboratory tests

(a) Direct or Box shear test

(b) Triaxial compression test

(c) Unconfined compression tests

(d) Laboratory vane shear test

(ii) Field test — vane shear test.

Direct or Box Shear Test:

The direct shear test is the simplest method of shear test for determining the shear strength of soil. In this test soil sample, undisturbed or remoulded, is placed in a metal box having square or circular in section. The shear box can be split in two half horizontally. The size of the box normally used for clays and sand is 6 cm square and the sample is 2 cm thick.

The large size shear box is 30 cm square with sample thickness of 15 cm, used for gravelly soil. The lower half of the box can slide relative to the upper half when pushed by a hand operated or motorized drive unit, while a yoke supporting a load hanger provides the normal pressure.

After placing the soil specimen in the box and making other necessary adjustment, a known normal load is applied. The normal load is maintained throughout the test and shear stress is gradually applied causing the two halves of the box to slide relative to each other. The shearing displacement is recorded by a dial gauge. Shear stress is applied in such a way that we get a shear displacement of 1.25 mm/min. If the soil does not fail then 12 mm strain is taken as failure point.

By dividing the normal load and the maximum applied shearing force with the cross-sectional area of the specimen at the shear plane gives respectively the normal stress and shears tress at failure of the sample. In order to obtain sufficient points to draw the coulomb graph, the test is repeated with different normal stresses on a number of identical samples. The value of each tests are plotted with normal stress on the x-axis and shear stress on Y-axis. The shear strength parameters are then obtained from the best line fitting the test points.

For performing a unconsolidated undrained (uu) test, plain toothed grids are used at the top and bottom faces of the samples. Shear force is applied immediately after applying the normal load. For consolidated undrained (Cu) test, perforated grids are used and the sample is first allowed to consolidate under normal load and the shear force is applied immediately after normal load. For consolidated drained (CD) test the sample is first consolidated under normal load and then sheared slowly so that further drainage can take place during shearing.

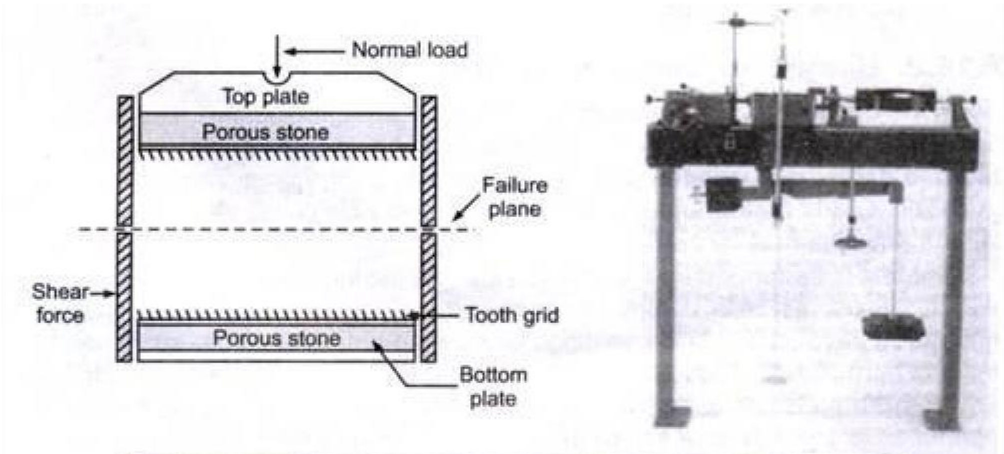


FIG. 7.15 (a) Set up of direct shear test (b) Direct shear apparatus

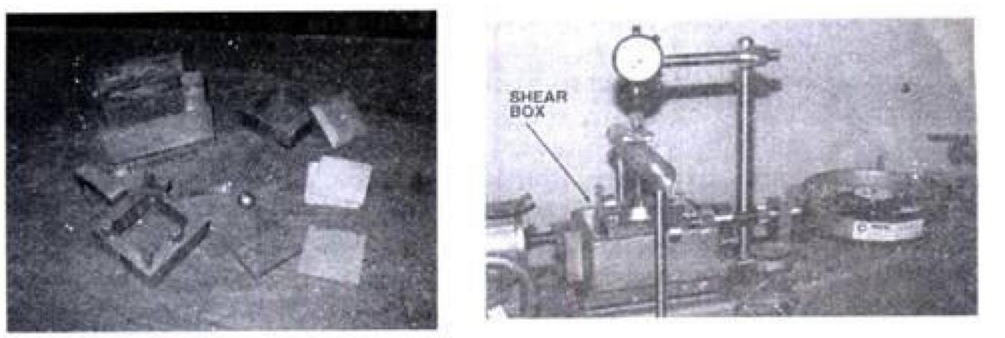


FIG. 7.15 (c) Dissembled shear box (d) Shear box in place in a direct shear apparatus

Advantages and Disadvantage of Shear Box Test:

Advantages:

(i) The test is simple and fast for granular soils.

(ii) Due to less thickness of soil sample, quick drainage of pore water is easy to achieve.

(iii) As the basic principle is easy to understand it can be extended to gravelly soil, which would be were expensive to test by other methods.

Disadvantages:

(i) It is difficult to control the drainage of water from the soil.

(ii) Only the total stresses are known as there is no way to measure the pore water pressure.

(iii) The failure plane is predetermined which may not necessarily be the weakest one.

(iv) The distribution of shear stress on the failure plane is non-uniform.

Unconfined Compression Test:

In the unconfined compression test, only the axial stress is applied and the confining or cell pressure is zero. Thus this test is a special case of triaxial test and it is named as unconfined compression test as the confining pressure is zero. This test is performed only on cohesive soil. Non-cohesive will not stand without any support. The test is performed on a cylindrical sample having height to diameter ratio of 2:1. The usual size is 38 mm. The ends of the cylindrical sample are hollowed in the form of cone. The cone seating's reduce the tendency of the specimen to become barrel shaped by reducing the end restraints.

The sample is then placed between the plates of a mechanical load frame. Axial load is applied in such manner as to give a rate of strain between 1 to 2% of sample height per min. The load can be read on the proving ring dial gauge and the corresponding deformation on the strain gauge. A set of readings of loads and the corresponding deformation is taken.

The deformation is continued till the sample fails. When the load readings start decreasing instead of increasing, failure point is reached. At failure, deformation is discontinued.

The values of axial strain corresponding to various deformation readings are calculated and then the deformed cross-sectional areas corresponding to these strain values are calculated by using equation (A) given below. The compressive stress at any strain is calculated by dividing the load at the stage with the corresponding deformed area (A_2).

A graph is prepared between stress on Y-axis and strain (%) on x-axis the stress at the peak of the curve represents the failure condition as shown in Fig. 7.17(b). If there is no definite peak in the curve, then stress corresponding to 20% strain is arbitrarily taken as the failure condition. The axial stress at failure or that corresponding to 20% strain is termed the 'unconfined compressive strength q_u', half of which is termed the 'undrained shear strength Su'.

S_u = qu/2

If the remoulded strength is also be measured for the determination of sensitivity, the failed sample is taken in a polythene bag with little more soil of same moisture content and remoulded thoroughly by squeezing and kneading. A test sample is formed by working the remoulded soil into a 38 mm diameter tube. It is then tested to get remoulded strength.

The changed or deformed cross-sectional area is given by

$$A_2 = \frac{V}{L_1 - \Delta L} = \frac{V}{1 - \frac{\Delta L}{L_1}} = \frac{A_1}{1 - e} \quad \text{...(A)}$$

where V = Original volume of the specimen
A_1 = Initial cross-sectional area
L_1 = Initial length of specimen
ΔL = Change in length
e = axial strain

Unconfined compressive strength can also be calculated as follows

Angle of failure plane $= \alpha = 45° + \frac{\phi}{2}$

We know (sec. 7.8)

$$\tau = \frac{\sigma_1 - \sigma_3}{2} \sin 2\alpha$$

For purely cohesive soil $\phi = 0$

$\therefore \quad \alpha = 45°$

$$\tau = \frac{\sigma_1 - \sigma_3}{2} (\sin 2 \times 45°) = \frac{\sigma_1 - \sigma_3}{2}$$

here $\sigma_3 = 0$

$$\therefore \quad \tau = \frac{\sigma_1}{2}$$

where σ_1 = stress at failure $= \frac{\text{Axial load at failure}}{\text{Cross-sectional area at failure}}$

$\therefore$ Undrained Shear strength $= \frac{\text{unconfined comp. strength}}{2}$

Advantages and disadvantage of unconfined compression test:

Advantages:

(i) It is widely used, simple and quick test.

(ii) This is most convenient and suitable for calculating sensitivity of clays.

(iii) The cost involved in this test is much less then the triaxial test due to simpler testing requirement.

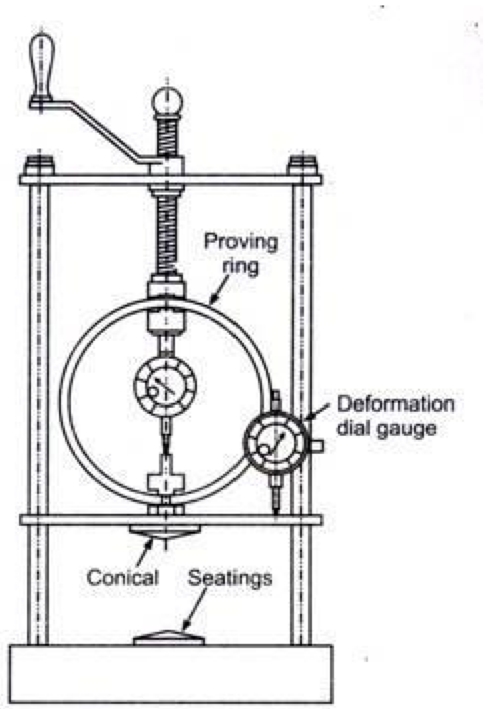


FIG. 7.16 (a) Set up of unconfined compression test

Disadvantages:

(i) As no covering or lateral support is provided to the sample in this test, it is applicable to soil which can stand unsupported and are impervious to maintain the un-drained condition throughout the test.

(ii) The sample must be fully saturated.

(iii) The test is suitable for intact homogeneous clays only.

(iv) The test under estimates in-situ strength because of the sampling disturbance.

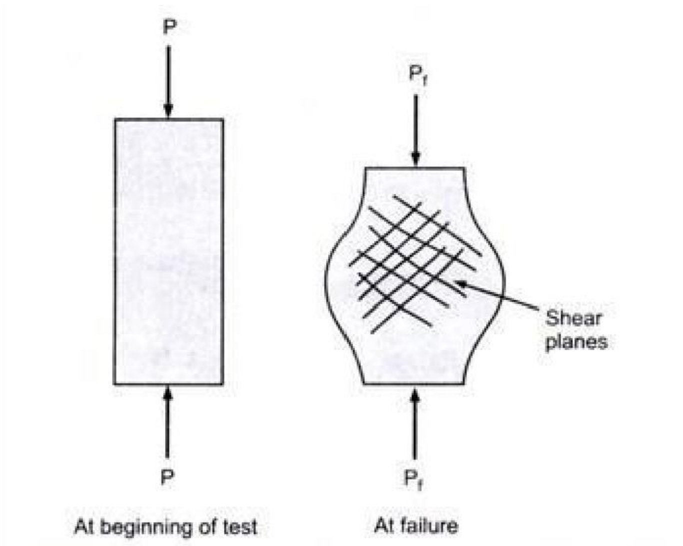
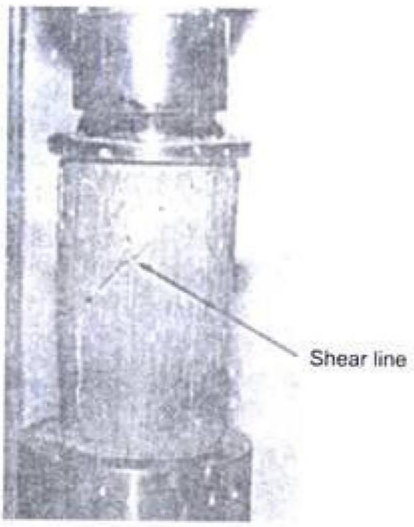
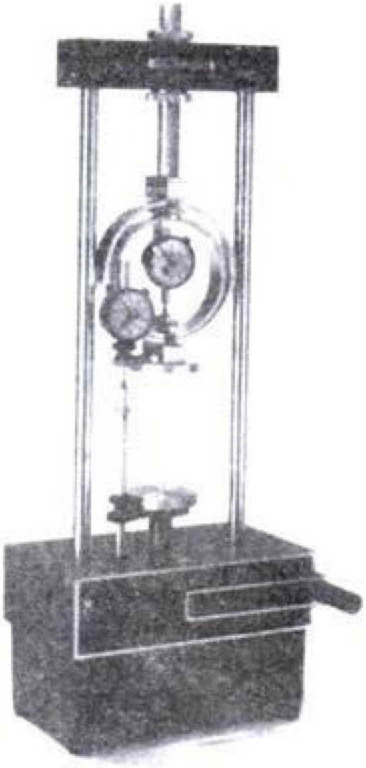


FIG. 7.16 (b) Shape of sample before and after the test.



(c)



(d)

FIG. 7.16 (c) shear lines produced as result of a compression test (d) Unconfined compression test apparatus

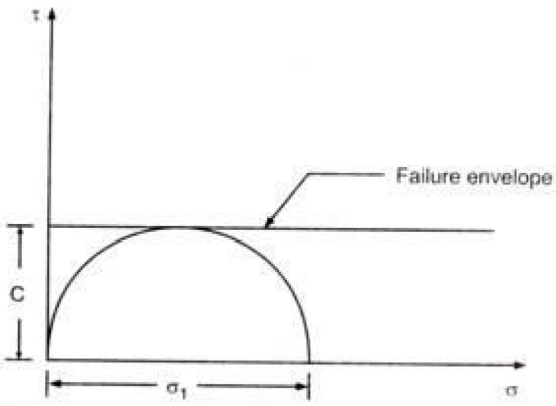


FIG. 7.17 (a) Mohr's circle of unconfined compression test

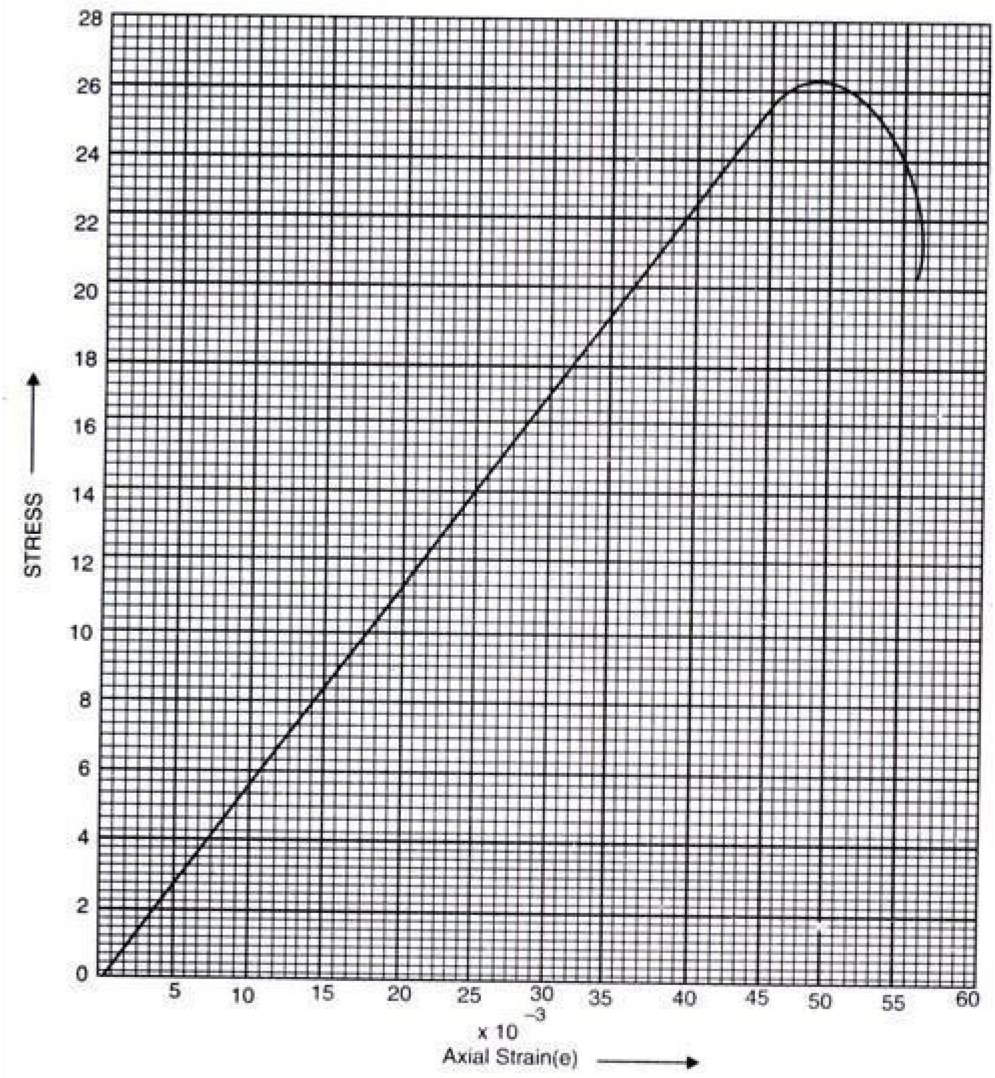


FIG. 7.17 (b) Unconfined compression test graph

Triaxial Test:

The test was first introduced in U.S.A. by casagrande and Karl Terzaghi in 1936-37. It is carried out in a cylindrical test specimen having height to diameter ratio of 2: 1. Usual diameter of the soil specimen used for the test is 38 mm. The specimen is placed between rigid non-porous end caps or porous discs depending upon the drainage condition of the test and covered with a rubber membrane. It is then placed in perspex cylinder which filled with water.

The specimen is subjected to a confining pressure, σ_3 and axial stress ($\sigma_1 - \sigma_3$). The confining pressure i.e., all round pressure is applied by water in the cylinder and axial stress is applied through a ram. The ram is forced down at a constant rate and the load on the plunger is recorded till the sample fails.

The test is repeated on different samples with different confining pressure and results are interpreted by drawing Mohr's circles. The confining pressure σ_3 is the minor principal stress and the total stress ($\sigma 1- \sigma 3 + \sigma 3$) = is the major principal stress, the horizontal and vertical planes are the principal planes. Different Mohr's circles are drawn for different tests and a common tangent to them gives the shear strength parameter c and ϕ as shown in figure 7.19.

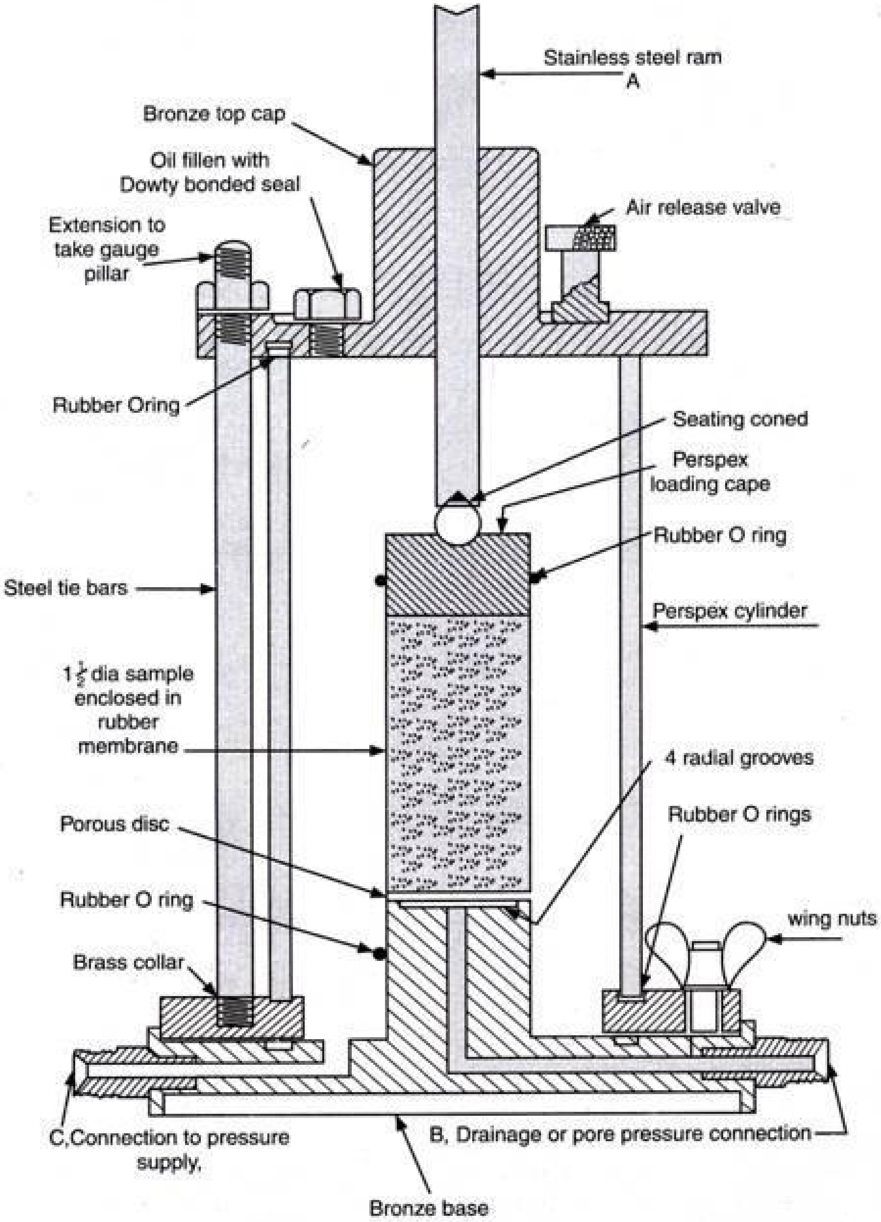


FIG. 7.18 (a) Set up of triaxial test

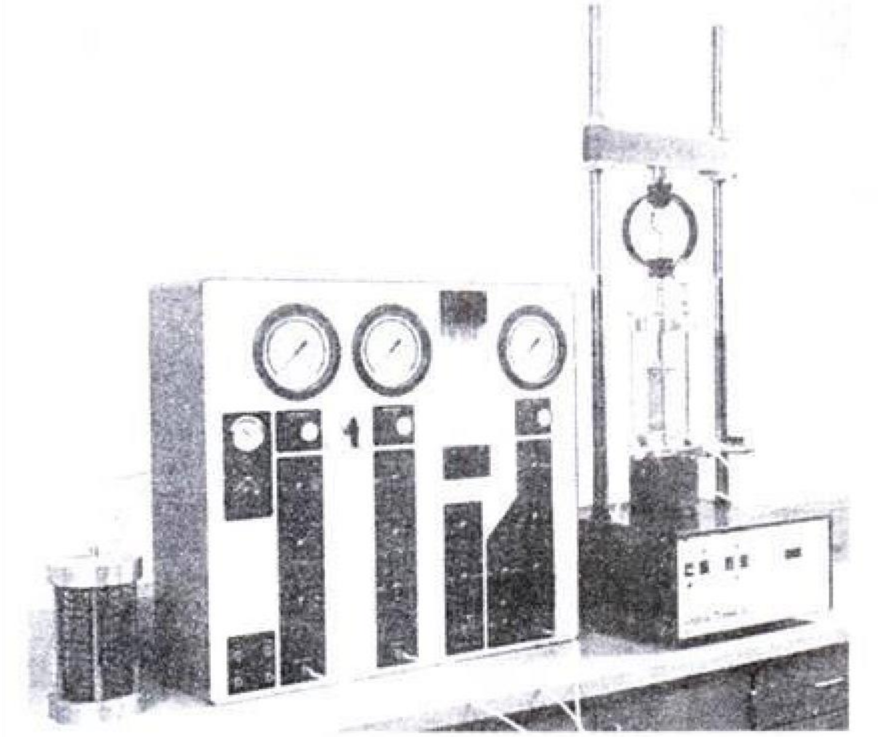


FIG. 7.18 (b) Triaxial test apparatus

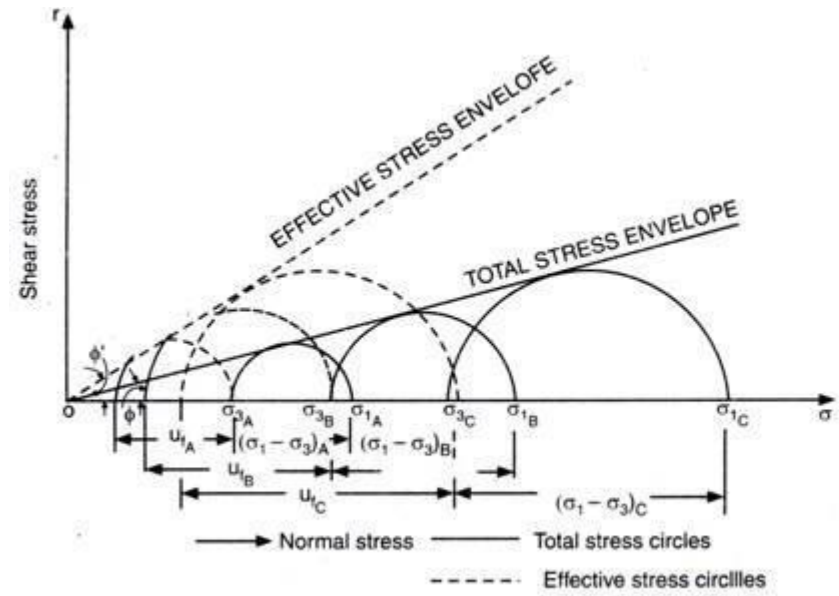


FIG. 7.19 Mohr circles of triaxial test.

<u>Depending upon the drainage condition the test is divided into three parts:</u>

<u>1. Unconsolidated un-drained (uu) test:</u>

<u>In this test the specimen is fitted between solid non-porous discs to avoid expulsion of water from the specimen. The required confining pressure is applied and axial load is applied without allowing the specimen to consolidated under the confining pressure, the axial load is usually applied at a rate of 2% strain per minute till the sample fails or an axial strain of 20% has reached.</u>

<u>2. Consolidated un-drained (Cu) test:</u>

In this type of test the specimen is fitted between porous discs and under confining pressure the specimen is allowed to consolidate (i.e., drainage is allowed). The drainage tap is then closed and axial load is applied till failure.

3. Consolidated drained (CD) test:

The specimen is fitted between porous discs and specimen is allowed to consolidate under confining pressure. The axial load is then applied without closing the drainage tap (i.e., drainage is allowed).

Advantages:

1. The test can be performed, with complete control, under all the three drainage conditions.

2. It is possible to take pore pressure measurements during the test.

3. The distribution of stress on the failure plane is uniform.

4. It is possible to determine the state of stress within the specimen at any stage of the test.

Disadvantages:

1. The test set up is more complicated than any other shear test. It requires a skilled person to handle the apparatus precisely.

2. Tests on small diameter samples (i.e., 38 mm) of stiff fissured clays give very high strength. Hence to obtain accurate result for such type of soils, large diameter specimens should be tested.

3. Consolidation of cohesive soil specimens take more time than in the shear box test.

Table 7.5. Undrained shear strength parameters for partially saturated clay.

S. No.	Type of soil	c-value		φ-value	
		$c_{undrained}$	$c_{effective}$	$\phi_{undrained}$	$\phi_{effective}$
1.	Sand with clay bindes	0.80	0.70	23°	40°
2.	Lean silty clay	0.87	0.45	13°	31°
3.	Clay with moderate plasticity	0.93	0.60	9°	28°
4.	Clay with high plasticity	0.87	0.67	8°	22°

7.17 COMPARISON BETWEEN DIRECT SHEAR TEST AND TRIAXIAL SHEAR TEST

S. No.	Direct shear	Triaxial shear test
1.	Direct shear test is the simplest and the oldest test.	Triaxial test is much more complicated
2.	It is difficult to control the drainage condition.	Drainage conditions during the test can be controlled.
3.	Pore water pressure cannot be measured.	Pore water pressure can be measured.
4.	The shear failure is predetermined	Shear failure is not predetermined.
5.	Only total stresses are known.	Effective stress can also be determined.
6.	Consolidation and drainage of sample is relatively fast.	Consolidation and drainage of sample take a much longer time.
7.	Stress distribution on the failure plane is non-uniform.	Stress distribution on the failure plane is uniform.
8.	Recompacted test samples are not difficult to prepare.	Samples of cohesionless soil like sands is difficult to prepare.

Vane Shear Test:

Vane shear test is a quick test and is used to determine the insitu un-drained shear strength of soft clays and silts which are difficult to sample. A vane shear test equipment consists of a four bladed vane shown in figure 7.20. The height of the vane is usually twice its diameter. The vane is welded orthogonally to a steel rod.

A boring is made to the depth at which the test is to be performed and the vane is inserted at the bottom of the boring. After inserting the vane in the ground it is slowly rotated (usually 0.1° per second). The torque is applied until the soil fails in shear, then the un-drained shear strength, Su is computed from this torque.

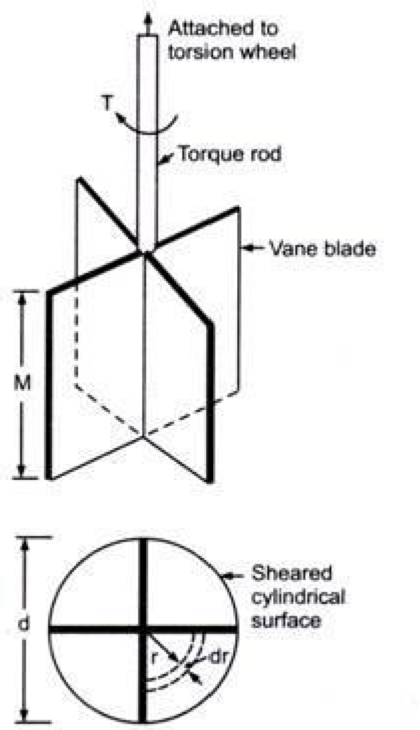


FIG. 7.20 (a) Vane share test

Let H = Height of the vane

D = Diameter of the vane

Assuming that the shear resistance S_u is constant over the cylinder of soil sheared by vane.

Maximum resistance offered to shearing along the cylindrical surface

= $(\pi DH)S_u$

and total resistance offered to shearing along the top and bottom faces of

$$\text{the cylinder} = \int_0^{D/2} (2\pi r\, dr)\, S_u \quad \text{...(ii)}$$

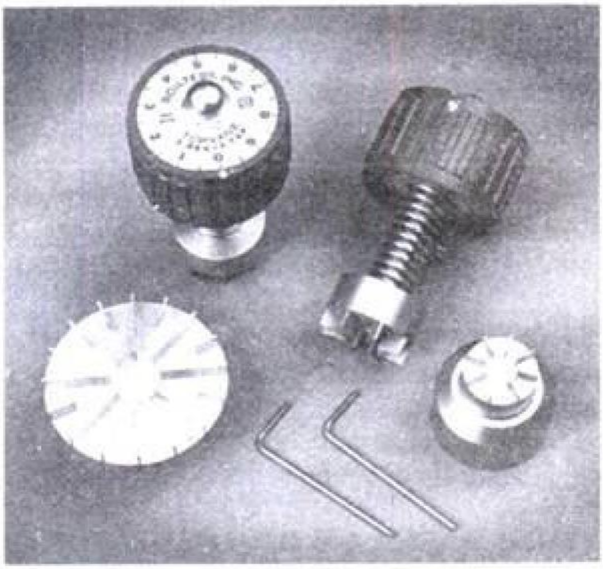


FIG. 7.20 (b) Hand operated vane shear test apparatus

The total shear resistance developed will be equal to the sum of (*i*) and (*ii*).

The maximum moment of the total shear resistance about the axis of the torque rod is equal to the torque T at failure.

$$\therefore \quad T = (\pi DH\, S_u) \times \frac{D}{2} + 2\int_0^{D/2} (2\pi r\, dr) \times r\, S_u$$

$$= \frac{\pi D^2 H}{2} S_u + 4\pi S_u \int_0^{D/2} r^2\, dr$$

$$= \frac{\pi D^2}{2} HS_u + 4\pi S_u \left[\frac{r^3}{3}\right]_0^{D/2}$$

$$= \frac{\pi D^2}{2} HS_u + \frac{4}{3}\pi S_u \cdot \frac{D^3}{8} = \pi D^2 S_u \left[\frac{H}{2} + \frac{D}{6}\right]$$

$$\text{or} \quad S_u = \frac{T}{\pi D^2 \left(\frac{H}{2} + \frac{D}{6}\right)}$$

Discrepancies between Laboratory and Field Shear Test:

1. Laboratory shear tests are direct method of determining the shear strength of soil. Field test results are combined with empirical correlations to estimate the shear strength, except in vane shear test in which shear strength is calculated directly

2. Laboratory vane shear test indicates that the actual failure surface is a shear zone and not a cylindrical surface as assumed in field vane shear test.

3. The samples used for laboratory tests may not truly representative of soil mass used for field test.

4. The shearing of soil in laboratory test may not be the same as occurs in the field.

5. In the laboratory tests, pore pressure measurement is possible whereas in the field test pore pressure measurement in not possible.

6. The mode of deformation imposed on the soil are different for different tests which may lead to discrepancies between value of soil parameters such as undrained shear strength.

Soil Types Based on Stress History:

Shear strength parameters of cohesive soils are greatly affected by the stress history.

Based on stress history soil is classified as:

(i) Normally consolidated soil:

It is the soil which has never been subjected to effective pressure greater than the existing effective over burden pressure. The present effective pressure is the maximum for such type of soil.

(ii) Over consolidated soil:

It is the soil which has ever been subjected to effective pressures greater than the present effective pressure.

Numerical:

Example 7.1:

The following results are obtained from a shear box test under drained condition of 30 cm^2 sample of sandy clay. Plot the strength envelop and the shear strength parameter c' and Φ.

Norma stress (KN/m^2) 25 50 75

Shear stress (KN/m^2) 27 38 50

Solution:

The strength envelop is show is figure 7.21

From the graph

c' = 13

Φ' = 27°

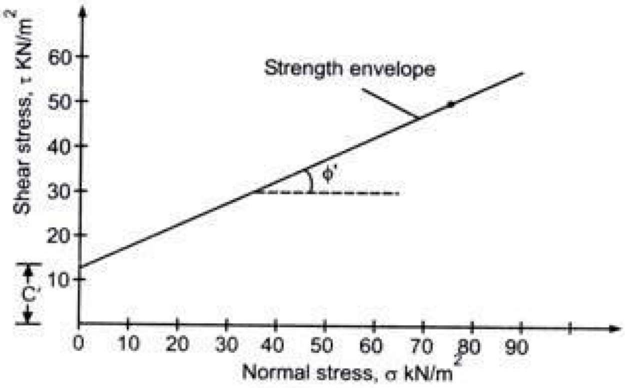


FIG. 7.21.

EXAMPLE 7.2. A direct shear box test performed on a remoulded sand sample and following results are obtained at the time of failure.

Normal load = 0.35 KN

Shear force = 0.19 KN

Area of sample = 36 cm². Determine the angle of internal friction.

Solution: Normal stress, $\sigma = \frac{\text{Normal load}}{\text{Area}} = \frac{0.35}{36 \times 10^{-4}} = 97.22 \text{ KN/m}^2$

Shear stress, $\tau = \frac{\text{Shear force}}{\text{Area}} = \frac{0.19}{36 \times 10^{-4}} = 5.78 \text{ KN/m}^2$

We know $\tau = S = \sigma \tan \phi + c$ ...(i)

As the soil is sandy, $c = 0$

$\therefore$ $\tau = \sigma \tan \phi$ ...(ii)

Putting the value of σ and τ in (*ii*) we get

$53.78 = 97.22 \tan \phi.$

$\therefore$ $\tan \phi = 0.54$

and $\phi = 28.50°$ **Ans.**

EXAMPLE 7.3. A cylindrical soil sample of saturated clay, 4 cm in diameter and 8 cm in height is tested in an unconfined compressive tester. Find the unconfined compressive strength, if the specimen failed under an axial load of 0.42 KN and the axial deformation is 7 mm.

Solution: Diameter of sample = D = 4 cm

Height = Initial length = L = 8 cm

Change of length = ΔL = 8 mm = 0.8 cm

Initial cross-sectional area = $A_1 = \frac{\pi}{4} D^2 = \frac{\pi}{4} \times 4^2 = 12.57 \text{ cm}^2$

Strain = $\epsilon = \frac{\Delta L}{L} = \frac{0.8}{8} = 0.1$

Area at failure = $A_2 = \frac{A_1}{1-\epsilon} = \frac{12.57}{1-0.1} = 13.97 \text{ cm}^2$

Unconfined compressive strength,

$$q_u = \frac{\text{Axial load at failure}}{\text{Area at failure}} = \frac{0.42}{13.97 \times 10^{-4}}$$

$$= \frac{0.42 \times 10^4}{13.97} = 300.64 \text{ KN/m}^2 \textbf{ Ans.}$$

Shear strength $Su = \frac{q_u}{2} = \frac{300.64}{2} = 150.32 \text{ KN/m}^2$

EXAMPLE 7.4. A vane, 11 cm long and 8 cm in diameter was used to measure shear strength of soft clay. Torque was applied and gradually increased to 500 kg-cm when failure took place. Calculate the shear strength. The vane, was then rotated rapidly so as to completely remoulded. The torque required to shear remoulded soil as 180 kg cm. Calculate the sensitivity.

Solution: (i) When the soil is at its natural state

$H = 11$ cm, $D = 8$ cm; $T = 500$ kg-cm

We know that

$$Su = \frac{T}{\pi D^2 \left(\frac{H}{2} + \frac{D}{6}\right)}$$

$$= \frac{500}{\pi \times (8)^2 \left(\frac{11}{2} + \frac{8}{6}\right)} = 0.364 \text{ kg/cm}^2 \quad \textbf{Ans.}$$

(ii) When the soil is remoulded

$T = 180$ kg-cm

$$S_u, \text{ remoulded} = \frac{T}{\pi D^2 \left(\frac{H}{2} + \frac{D}{6}\right)} = \frac{180}{\pi \times (8)^2 \left(\frac{11}{2} + \frac{8}{6}\right)} = 0.131 \text{ kg/cm}^2$$

$$\text{Sensitivity} = \frac{0.364}{0.131} = 2.78 \quad \textbf{Ans.}$$

11. Foundation Engineering:

SHALLOW FOUNDATIONS

Shallow foundations are also called spread footings or open footings. The 'open' refers to the fact that the foundations are made by first excavating all the earth till the bottom of the footing, and then constructing the footing. During the early stages of work, the entire footing is visible to the eye, and is therefore called an open foundation. The idea is that each footing takes the concentrated load of the column and spreads it out over a large area, so that the actual weight on the soil does not exceed the safe bearing capacity of the soil.

There are several kinds of shallow footings: individual footings, strip footings and raft foundations.

In cold climates, shallow foundations must be protected from freezing. This is because water in the soil around the foundation can freeze and expand, thereby damaging the foundation. These foundations should be built below the frost line, which is the level in the ground above which freezing occurs. If they cannot be built below the frost line, they should be protected by insulation: normally a little heat from the building will permeate into the soil and prevent freezing.

Individual footings are one of the most simple and common types of foundations. These are used when the load of the building is carried by columns. Usually, each column will have its own footing. The footing is just a square or rectangular pad of concrete on which the column sits. To get a very rough idea of the size of the footing, the engineer will take the total load on the column and divide it by the safe bearing capacity

(SBC) of the soil. For example, if a column has a vertical load of 10T, and the SBC of the soil is 10T/m2, then the area of the footing will be 1m2. In practice, the designer will look at many other factors before preparing a construction design for the footing.

STRIP FOOTINGS

Strip footings are commonly found in load-bearing masonry construction, and act as a long strip that supports the weight of an entire wall. These are used where the building loads are carried by entire walls rather than isolated columns, such as in older buildings made of masonry.

Raft Foundations, also called Mat Foundations, are most often used when basements are to be constructed. In a raft, the entire basement floor slab acts as the foundation; the weight of the building is spread evenly over the entire footprint of the building. It is called a raft because the building is like a vessel that 'floats' in a sea of soil.

Mat Foundations are used where the soil is week, and therefore building loads have to be spread over a large area, or where columns are closely spaced, which means that if individual footings were used, they would touch each other.

DEEP FOUNDATIONS.

PILE FOUNDATIONS

A pile is basically a long cylinder of a strong material such as concrete that is pushed into the ground so that structures can be supported on top of it.

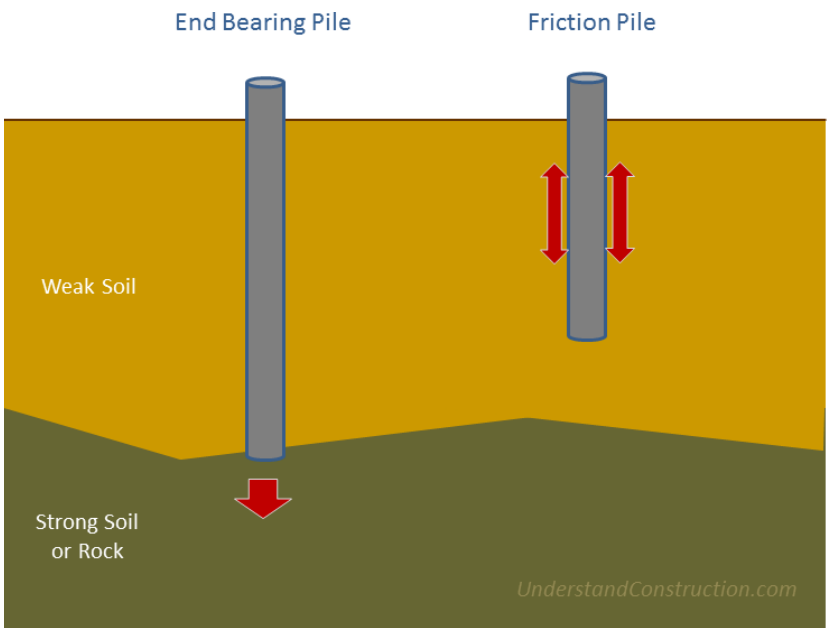
Pile foundations are used in the following situations:

When there is a layer of weak soil at the surface. This layer cannot support the weight of the building, so the loads of the building have to bypass this layer and be transferred to the layer of stronger soil or rock that is below the weak layer.

When a building has very heavy, concentrated loads, such as in a high rise structure.

Pile foundations are capable of taking higher loads than spread footings.

There are two types of pile foundations, each of which works in its own way.



End Bearing Piles

In end bearing piles, the bottom end of the pile rests on a layer of especially strong soil or rock. The load of the building is transferred through the pile onto the strong layer. In a sense, this pile acts like a column. The key principle is that the bottom end rests on the surface which is the intersection of a weak and strong layer. The load therefore bypasses the weak layer and is safely transferred to the strong layer.

Friction Piles

Friction piles work on a different principle. The pile transfers the load of the building to the soil across the full height of the pile, by friction. In other words, the entire surface of the pile, which is cylindrical in shape, works to transfer the forces to the soil.

To visualise how this works, imagine you are pushing a solid metal rod of say 4mm diameter into a tub of frozen ice cream. Once you have pushed it in, it is strong enough to support some load. The greater the embedment depth in the ice cream, the more load it can support. This is very similar to how a friction pile works. In a friction pile, the amount of load a pile can support is directly proportionate to its length.

PILE FOUNDATIONS

A pile is basically a long cylinder of a strong material such as concrete that is pushed into the ground to act as a steady support for structures built on top of it.

Pile foundations are used in the following situations:

1. When there is a layer of weak soil at the surface. This layer cannot support the weight of the building, so the loads of the building have to bypass this layer and be transferred to the layer of stronger soil or rock that is below the weak layer.

2. When a building has very heavy, concentrated loads, such as in a high rise structure, bridge, or water tank.
   Pile foundations are capable of taking higher loads than spread footings.

   There are **two fundamental types of pile foundations** (based on structural behaviour), each of which works in its own way.

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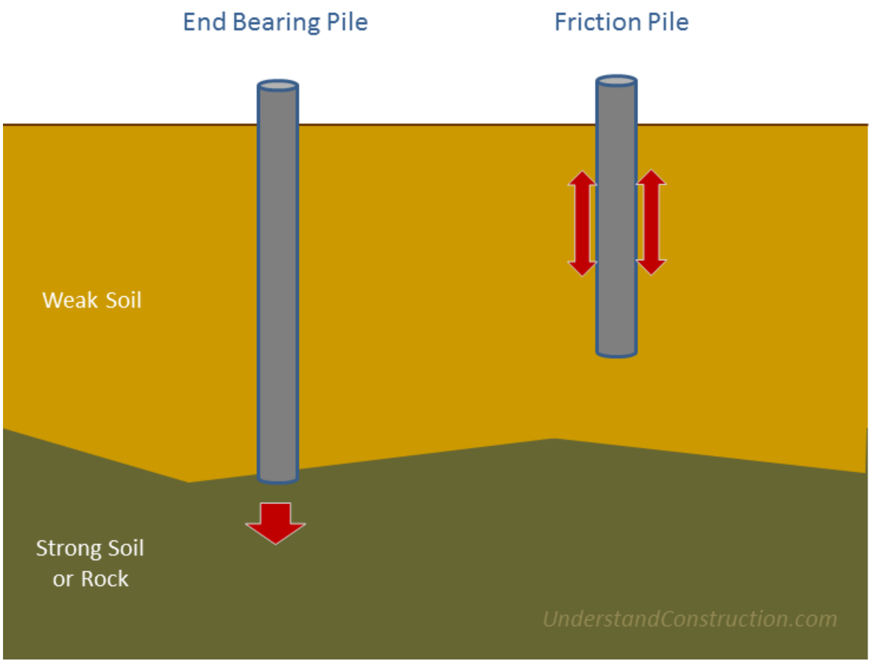
End Bearing Pile
Friction Pile
Weak Soil
Strong Soil
or Rock
UnderstandConstruction.com