Soil and foundation Engg.

Soil Mechanics is a discipline of Civil Engineering involving the study of soil, its behaviour and application as an engineering material.

Soil: To an engineer, it is a material that can be:

- **built on:** foundations of buildings, bridges
- **built in:** basements, culverts, tunnels
- **built with:** embankments, roads, dams
- **supported:** retaining walls

Soil Formation: Soils are formed from materials that have resulted from the disintegration of rocks by various processes of physical and chemical weathering.

Breakdown of parent rock: weathering, decomposition, erosion.

- **Transportation** to site of final deposition: gravity, flowing water, ice, wind.
- **Environment** of final deposition: flood plain, river terrace, glacial moraine, lacustrine or marine.
- **Subsequent conditions** of loading and drainage: little or no surcharge, heavy surcharge due to ice or overlying deposits, change from saline to freshwater, leaching, contamination.

All soils originate, directly or indirectly, from different rock types.

Physical weathering reduces the size of the parent rock material, without any change in the original composition of the parent rock. Physical or mechanical processes taking place on the earth's surface include the actions of water, frost, temperature changes, wind and ice.

Chemical weathering not only breaks up the material into smaller particles but alters the nature of the original parent rock itself. The main processes responsible are hydration, oxidation, and carbonation. New compounds are formed due to the chemical alterations.

Transportation agencies can be combinations of gravity, flowing water or air, and moving ice. In water or air, the grains become sub-rounded or rounded, and the grain sizes get sorted so as to form poorly-graded deposits. In moving ice, grinding and crushing occur, size distribution becomes wider forming well-graded deposits.

Geological Classification of Soils

Soils as they are found in different regions can be classified into two broad categories:

(1) Residual soils
(2) Transported soils

Residual Soils
Residual soils are found at the same location where they have been formed. Generally, the depth of residual soils varies from 5 to 20 m.

Transported Soils
Weathered rock materials can be moved from their original site to new locations by one or more of the transportation agencies to form transported soils. Tranported soils are classified based on the mode of transportation and the finaldeposition environment.

Alluvial Deposits, Aeolian deposits, Marine deposits, Lacustrine deposits, Colluvial deposits

(a) Soils that are carried and deposited by rivers are called ***alluvial deposits.***

(b) Soils that are deposited by flowing water or surface runoff while entering a lake are called ***lacustrine deposits.***Atlernate layers are formed in different seasons depending on flow rate.

(c) If the deposits are made by rivers in sea water, they are called ***marine deposits.*** Marine deposits contain both particulate material brought from the shore as well as organic remnants of marine life forms.

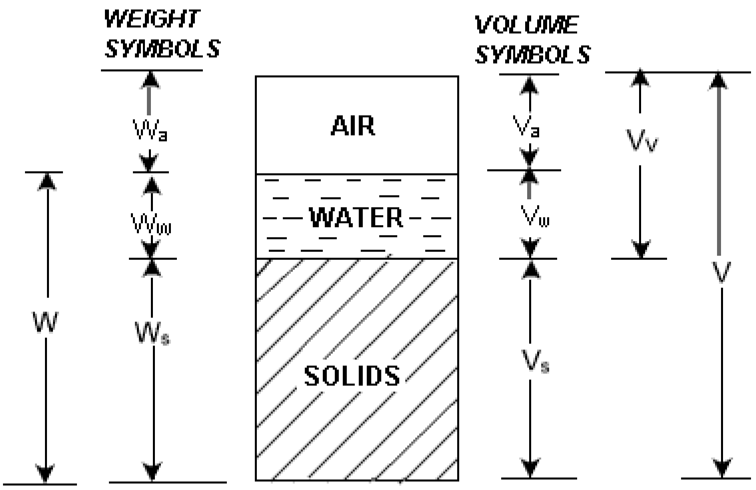
(d) Melting of a glacier causes the deposition of all the materials scoured by it leading to formation of ***glacial deposits.***

(e) Soil particles carried by wind and subsequently deposited are known as ***aeolian deposits.***

Chapter :2 Saturated and Partially saturated soils

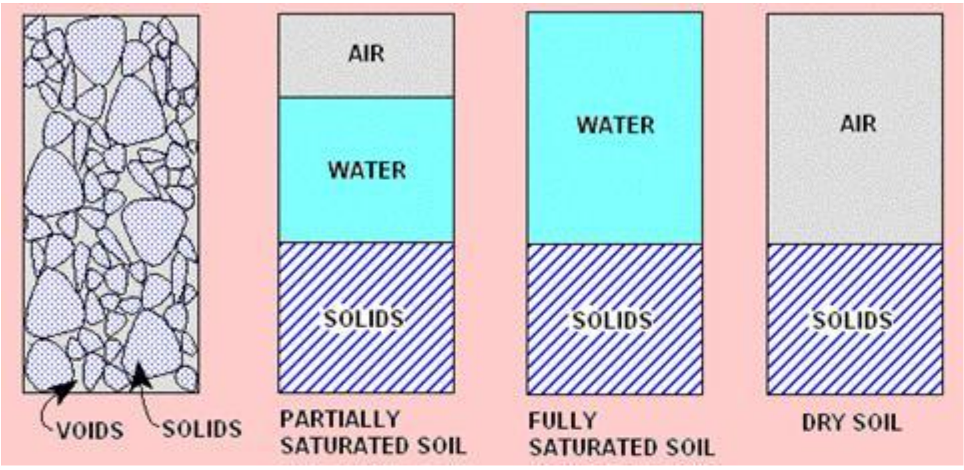
Soil consist of solid particles (mineral grains, rock fragments) with water and air in the voids between the particles.

As the relative proportions of the three phases vary in any soil deposit, it is useful to consider a soil model which will represent these phases distinctly and properly quantify the amount of each phase. A schematic diagram of the three-phase system is shown in terms of weight and volume symbols respectively for soil solids, water, and air. The weight of air can be neglected.



The soil model is given dimensional values for the solid, water and air components.

Total volume, $V = V_s + V_w + V_v$



Volume Relations

As the amounts of both water and air are variable, the volume of solids is taken as the reference quantity. Thus, several relational volumetric quantities may be defined. The following are the **basic volume relations:**

1. Void ratio (e) is the ratio of the volume of voids (V_v) to the volume of soil solids (V_s), and is expressed as a decimal.

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

2. Porosity (n) is the ratio of the volume of voids to the total volume of soil (V), and is expressed as a percentage.

$$n = \frac{V_v}{V} x\, 100$$

Void ratio and porosity are inter-related to each other as follows:

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

3. The volume of water (V_w) in a soil can vary between zero (i.e. a dry soil) and the volume of voids. This can be expressed as the **degree of saturation (S)** in percentage.

$$S = \frac{V_w}{V_v} x\, 100$$

For a dry soil, S = 0%, and for a fully saturated soil, S = 100%.

4. Air content (a_c) is the ratio of the volume of air (V_a) to the volume of voids.

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

5. Percentage air voids (n_a) is the ratio of the volume of air to the total volume.

$$n_a = \frac{V_a}{V} x\, 100 = n\ x\ a_c$$

Weight Relations

Density is a measure of the quantity of mass in a unit volume of material. Unit weight is a measure of the weight of a unit volume of material. Both can be used interchangeably. The units of density are ton/m³, kg/m³ or g/cm³. The following are the **basic weight relations:**

1. The ratio of the mass of water present to the mass of solid particles is called the **water content (w)**, or sometimes the **moisture content.**

$$w = \frac{W_W}{W_S}$$

Its value is 0% for dry soil and its magnitude can exceed 100%.

2. The mass of solid particles is usually expressed in terms of their **particle unit weight** (γ_s) or **specific gravity** (**G_s**) of the soil grain solids .

$$\gamma_s = \frac{W_s}{V_s} = G_s \cdot \gamma_W$$

where γ_W = Unit weight of water

For most inorganic soils, the value of G_s lies between 2.60 and 2.80. The presence of organic material reduces the value of G_s.

3. Dry unit weight (γ_d) is a measure of the amount of solid particles per unit volume.

$$\gamma_d = \frac{W_s}{V}$$

4. Bulk unit weight $(\gamma_t \text{ or } \gamma)$ is a measure of the amount of solid particles plus water per unit volume.

$$\gamma_t = \gamma = \frac{(W_s + W_W)}{(V_s + V_V)}$$

5. Saturated unit weight (γ_{sat}) is equal to the bulk density when the total voids is filled up with water.

6. Buoyant unit weight (γ') or **submerged unit weight** is the effective mass per unit volume when the soil is submerged below standing water or below the ground water table.

$$\gamma' = \gamma_{sat} - \gamma_W$$

Inter-Relations

It is important to quantify the state of a soil immediately after receiving in the laboratory and prior to commencing other tests. The water content and unit weight are particularly important, since they may change during transportation and storage.

Some physical state properties are calculated following the practical measurement of others. For example, dry unit weight can be determined from bulk unit weight and water content. The following are some **inter-relations:**

1. $$w = \frac{W_W}{W_s} = \frac{\gamma_W . V_W}{G_s . \gamma_W . V_s} = \frac{V_W}{G_s . V_s} = \frac{S . V_v}{G_s . V_s} = \frac{S . e}{G_s}$$

2. $$\gamma = \frac{(G_s + S.e).\gamma_w}{1+e}$$

3. $$\gamma = \frac{(1+w).G_s.\gamma_w}{1+e}$$

4. $$\gamma_d = \frac{G_s.\gamma_w}{1+e}$$

5. $$\gamma_d = \frac{\gamma}{1+w}$$

6. $$\gamma' = \frac{[(G_s - 1) + (S-1)e] \; x \; \gamma_w}{1+e}$$

7. $$\gamma' = \frac{(G_s - 1).\gamma_w}{1+e}$$

Examples

Example 2: The dry density of a sand with porosity of 0.387 is 1600 kg/m^3. Find the void ratio of the soil and the specific gravity of the soil solids. [Take $\gamma_w = 1000\ kg/m^3$]

n = 0.387

γ_d = 1600 kg/m^3

Solution:

(a) e = $\frac{n}{1-n} = \frac{0.387}{1-0.387}$ = 0.631

(b) $\gamma_d = \frac{G_s.\gamma_w}{1+e}$

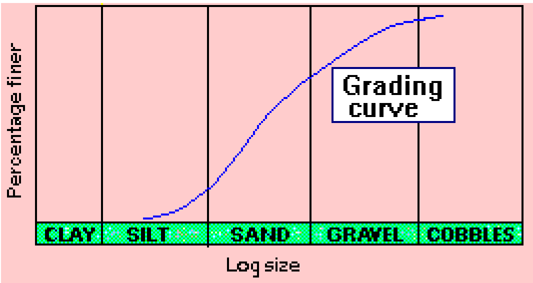
$\therefore$ $G_s = \frac{(1+e)}{\gamma_w}.\gamma_d = \frac{1+0.631}{1000}\ x\ 1600 = 2.61$

CHAPTER:3 CLASSIFICATION AND IDENTIFICATION OF SOILS

Classification of soil is the separation of soil into classes or groups each having similar characteristics and potentially similar behaviour. A classification for engineering purposes should be based mainly on mechanical properties: permeability, stiffness, strength. The class to which a soil belongs can be used in its description.

GRAIN SIZE DISTRIBUTION CURVE

The size distribution curves, as obtained from coarse and fine grained portions, can be combined to form one complete **grain-size distribution curve** (also known as **grading curve**). A typical grading curve is shown.

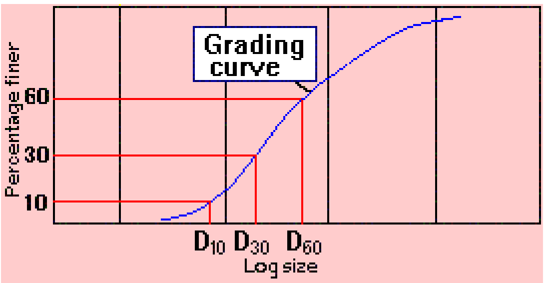


From the complete grain-size distribution curve, useful information can be obtained such as:

1. **Grading characteristics**, which indicate the uniformity and range in grain-size distribution.

   2. Percentages (or **fractions)** of gravel, sand, silt and clay-size.

A grading curve is a useful aid to soil description. The geometric properties of a grading curve are called **grading characteristics**.



To obtain the grading characteristics, three points are located first on the grading curve.

D_{60} = size at 60% finer by weight
D_{30} = size at 30% finer by weight
D_{10} = size at 10% finer by weight

The grading characteristics are then determined as follows:

1. Effective size = D_{10}

2. Uniformity coefficient, $C_u = \dfrac{D_{60}}{D_{10}}$

3. Curvature coefficient, $C_c = \dfrac{(D_{30})^2}{D_{60} . D_{10}}$

Both $\mathbf{C_u}$ and $\mathbf{C_c}$ will be 1 for a single-sized soil.

$C_u > 5$ **indicates a well-graded soil**, i.e. a soil which has a distribution of particles over a wide size range.

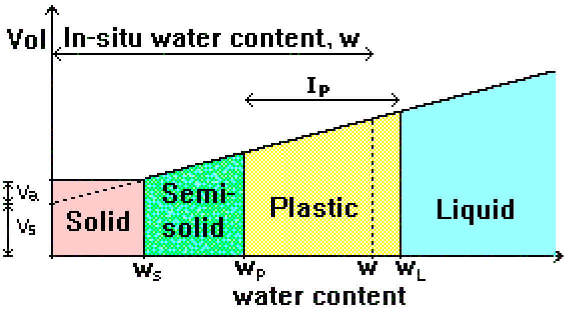
C_c **between 1 and 3** also indicates a well-graded soil.

$C_u < 3$ indicates a **uniform soil**, i.e. a soil which has a very narrow particle size range.

The **consistency** of a fine-grained soil refers to its firmness, and it varies with the water content of the soil.

A gradual increase in water content causes the soil to change from ***solid*** to ***semi-solid*** to ***plastic*** to ***liquid*** states. The water contents at which the consistency changes from one state to the other are called **consistency limits** (or **Atterberg limits**).

The three limits are known as the shrinkage limit (**W_S**), plastic limit (**W_P**), and liquid limit (**W_L**) as shown. The values of these limits can be obtained from laboratory tests.



Two of these are utilised in the classification of fine soils:

Liquid limit (W_L) - change of consistency from plastic to liquid state
Plastic limit (W_P) - change of consistency from brittle/crumbly to plastic state

The difference between the liquid limit and the plastic limit is known as the **plasticity index** (**I_P**), and it is in this range of water content that the soil has a plastic consistency. The consistency of most soils in the field will be plastic or semi-solid.

Classification Based on Grain Size
The range of particle sizes encountered in soils is very large: from boulders with dimension of over 300 mm down to clay particles that are less than 0.002 mm. Some clays contain particles less than 0.001 mm in size which behave as colloids, i.e. do not settle in water.

In the **Indian Standard Soil Classification System (ISSCS),** soils are classified into groups according to size, and the groups are further divided into coarse, medium and fine sub-groups.

The grain-size range is used as the basis for grouping soil particles into boulder, cobble, gravel, sand, silt or clay.

Very coarse soils	**Boulder size**		**> 300 mm**
	Cobble size		**80 - 300 mm**
Coarse soils	**Gravel size (G)**	***Coarse***	**20 - 80 mm**

		Fine	**4.75 - 20 mm**
	Sand size (S)	***Coarse***	**2 - 4.75 mm**
		Medium	**0.425 - 2 mm**
		Fine	**0.075 - 0.425 mm**
Fine soils	**Silt size (M)**		**0.002 - 0.075 mm**

	Clay size (C)		**< 0.002 mm**

Gravel, sand, silt, and clay are represented by **group symbols G, S, M, and C** respectively.

Physical weathering produces very coarse and coarse soils. Chemical weathering produce generally fine soils.

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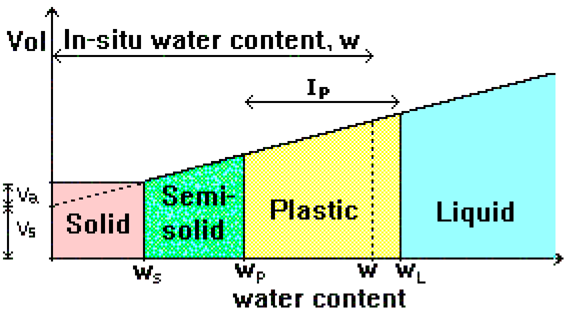

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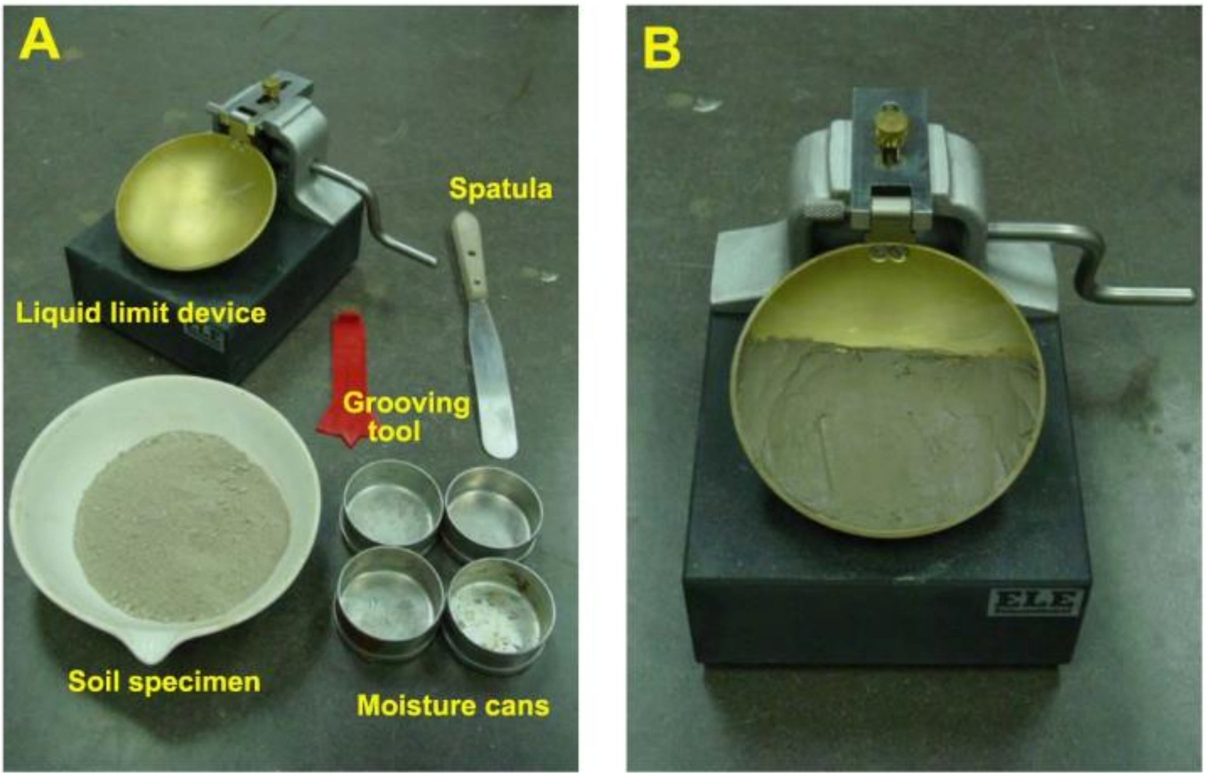
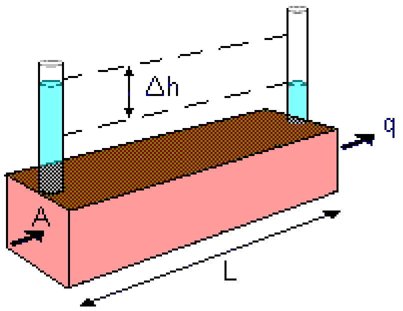


FIG--- Cassagrandeys Liguid Limit Device

4. PERMEABILITY OF SOILS

Permeability is a property of the soil by which it allows water to pass through it.

Darcy's law states that there is a linear relationship between flow velocity (**v**) and hydraulic gradient (**i**) for any given saturated soil under steady laminar flow conditions.



If the rate of flow is **q** (volume/time) through cross-sectional area (**A**) of the soil mass, Darcy's Law can be expressed as

v = q/A = k.i

where **k =** permeability of the soil
i = Δh/L
Δh = difference in total heads
L = length of the soil mass

The flow velocity (**v**) is also called the Darcian velocity or the **superficial velocity**. It is different from the actual velocity inside the soil pores, which is known as the **seepage velocity, v_S**. At the particulate level, the water follows a tortuous path through the pores. Seepage velocity is always greater than the superficial velocity, and it is expressed as:

$$v_s = \frac{q}{A_v} = \frac{q}{A_v}.\frac{A}{A} \approx \frac{v}{n}$$

where **A_V** = Area of voids on a cross section normal to the direction of flow
n = porosity of the soil

PERMEABILITY OF DIFFERENT SOILS

Permeability (**k**) is an engineering property of soils and is a function of the soil type. Its value depends on the average size of the pores and is related to the distribution of particle sizes, particle shape and soil structure. The ratio of permeabilities of typical sands/gravels to those of typical clays is of the order of $\mathbf{10^6}$. A small proportion of fine material in a coarse-grained soil can lead to a significant reduction in permeability.

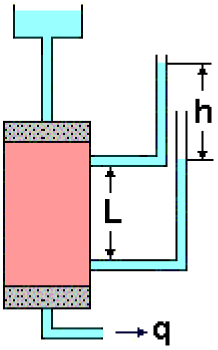
For different soil types as per grain size, the orders of magnitude for permeability are as follows:

Soil	k (cm/sec)
Gravel	10^0
Coarse sand	10^0 to 10^{-1}
Medium sand	10^{-1} to 10^{-2}
Fine sand	10^{-2} to 10^{-3}
Silty sand	10^{-3} to 10^{-4}
Silt	1×10^{-5}
Clay	10^{-7} to 10^{-9}

Methods of finding out Permeability of soils

Constant Head Flow

Constant head permeameter is recommended for coarse-grained soils only since for such soils, flow rate is measurable with adequate precision. As water flows through a sample of cross-section area **A**, steady total head drop **h** is measured across length **L**.

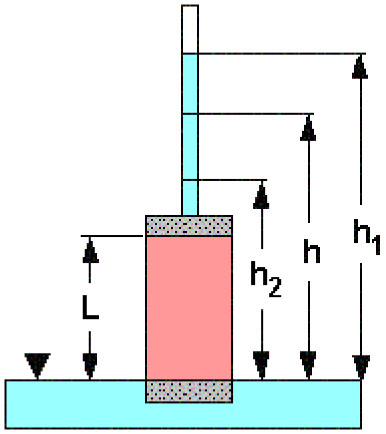


Permeability **k** is obtained from:

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

Falling Head Flow

Falling head permeameter is recommended for fine-grained soils.



Total head **h** in standpipe of area **a** is allowed to fall. Hydraulic gradient varies with time. Heads $\mathbf{h_1}$ and $\mathbf{h_2}$ are measured at times $\mathbf{t_1}$ and $\mathbf{t_2}$. At any time **t**, flow through the soil sample of cross-sectional area **A** is

$$q = k.h.\frac{A}{L}$$ --------------------- (1)

Flow in unit time through the standpipe of cross-sectional area **a** is

= $$a \times \left(-\frac{dh}{dt}\right)$$ ----------------- (2)

Equating **(1)** and **(2)** ,

$$-a.\frac{dh}{dt} = k.h\frac{A}{L}$$

or $$-\frac{dh}{h} = \left(\frac{kA}{La}\right)dt$$

Integrating between the limits,

$$\log_e\left(\frac{h_1}{h_2}\right) = \frac{k.A}{L.a}(t_2 - t_1)$$

$$k = \frac{L.a.\log_e\left(\frac{h_1}{h_2}\right)}{A(t_2 - t_1)}$$

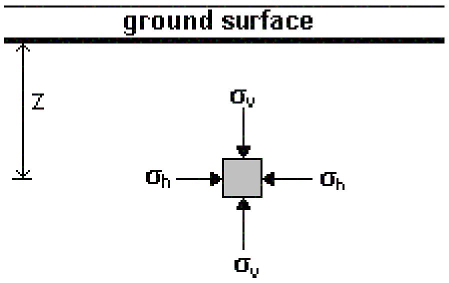
$$= \frac{2.3L.a\log_{10}\left(\frac{h_1}{h_2}\right)}{A(t_2 - t_1)}$$

CHAPTER NO. 5

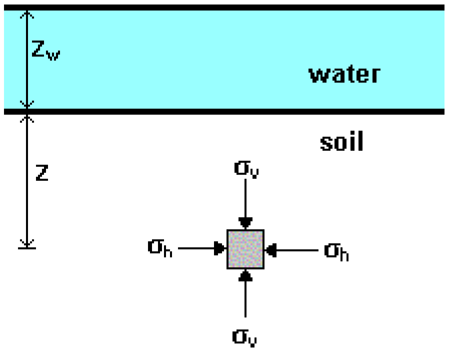
EFFECTIVE STRESS

Total Stress
When a load is applied to soil, it is carried by the solid grains and the water in the pores. The **total vertical stress** acting at a point below the ground surface is due to the weight of everything that lies above, including soil, water, and surface loading. Total stress thus increases with depth and with unit weight.

Vertical total stress at depth z, $\sigma_v = \gamma.Z$



Below a water body, the total stress is the sum of the weight of the soil up to the surface and the weight of water above this. $\sigma_v = \gamma.Z + \gamma_w.Z_w$

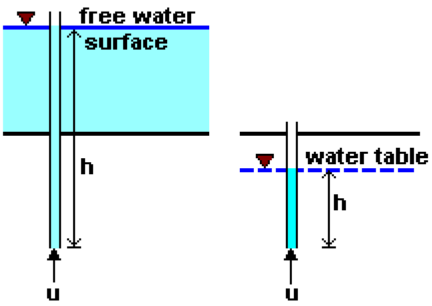


The total stress may also be denoted by σ_z or just σ. It varies with changes in water level and with excavation.

Pour Water Pressure/Neutral stress

The pressure of water in the pores of the soil is called **pore water pressure (u).** The magnitude of pore water pressure depends on:

- the depth below the water table.
- the conditions of seepage flow.



Under hydrostatic conditions, no water flow takes place, and the pore pressure at a given point is given by
$\mathbf{u = \gamma_w . h}$

where h = depth below water table or overlying water surface

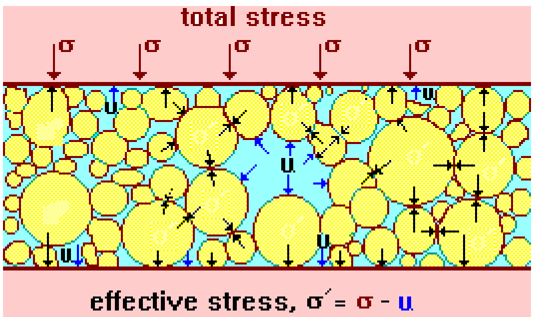
Principle of effective Sress

The **principle of effective stress** was enunciated by **Karl Terzaghi** in the year 1936. This principle is valid only for saturated soils, and consists of two parts:

1. At any point in a soil mass, the effective stress (represented by $\bar{\sigma}$ or σ') is related to total stress (σ) and pore water pressure (u) as

$\bar{\sigma} = \sigma - u$

Both the total stress and pore water pressure can be measured at any point.



2. In a saturated soil system, as the voids are completely filled with water, the pore water pressure acts equally in all directions.

The effective stress is not the exact contact stress between particles but the distribution of load carried by the soil particles over the area considered. It cannot be measured and can only be computed.

If the total stress is increased due to additional load applied to the soil, the pore water pressure initially increases to counteract the additional stress. This increase in pressure within the pores might cause water to drain out of the soil mass, and the load is transferred to the solid grains. This will lead to the increase of effective stress.

Importance of Effective Stress

At any point within the soil mass, the magitudes of both total stress and pore water pressure are dependent on the ground water position. With a shift in the water table due to seasonal fluctuations, there is a resulting change in the distribution in pore water pressure with depth.

Changes in water level ***below ground*** result in changes in effective stresses below the water table. A rise increases the pore water pressure at all elevations thus causing a decrease in effective stress. In contrast, a fall in the water table produces an increase in the effective stress.

Changes in water level ***above ground*** do not cause changes in effective stresses in the ground below. A rise above ground surface increases both the total stress and the pore water pressure by the same amount, and consequently effective stress is not altered.

In some analyses it is better to work with the *changes* of quantity, rather than in absolute quantities. The effective stress expression then becomes:

$$\Delta\sigma' = \Delta\sigma - \Delta u$$

If both total stress and pore water pressure change by the same amount, the effective stress remains constant.

Total and effective stresses must be distinguishable in all calculations.Ground movements and instabilities can be caused by changes in total stress, such as caused by loading by foundations and unloading due to excavations. They can also be caused by changes in pore water pressures, such as failure of slopes after rainfall.