Geotechnical Engineering

For

Civil Engineering

By

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Syllabus for Geotechnical Engineering

Soil Mechanics: Origin of Soils, Soil Structure and Fabric; Three-Phase System and Phase Relationships, index Properties; Unified and Indian Standard Soil Classification System; Permeability-One Dimensional Flow, Darcy's Law; Seepage Through Soils-Two-Dimensional Flow, Flow Nets, Uplift Pressure, Piping; Principle of Effective Stress, Capillarity, Seepage Force and Quicksand Condition; Compaction in Laboratory and Field Conditions; One-Dimensional Consolidation, Time Rate of Consolidation; Mohr's Circle, Stress Paths, Effective and Total Shear Strength Parameters, Characteristics of Clays and Sand.

Foundation Engineering: Sub-Surface Investigations - Scope, Drilling Bore Holes, Sampling, Plate Load Test, Standard Penetration and Cone Penetration Tests; Earth Pressure Theories -Rankine and Coulomb; Stability of Slopes-Finite and Infinite Slopes, Method of Slices and Bishop's Method; Stress Distribution in Soils-Boussinesq's and Westergaard's Theories, Pressure Bulbs; Shallow Foundations-Terzaghi's and Meyerhoff's Bearing Capacity Theories, Effect of Water Table; Combined Footing and Raft Foundation; Contact Pressure; Settlement Analysis in Sands and Clays; Deep Foundations-Types of Piles, Dynamic and Static Formulae, Load Capacity of Piles in Sands and Clays, Pile Load Test, Negative Skin Friction.

Previous Year GATE Papers and Analysis

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"For it matters not how small the beginning may seem to be. What is once well done, is well done forever"

...**Henry David Thoreau**

CHAPTER 1

Introduction to Soil Mechanics

Learning Objectives

After reading this chapter, you will know:

1. Three Phase System
2. Origin of Soil
3. Water Content Density and Unit Weight
4. Pyrometer Method

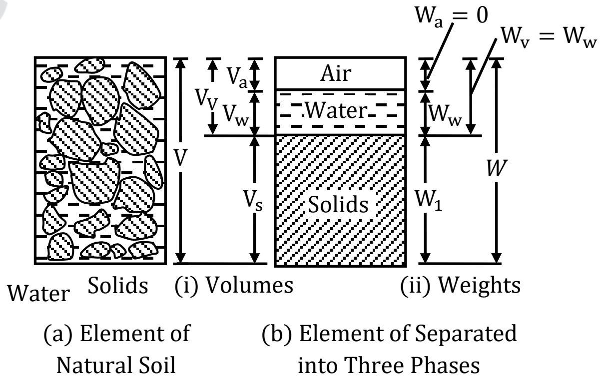
Origin of Soil

Soil is a complex material produced by weathering of solid rock. Weathering is caused by physical agencies and geological cycle followed by transportation, denudation and upheaval.

- Residual soil which remain in place directly over parent rock.
- Transported soil is transported by physical agencies like wind, water etc.
- Water Transported soil are called alluvial, marine or lacustrine.
- Lacustrine soil find their origin in lakes.
- Alluvial soil in flowing water and marine soil in seas.
- Air blown soil are called Aeolian.
- Loess is windblown silt or salty clay.
- Accumulation of decaying and chemically deposited vegetable matter under excessive moisture results in formation of cumulose soils (peat and muck).

Three Phase System

- Soil mass is 3 phase system consisting of solid particles, water and air.
- In dry soil, only soil particles and air voids are present. As shown in figure. Figure (a) shows the element of natural soil and figure (b) shows elements separated into 3 phases.



Soil as a Three Phase System

Water Content, Density and Unit Weights

(a) **Water Content:** Ratio of weight of water W_w to weight of solids, W_s

$$w = \frac{W_w}{W_d} \times 100$$

(b) **Density of Soil:** Mass of soil per unit volume is called density of soil

- **Bulk Density:** Also known as moist density is total mass M of soil per unit of its total volume.
  $$\rho = \frac{M}{V}$$
- **Dry Density (ρ_d):** Mass of solids per unit of total volume (prior to drying) of the soil mass.
  $$\rho_d = \frac{M_d}{V}$$
- **Density of Solid (ρ_s):** Mass of soil solids (M_d) per unit volume of solids V_s
  $$\rho_s = \frac{M_d}{V_s}$$
- **Saturated Density:** When soil mass is saturated its bulk density is called saturated density (ρ_{sat})
- **Submerged Density:** Submerged mass of solids $(M_d)_{sub}$ per unit of total volume.
  $$\rho' = \frac{(M_d)_{sub}}{V}$$
  $$\rho' = \rho_{sat} - \rho_w$$

Unit Weight of Soil Mass

- **Bulk Unit Weight (γ)=** Total weight W of a soil mass per unit of its total volume V
  $$\gamma = \frac{W}{V}$$
- **Dry Unit Weight:** Weight of solids per unit of its total volume of soil mass
  $$\gamma_d = \frac{W_d}{V}$$
- **Unit Weight of Solids:** weight of soil solids is weight of soil solids W_d per unit volume of solids
  $$\gamma_s = \frac{W_d}{W_s}$$
- **Saturated Unit Weight (γ_{sat}):** When the soil mass is saturated, its bulk unit weight is called saturated unit weight.
- **Submerged Unit Weight (γ'):** Submerged unit weight of soil solids $(W_d)_{sub}$ per unit of total volume (V) of soil mass.
  $$\gamma' = \frac{(W_d)_{sub}}{V}$$

Specific Gravity:

Specific gravity G is defined as the ratio of the weight of a given volume of soil solids at a given temperature to the weight of an equal volume of distilled water at same temperature.

$$G = \frac{\gamma_s}{\gamma_w}$$

The apparent specific gravity G_m denotes mass of soil to equal mass of water

$$G_m = \frac{\gamma}{\gamma_w}$$

Voids Ratio, Porosity and Degree of Saturation

Voids Ratio: Voids ratio e of a given soil sample is the ratio of the volume of voids to the volume of soil solids in given soil mass.

Thus $e = \frac{V_v}{V_s}$

Void ratios of fine grained soils are generally higher than those of coarse grained soils in general $e > 0$

Porosity: The porosity n of a given soil sample is the ratio of the volume of voids to the total volume of the given soil mass.

$$n = \frac{V_v}{V}$$

Relation between e and n

$$n = \frac{e}{(1+e)}$$

$$e = \frac{n}{1-n}$$

Degree of Saturation:

Volume of water to volume of voids is called degree of saturation

$$S = \frac{V_w}{V_v}$$

For perfectly dry sample, $S = 0$ and for perfectly saturated sample, $S = 1$.

Percentage of Air Voids:

Ratio of volume of air voids to the total volume of soil mass and is expressed as percentage

$$n_a = \frac{V_a}{V} \times 100$$

Air Content:

Air content a_c is defined as the ratio of volume of air voids to the volume of voids

$$a_c = \frac{V_a}{V_v}$$

$$V_a = V_V - V_w$$

$$a_c = 1 - S$$

Density Index and Relative Compaction:

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

The term density Index is applicable only for cohesionless soil.

Relative Compaction: Relative compaction is defined as

$$R_c = \frac{\gamma_d}{\gamma_{d,max}}$$

Where $\gamma_{d,max}$ is obtained from compaction test.

Fundamental Relationships:

- Relation between e, w, G and S

  $S = \frac{V_w}{V_v} = \frac{e_w}{e}$

  Hence $e_w = e_s$

  The term e_w is known as the water voids ratio and other symbols have their usual meaning.

  $e = \frac{e_w}{s}$

- Relation between e, S and n_a

  $n_a = \frac{V_a}{V}$

  $V_a = V_v - V_w$

  $V = V_s + V_v = 1 + e$

  $\therefore n_a = \frac{e - e_w}{1 + e}$, since $e_w = e_s$

  $\therefore n_a = \frac{e(1 - s)}{1 + e}$

- Relation between n_a, n and a_c

  $n_a = n.a_c$

- Relation between γ_d, G and e (or n)

  $\gamma_d = \frac{G\gamma_w}{1 + e}$

  Also $\gamma_d = (1 - n)G\gamma_w$

- Relation between γ_{sat}, G and e

  $\gamma_{sat} = \frac{\text{total weight of saturated soil}}{\text{Total volume of soil}}$

  $= \frac{\gamma_s V_s + \gamma_w V_w}{V}$

  $\gamma_{sat} = \frac{(G + e)\gamma_w}{1 + e}$

- Relation between γ, G, e and S

  $\gamma = \frac{(G + e)\gamma_w}{1 + e}$

  for γ_{sat},

  $\gamma_{sat} = \frac{(G + R)\gamma_w}{1 + e}$

  for γ submerged

  $\gamma_{sub} = \frac{(G - 1)\gamma_w}{1 + e}$

- Relation between γ', γ_d and n

  $\gamma' = \gamma d - (1 - n)\gamma_w$

- Relation between γ_d, G, w and n_a

  $\gamma_d = \frac{(1 - n_a)\gamma_w}{w + \frac{1}{G}}$

Pycnometer Method

This is also a quick method of determining the water content of those soils whose specific gravity G is accurately known. Pycnometer is a large size density bottle of about 900 ml capacity.

Test Procedure:

- Take a clean, dry pycnometer, and find its mass with its cap and washer (M_1)
- Put about 200g to 400g of wet soil sample in the pycnometer and find its mass with its cap and washer (M_2)
- Fill the pycnometer to half its height and mix it thoroughly with the glass rod. Add more water, and stir it. Replace the screw top and fill the pycnometer flush with the hole in the conical cap. Dry the pycnometer from outside, and find its mass (M_3)
- Empty the pycnometer, clean it thoroughly, and fill it with clean water to the hole of the conical cap, and find its mass (M_4)
- The water content is then calculated from the following expression:

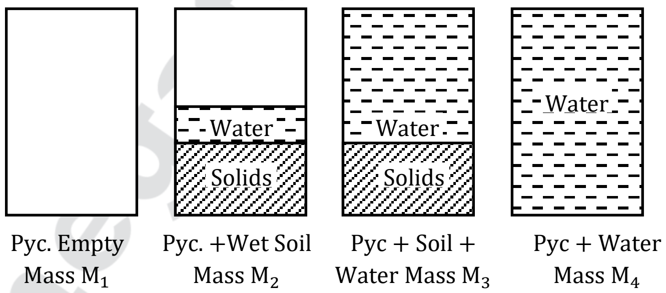
$$w = \left[\left[\frac{M_2 - M_1}{M_3 - M_4}\right]\left[\frac{G-1}{G}\right] - 1\right] \times 100$$

If M_d is the mass of soil particles; the volume of solid particles will be equal to M_d/G. Thus, if the solids from (iii) are replaced with water of mass M_d/G, we get the mass M4 indicated in (iv). Thus,

$$M_4 = M_3 - M_d + \frac{M_d}{G} \text{ or } M_d\left[\frac{G-1}{G}\right] = M_3 - M_4$$

From which, $M_d = (M_3 - M_4)\dfrac{G}{G-1}$

Now mass of water M_w in the wet soil sample $= (M_2 - M_1) - M_d$



Water Content Determintation

$$w = \frac{M_w}{M_d} \times 100 = \frac{M_2 - M_2 - M_d}{M_d} \times 100$$

$$= \left[\frac{M_2 - M_1}{M_d} - 1\right] 100 = \left[\left[\frac{M_2 - M_1}{M_3 - M_4}\right]\left[\frac{G-1}{G}\right] - 1\right] \times 100$$

Note: This method is suitable for coarse grained soils only, since w_3 cannot be determined for fine grained soils accurately.