GEOTECHNICAL ENGINEERING
REVISION – SHORT NOTES

MODULE 1

SOIL

Soil can be defined as a mixture of weathered rocks, minerals, humus, organic and inorganic matters. Soil is formed by the natural process of disintegration and weathering of rocks under the action of nature and climate.

Types of soil

- Residual soil
- Transported soil
    - Water transported soil
    - Wind transported soil
    - Glacier deposited soil
    - Gravity deposited soil

Field applications of soil mechanics

- Foundations
- Earthen dams
- Pavements
- Retaining wall

Three phase diagram

Functional Relationships

Index properties

Those properties of soil which are used in the identification and classification of soils are known as index properties.

Various index properties are :

1. Water content
2. Specific gravity

3. In situ density (Field density)
4. Particle size distribution
5. Consistency

Water content

The water content w, also called the moisture content is defined as the ratio of weight of water W_w to the weight of solids W_s in a given mass of soil.

$$w = \frac{Ww}{Ws} \times 100$$

Oven Drying method

105 °C – 110 °C , 24 hrs

$$w = \frac{M2 - M1}{M3 - M1} \times 100\ \%$$

- M_1 = mass of container with lid
- M_2 = mass of container with lid and wet soil
- M_3 = mass of container with lid and dry soil

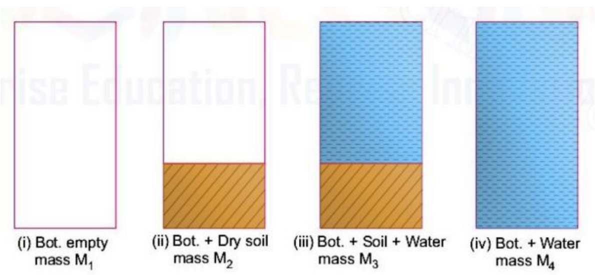
Specific gravity

There are two methods for the determination of specific gravity of soil.

1. Pycnometer method
2. Specific gravity bottle/ density bottle method

$$G = \frac{(M2 - M1)}{(M2 - M1) - (M3 - M4)}$$

M_1 = Mass of empty pycnometer
M_2 = Mass of pycnometer and dry soil
M_3 = Mass of pycnometer, soil and water
M_4 = Mass of pycnometer filled with water only



In situ density / field density

- Density is a measure of the strength of the soil.
- It is useful in estimating bearing capacity of soils, settlement of footings, earth pressure behind the retaining walls and embankments.
- There are two methods for the determination of field density:
  i. Core cutter method
  ii. Sand replacement method

Particle size distribution

Sieve analysis is the method of particle size analysis, using which we determine the amount of particles of different sizes present in the soil sample.

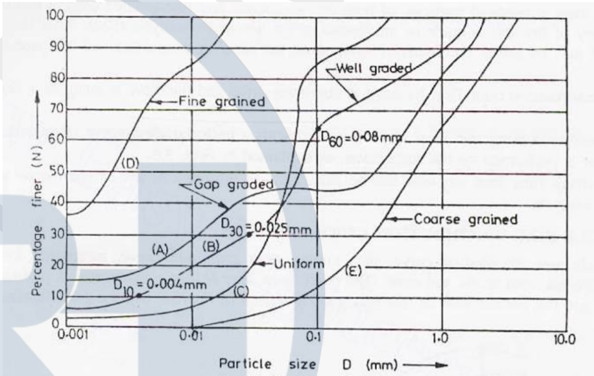


Fig. 3.8. Grading os Soils.

A curve with a hump, such as curve A, represents the soil in which some of the intermediate size particles are missing. Such a soils is called gap-graded or skip-graded.

- A flat S-curve, such as curve B, represents a soil which contains the particles of different sizes in good proportion. Such a soil is called a well-graded (or uniformly graded) soil.

- A steep curve, like C, indicates a soil containing the particles of almost the same size. Such soils are known as uniform soils.

The uniformity of a soil is expressed qualitatively by a term known as **uniformity coefficient (C_u)**

$$C_u = \frac{D60}{D10}$$

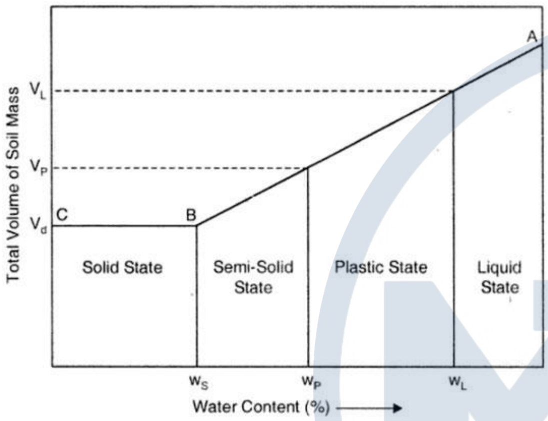
D10 size is also known as **effective size**.

The general shape of the particle size distribution curve is described by another coefficient known as the **coefficient of curvature (C_c) or the coefficient of gradation (C_g).**

$$Cc = \frac{(D30)^2}{D60 \ x \ D10}$$

Consistency

Consistency is a term which is used to describe the degree of firmness of soil.



CONSISTENCY LIMITS

Plasticity index

Consistency index

Flow index

Liquidity index

MODULE 2

PERMEABILITY OF SOIL

The ability of soil to allow flow of water through it is called as ***permeability*** of soil

Darcy's Law

- Darcy's law states that there is a linear relationship between flow velocity (v) and hydraulic gradient (i) for any given saturated soil.
- Darcy's Law can be expressed as

$$v \propto i$$
$$v = k\ i$$

k = coefficient of permeability

Factors affecting permeability

- Particle size
- Specific Surface Area of Particles
- Shape of particles
- Void ratio
- Soil structure
- Degree of saturation
- Properties of water
- Adsorbed water
- Organic matter

Determination of coefficient of permeability

Coefficient of permeability of soil can be determined by the following two methods :

1. Constant head permeability test
2. Variable head permeability test

Constant head method is suitable for coarse grained soils which are relatively more pervious because of their larger voids. While variable head is more suitable for fine grained soils which are relatively less pervious.

Constant head permeability test

$$k = \frac{qL}{Ah}$$

q = Discharge per unit time
L = length of specimen
A = Cross sectional area of soil sample
h = head causing the flow

Variable head permeability test

$$k = \frac{2.30\, a\, L}{A\, t} \log_{10}(h_1/h_2)$$

a = Area of stand pipe
L = length of specimen
A = Cross sectional area of soil sample
h1,h2 = head difference in time t

SHEAR STRENGTH OF SOIL

Shear strength of a soil is its maximum resistance to shear stresses just before the failure.

Shearing resistance is composed of

(i) Cohesion and
(ii) Friction

Classification of soils

Based on cohesion and friction, soils can be classified into $\varphi -$ soils, c- soils and $c - \varphi$ soils.

- $\varphi -$ soils are cohesion less or frictional or coarse-grained soils. e.g., sands and gravels.
- c- soils are called frictionless cohesive or fine-grained soils. e.g., clays.
- $c - \varphi$ soils are called cohesive and frictional soils like silts.

Mohr-Coulomb failure theory

Mohr stated that shear failure of any soil happens with a combination of both shear and normal stresses.

- Later, Coulomb separated the shear strength of soil into two components:

(i) Cohesion between the particles
(ii) Friction between the particles.

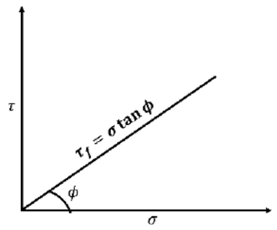
$$\tau_f = c + \sigma tan\varphi$$

τ_f - Shear strength of soil,

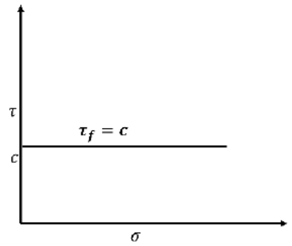
σ - Normal stress on soil,

c - Cohesion

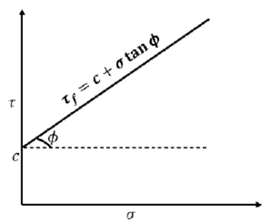
φ- Angle of internal friction.



ϕ - soils



c - soils



$c - \phi$ - soils

Modified Mohr-Coulomb failure theory

- Terzaghi established that the strength of soil is controlled by effective stresses and not by total stresses.

$$\tau_f = c' + \bar{\sigma} \tan\varphi'$$

$\bar{\sigma}$ - Effective normal stress $= \sigma - \mu$

σ - total normal stress.

u - Pore water pressure,

c' - cohesion in terms of effective stresses and

and φ' - angle of shearing resistance in terms of effective stresses.

Determination of shear strength

The following tests are used to measure the shear strength of soil.

i. Direct shear test
ii. Triaxial test
iii. Unconfined compression test
iv. Vane shear test

Vane shear test

$$\tau_f = \frac{T}{\Pi D^2[(H/2) + (D/6)]}$$

If only bottom end take part in shearing, then

$$\tau_f = \frac{T}{\Pi D^2[(H/2) + (D/12)]}$$

where T - Maximum torque at failure.

H - Height of vanes,

D - Diameter of rotating blades.

MODULE 3

COMPACTION OF SOIL

Soil compaction is the practice of applying mechanical compactive effort to densify a soil by reducing the air void space between soil particles.

Necessity of compaction

- Bearing capacity
- Shear strength
- Settlement of foundation
- Soil shrinking, expanding

Standard proctor test

3 layers – 25 blows

$$\rho = \frac{M}{V} \text{ gm/ml}$$

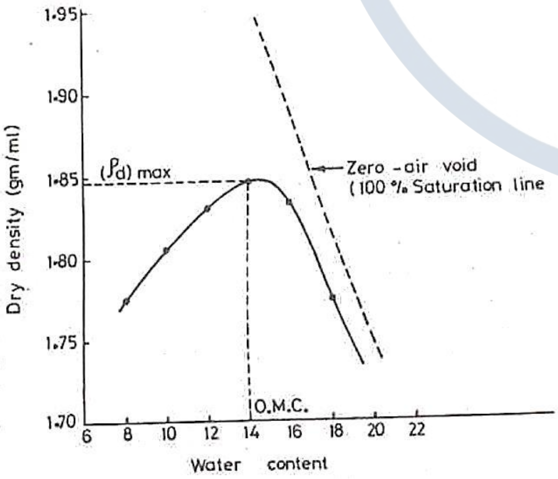
M – Mass of compacted soil (gm)
V – volume of the mold (ml)

$$\text{Dry density, } \rho_d = \frac{\rho}{1 + w}$$

w – Water content

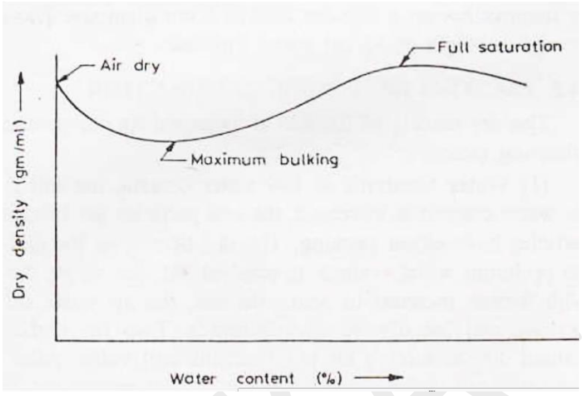
Compaction curve

1. Cohesive soil



It is observed that the dry density initially increases with an increase in water content till the **maximum density** $(\rho_d)_{max}$ is attained. With further increase in water content, the dry density decreases. The water content corresponding to the maximum dry density is known as optimum water content (O.W.C.) or the **optimum moisture content (O.M.C.).**

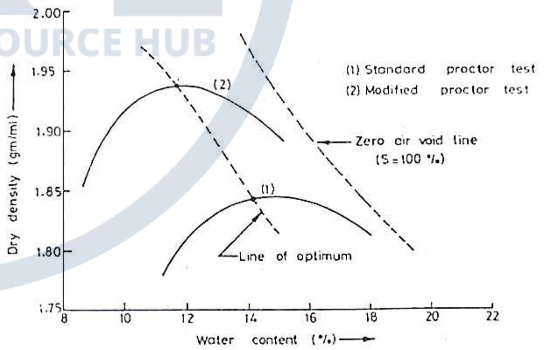
2. Cohesionless soil



In the case of pure cohesionless soils, the effect of water content on dry density of soil is not well defined when the water content is below the optimum value. There is a large scattering of the points on the compaction curve. This is due to bulking of sand. Generally, the dry density decreases with an increase in water content in this range. The maximum dry density occurs when the soil is fully saturated. If the water content is increased beyond this point, the dry density again decreases. They do not display a distinct optimum moisture content.

<u>MODIFIED PROCTOR TEST</u>

5 layers – 25 blows



Compaction Crves of Standard Proctor Test and Modified Proctor Test.

Facotors affecting compaction

- Water content
- Amount of compaction
- Type of soil
- Method of compaction
- Admixture

Methods of compaction

1. Tampers
2. Rollers
3. Vibratory compactors

Suitability of various compaction equipment

- Smooth wheel roller - Suitable for coarse grained soil like gravel, crushed stone and sand etc. Generally used in construction of road.
- Sheep foot roller - Suitable for cohesive soil. Used in construction of earthen dam
- Pneumatic tyred roller - Suitable for all types of soil but generally preferred for cohesive soil.
- Rammer- Rammers are generally preferred for cohesive soil
- Vibrator - This method is best suited for compaction of sand.

CONSOLIDATION OF SOIL

Reduction in volume of soil due to the expulsion of water under gradually applied load.

Compaction	Consolidation
Compaction is the compression of soil by the expulsion of air from the voids of the soil.	Consolidation is the compression of soil by the expulsion of water from voids of the soil.
It is a quick process.	It is a slow process.
Short term loading is required	Long term loading is required.
Loading is applied in a dynamic way.	Loading is static and constant.
Any type of soil either it is cohesion or cohesionless can be compacted.	Consolidation applies to cohesive soils only especially for low permeable clay.
Degree of saturation of soil to be compacted should be less than 100%.	Degree of saturation of soil to be consolidated should be 100%.
Shear strength of soil increases.	Shear strength of soil increases.
Compaction is done purposely in order to get maximum dry density of soil.	Consolidation of soil occurs naturally due to structural loads from foundations.
It is done before the construction of structure.	It begins naturally along with the construction work.
To construct roads, earthen dams, embankments etc. compaction is useful.	The foundation soil properties will improve over long period due to consolidation.

Different stages of consolidation

1. Initial consolidation

It is the reduction in volume of soil just after the application of load.
Partially sat soil – air voids
Fully sat soil – solid particles

2. Primary consolidation

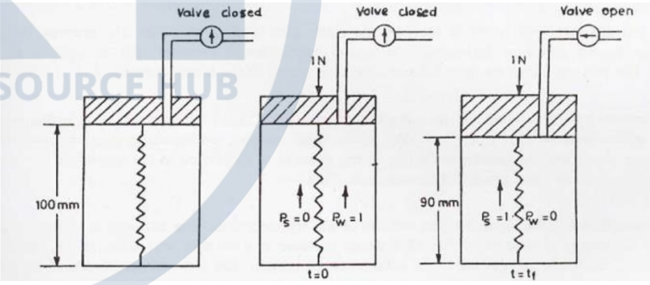
After initial consolidation, further reduction in volume occurs due to expulsion of water from voids.
This decrease in volume depends on permeability of soil and hence is time dependent.

3. Secondary consolidation

The reduction in volume continues even after the primary consolidation is over.
It is due to the rearrangement of soil and water particles.

Spring analogy for consolidation

- Given by Terzaghi
- The process of consolidation is explained with the help of spring analogy.
- The system consists of a cylinder fitted with a piston having a valve. The cylinder is filled with water and contains a spring.



MODULE 4

SOIL EXPLORATION

Both field and laboratory investigations required to obtain the necessary data for the soils for this purpose are collectively called soil exploration.

Objectives of site investigation

- the nature of the soil deposits.
- type and depth of foundation
- bearing capacity of soil.
- depth and thickness and extent of the soil strata
- probable maximum and differential settlement.
- ground water .
- lateral earth pressure .
- To select suitable construction techniques.

Stages of site investigation

Sub-surface explorations are carried out in 3 stages:

1) Reconnaissance
2) Preliminary exploration
3) Detailed exploration

Reconnaissance is the first step which includes a visit to the site and study of maps and other relevant records. It helps in deciding future programme of site investigations, scope of work, method of exploration to be adopted, types of samples to be taken.

Preliminary exploration is to determine the depth, thickness, extent and composition of each soil stratum at the site. Depth of the bed rock and ground water table is also determined.

Detailed explorations are done to determine the engineering properties of soils in different strata. It includes an extensive boring programme, sampling and testing of samples in laboratory.

DEPTH, LOCATION AND NUMBER OF TEST PITS OR BORE HOLES

Nature of the project	Spacing of borings (m)
Highway (subgrade survey)	300 to 600
Borrow pits	30 to 120
Earth dam	30 to 60
Single story factories	30 to 90
Multi-storey buildings	15 to 30

Nature of the project	Depth of exploration (m)
Isolated spread footings or raft or adjacent footings with clear spacing equal or greater than four times the width	One and half times the width
Adjacent footings with clear spacing less than twice the width	One and half times the length
Adjacent rows of footings (i) With clear spacing between rows less than twice the width (ii) With clear spacing between the rows greater than twice the width (iii) With clear spacing between rows greater than or equal to four times the width	 (i) Four and half times the width (ii) Three times the width (iii) One and half times the width
Pile and Well foundations	One and half times the width of structure from bearing level (toe of pile or bottom of well)
Road cuts	Equal to the bottom width of the cut
Fill	Two metres below the ground level or equal to the height of the fill whichever is greater

Methods of the explorations

The various methods of the explorations may be grouped as follows:

1. Open excavations
2. Borings
3. Geophysical methods.

The methods of boring or drilling are:

1. Auger boring
2. Wash boring
3. Percussion boring
4. Rotary boring
5. Core drilling

There are two geophysical methods
1.Seismic refraction method
2.Electrical resistivity method

Types of soil samples

- Disturbed samples are the samples in which the natural structure of the soil gets disturbed during sampling. But these samples represent the composition and the mineral content of the soil.
- Used to determine the index properties of soil.
- Undisturbed samples are the samples in which the natural structure of the soil and the water content are retained. - engineering properties of soil

BEARING CAPACITY OF SOIL

Soil when stressed due to loading, tend to deform. The maximum load per unit area which the soil or rock can carry without yielding or displacement is termed as the bearing capacity of soils.

Ultimate bearing capacity (q_u)

- The gross pressure at the base of the foundation at which soil fails is called ultimate bearing capacity.

Gross safe bearing capacity (q_s)

- When ultimate bearing capacity is divided by factor of safety it will give gross safe bearing capacity.
- $q_s = q_u/F$

Net allowable bearing pressure (q_{na})

- This is the pressure we can used for the design of foundations. This is equal to net safe bearing pressure if $q_{np} > q_{ns}$. In the reverse case it is equal to net safe settlement pressure.

Terzaghi's bearing capacity theory

Terzaghi's bearing capacity theory is useful to determine the bearing capacity of soils under a strip footing.

Assumptions:

- The base of the strip footing is rough.
- The depth of footing is less than or equal to its breadth i.e., shallow footing.
- He neglected the shear strength of soil above the base of footing and replaced it with uniform surcharge. (D_f)
- The load acting on the footing is uniformly distributed and is acting in vertical direction.
- He assumed that the length of the footing is infinite.
- He considered Mohr-coulomb equation as a governing factor for the shear strength of soil.

Terzaghi's Bearing capacity equations:

- Strip footings:

$$q_u = c\,N_c + \gamma\,D\,N_q + 0.5\,\gamma\,B\,N_\gamma$$

- Square footings:

$$q_u = 1.2\,c\,N_c + \gamma\,D\,N_q + 0.4\,\gamma\,B\,N_\gamma$$

- Circular footings:

$$q_u = 1.2\,c\,N_c + \gamma\,D\,N_q + 0.3\,\gamma\,B\,N_\gamma$$

Bearing capacity failures

1. General shear failure
2. Local shear failure
3. Punching shear failure

General Shear Failure

- This type of failure is seen in dense and stiff soil.
- Continuous, well defined and distinct failure surface develops between the edge of footing and ground surface.
- Dense or stiff soil that undergoes low compressibility experiences this failure.
- Continuous bulging of shear mass adjacent to footing is visible.
- Failure is accompanied by tilting of footing.

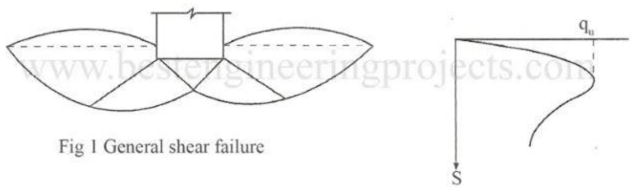


Fig 1 General shear failure

Local Shear Failure

- This type of failure is seen in relatively loose and soft soil.
- A significant compression of soil below the footing and partial development of plastic equilibrium is observed.
- Failure is not sudden and there is no tilting of footing.
- Failure surface does not reach the ground surface and slight bulging of soil around the footing is observed.
- Failure surface is not well defined

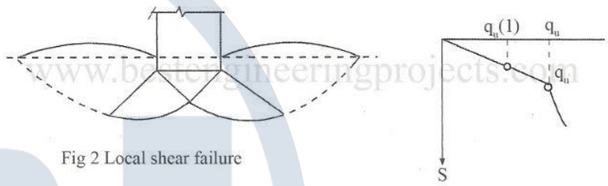
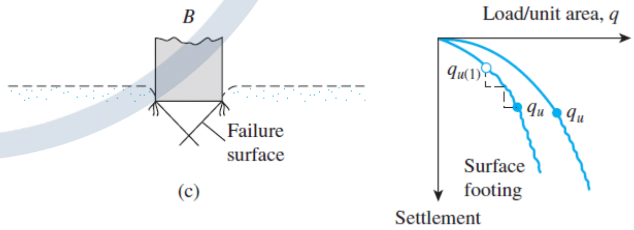


Fig 2 Local shear failure

Punching shear failure

- This type of failure occurs in a soil of very high compressibility.
- Failure pattern is not observed. Bulging of soil around the footing is absent.
- Failure is characterized by very large settlement.

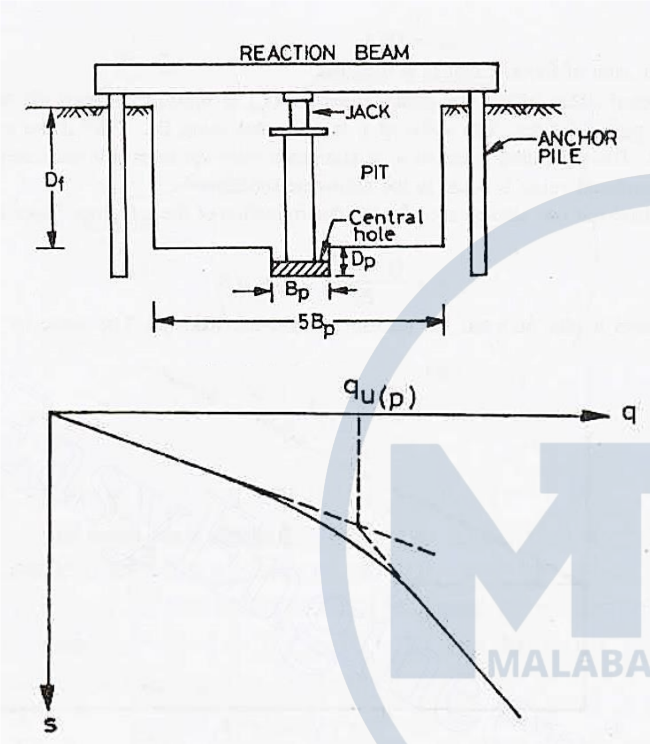


Determination of bearing capacity of soil

1. Plate load test
2. Standard Penetration Test

Plate load Test

- The plate load test is a field test, which is performed to determine the ultimate bearing capacity of the soil and the probable settlement under a given load.
- This test is very popular for the selection and design of the shallow foundation.
- The test essentially consists of loading a rigid plate at the foundation level and determining the settlement corresponding to each load increment.
- The ultimate bearing capacity then takes as the load at which the plate starts sinking at a rapid rate.



Standard Penetration Test

- The standard penetration tests are carried out in borehole.
- The test will measure the resistance of the soil strata to the penetration undergone.
- A correlation is derived between the soil properties and the penetration resistance.
- The test is extremely useful for determining the relative density and the angle of shearing resistance of cohesionless soils.

FOUNDATIONS