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SOIL MECHANICS/GEOTECHNICAL ENGINEERING I
COMPACTION OF SOIL

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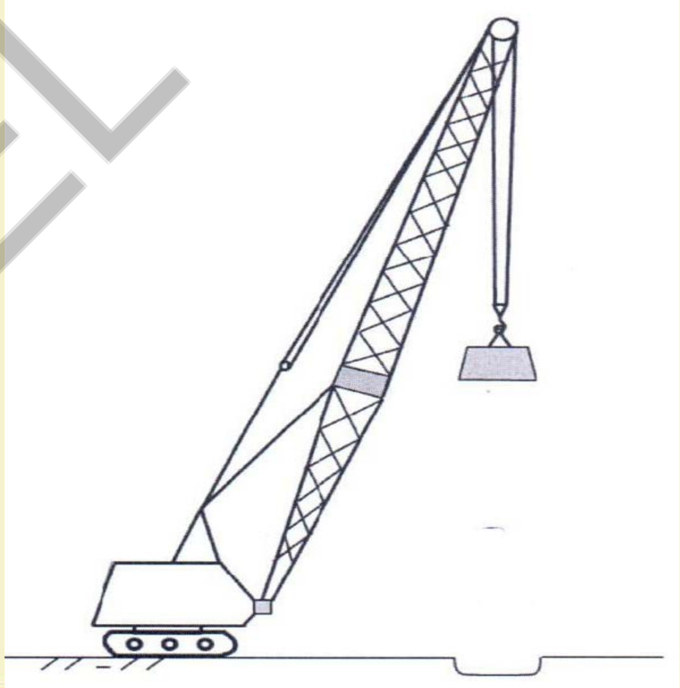
Deep Dynamic Compaction

Dynamic Densification: When dynamic Compaction is used on unsaturated granular geo-material, the impact by a heavy tamper immediately displaces particles to a denser state, compresses or expels air out of voids, and reduces the volume of voids



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- Deep dynamic compaction is generally not recommended for clayey soils with high plasticity index and high degree of saturation

- Drainage and dewatering are required to reduce excess pore water pressure in clayey soil generated by deep dynamic compaction if used for such soils

- High water table reduces the effectiveness dynamic compaction

Application : Used to improve problematic geomaterials by increasing bearing capacity, reducing settlement, minimizing collapsible potential and mitigating liquefaction potential for commercial and residential buildings, storage tanks, highways and railways, airports, and harbors

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Advantages:

- ❑Improve a large area of geo-materials in a relatively short time at low cost
- ❑Effective for loose and partially saturated fill with less than 15 % fines
- ❑Can detect weak or loose areas during operation
- ❑Can change a heterogeneous material to a more uniform, denser, and stronger material
- ❑Major equipment needed for this method is a crane and tamper which are readily available

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Disadvantages:

- ❑Generally less to not effective to improve saturated clayey soils
- ❑Drainage and dewatering and long waiting period is required to use for saturated clay soils
- ❑Induce noise, vibration and lateral movement which may cause problems to nearby buildings, substructure and utility lines
- ❑Mobilization cost may be high when large crane and tamper are used
- ❑Required instrumentation to monitor various aspects

COMPACTION OF SOIL

Design Consideration: **Before the design of deep compaction a geotechnical investigation is required to evaluate the site conditions which includes:**

- **Geotechnical profiles including geo-material type, particle size, fine content, degree of saturation and Atterberg limits**
- **Relative density of cohesionless geo-material**
- **Ground water level**
- **Possible voids**
- **Possible presence of hard lenses within the depth of improvement**
- **Possible sensitive soil**

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COMPACTION OF SOIL

Influence Factors: The design of deep dynamic compaction should consider the following influence factors:

- ❑Geo-material type
- ❑Depth and area of improvement
- ❑Tamper geometry and weight
- ❑Drop height and energy
- ❑Pattern and spacing of drops
- ❑Depth of crater
- ❑Number of drops and passes
- ❑Degree of improvement and Induced settlement
- ❑Environmental impact (vibration, noise and lateral ground movement)
- ❑Presence of soft layer, Hard layer, High ground water table, Elapsed time and Pilot trial

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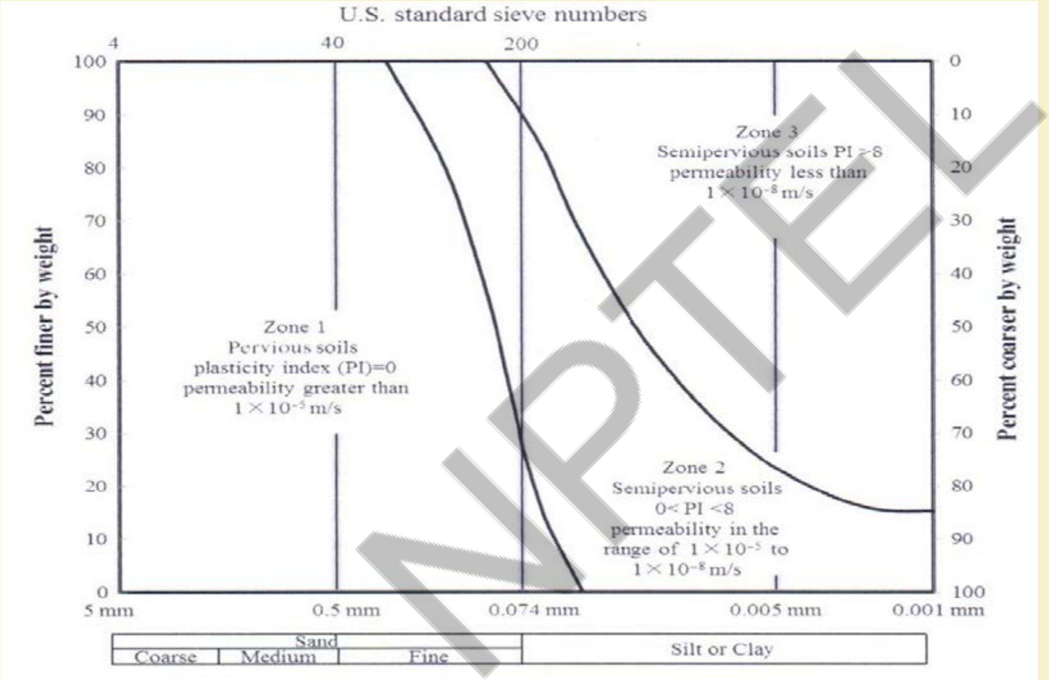
COMPACTION OF SOIL



COMPACTION OF SOIL

Depth and area of Improvement:

Depth of improvement depends on project requirements for desired performance

For example, a loose and saturated sand layer susceptible to liquefaction, should be improved to the depth below which no liquefaction will occur. An empirical formula developed based on field data:

Di = nc√(Wt Hd)

Di = depth of improvement in m, wt = weight of tamper (ton), Hd = height of drop in m, nc = constant

Sand up to 10 m and Cohesive soils and clay fill up to 5 m

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COMPACTION OF SOIL

Type of soil	Degree of Saturation	nc
Pervious soil deposits – Granular soil	High	0.5
	low	0.5-0.6
Semi-pervious deposits – Primary silts with PI≤8	High	0.35-0.4
	Low	0.4-0.5
Semi-pervious deposits – primary clayey soils with PI>8	High	NR
	Low (w<PI)	0.35-0.4

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COMPACTION OF SOIL

Tamper geometry and weight:

- ❑Made of steel or steel shell infilled with sand or concrete
- ❑Circular or square base with area 3-6 sq m or more
- ❑Tamper with smaller base area are commonly used for granular soils
- ❑Large areas are used for cohesive soils
- ❑Weight typically 5 to 40 tons

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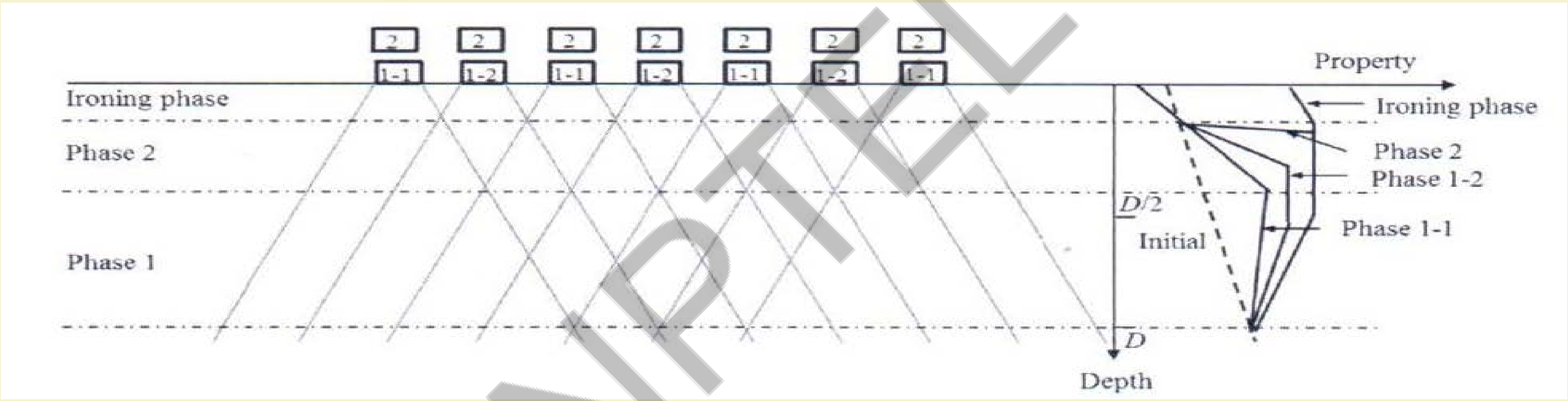

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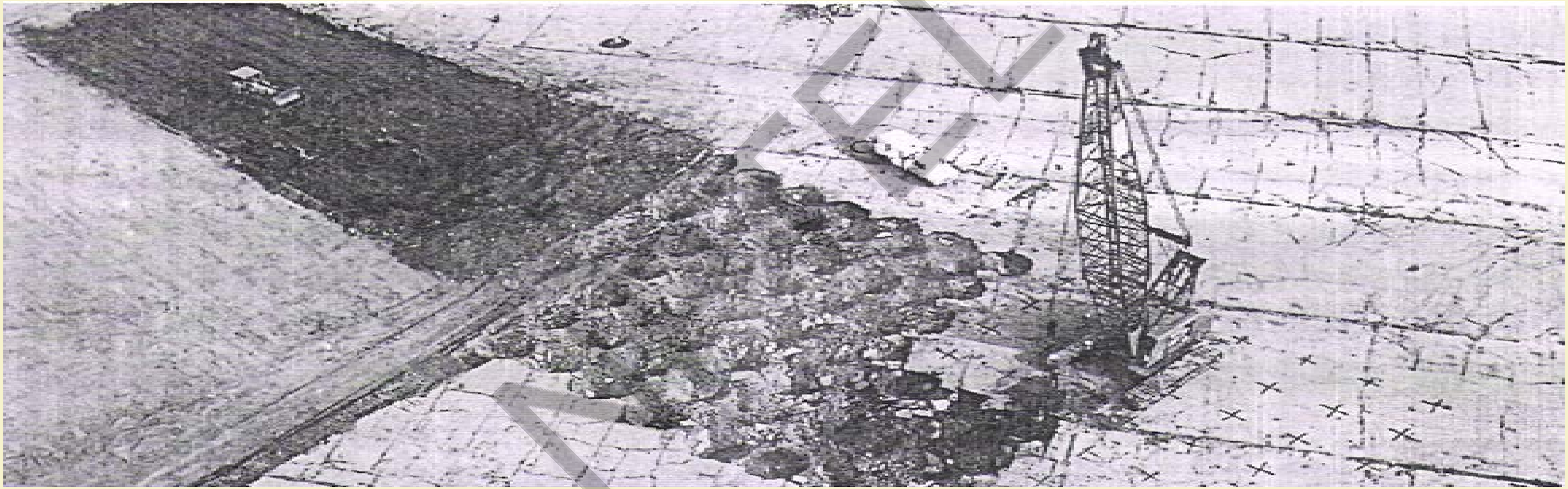

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COMPACTION OF SOIL

Induced settlement

Soil type	Percent of depth
Natural clays	1-3
Clay fills	3-5
Natural sands	3-10
Granular fills	5-15
Uncontrolled fills	5-20

Typical Threshold particle velocity

Structure Type	Velocity(mm/s)
Commercial, industrial	20-40
Residential	5-15
Sensitive	3-5

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SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

PROBLEMS ON CRITICAL HYDRAULIC GRDIENT & COMPACTION

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CRITICAL HYDRAULIC GRADIENT: Application 1

1. A large sized excavation is made in stiff clay whose saturated unit weight is 17.27 kN/m^3. When the depth of excavation reaches 7.5m, cracks appear and water begins to flow upward to bring up sand to the surface. Subsequent boring indicate that the clay is underlain by sand at a depth of 11m below the original ground surface. What is the depth to the water table outside the excavation below the original ground level?

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CRITICAL HYDRAULIC GRADIENT: Application 2

2. If excavation is carried out in a soil with a porosity of 0.40 and the specific gravity of solids of 2.65, determine the critical gradient. A 1.50m layer of the soil is subjected to an upward seepage head of 1.95m. What depth of coarse sand would be required above the soil to provide a factor of safety of 2.5? Assume that sand has the same porosity and specific gravity of solids as the soil.

COMPACTION OF SOIL: Application 1

3. The following data refers to a light compaction test as per Indian Standard:

Water content(%)	8.5	12.2	13.75	15.5	18.2	20.2
Wt of wet sample(kg)	1.80	1.94	2.00	2.05	2.03	1.98

If the specific gravity of soil grains was 2.7 (i) Plot the compaction curve and obtain the maximum dry unit weight and the optimum moisture content (ii) plot the 80 % and 100% saturation lines (iii) if it is proposed to secure a relative compaction of 95% in the field, what is the range of water content that can be allowed? (iv) would the 20 % air voids curve be the same as the 80% saturation curve?

COMPACTION OF SOIL: Application 1

IS mould volume = 1000 cc

$$\gamma_d = \frac{\gamma_{bulk}}{(1+w)}$$

Water content	8.5	12.20	13.75	15.50	18.20	20.20
Dry unit weight, γ_d (kN/m^3)	16.26	16.94	17.23	17.39	16.83	16.14
γ_d for S = 80% (kN/m^3)	20.56	18.74	18.07	17.37	16.39	15.73
γ_d for S = 100% (kN/m^3)	21.52	19.89	19.30	18.65	17.74	17.12

$$\gamma_d = \frac{G_s \gamma_w}{1 + (wG_s/S)}$$

COMPACTION OF SOIL: Application 2

A 1200 m long embankment of width 8 m and of 0.7 m compacted thickness is to be constructed in a part of road way project. Construction specifications require the soil to be compacted to moisture content of 19.6% achieving a dry unit weight of 17.0 kN/m^3. Soil is to be excavated and transported to the site from a borrow pit where soil has moisture content of 15% and bulk unit weight 17.25 kN/m^3. While loading into the dump truck, the soil looses and its dry unit weight drops to 14.0 kN/m^3. Determine: (i) the volume of soil to be excavated from the borrow area, (ii) the number of trips of truck between the borrow area and the construction site assuming each truck can carry 7.5 m^3 of loose soil (iii) the volume of water, in cubic meter, to be added at the construction site to achieve the desired moisture content before compaction (iv) the degree of saturation of soil at the construction site after compaction and (v) the moisture content of the compacted soil if it is saturated after construction due to rainfall.

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SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

EFFECTIVE STRESS CONCEPT

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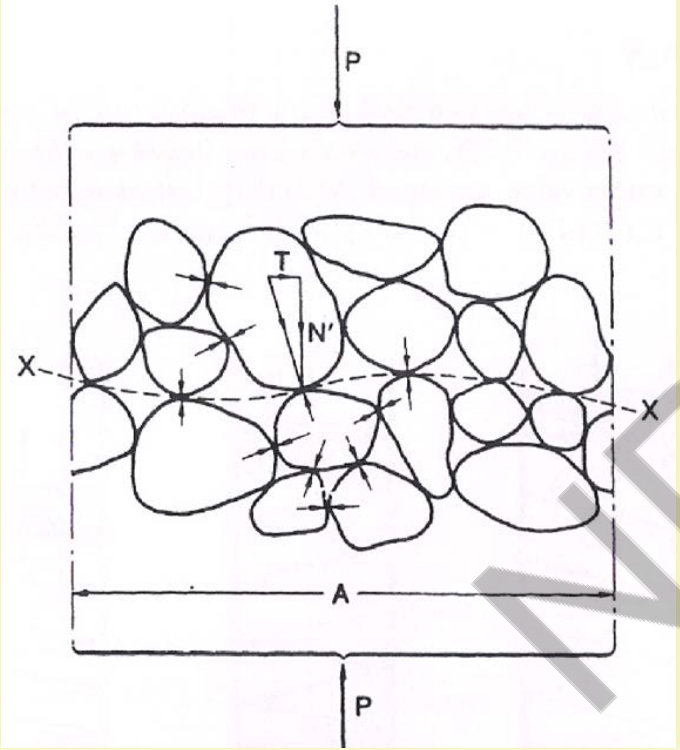
Effective stress in soil

Concept was first introduced by Terzaghi 1923

The principle applies only to saturated soils and relates the following three stresses:

1. The total Normal Stress on a plane within the soil mass, being the force per unit area transmitted in Normal direction across the plane imagining the soil to be a solid material
2. The Pore water pressure being the pressure of water filling the void space between the solid particles
3. The effective normal stress on the plane representing the stress transmitted through the soil skeleton only

EFFECTIVE STRESS



The principle can be demonstrated by the following physical model:

Consider a 'plane' XX in a fully saturated soil passing through inter-particle contact only as shown in the figure. The wavy plane XX is really indistinguishable from a true plane on the mass scale due to the relatively small size of individual soil particles. A Normal force P applied over an area A may be resisted partly by inter-particle forces and partly by the pressure in the pore water.

EFFECTIVE STRESS

The inter-particle forces are very random in both magnitude and direction throughout the soil mass but at every point of contact on the wavy plane may be split into components normal and tangential to the direction of the true plane to which XX approximates. The Normal and Tangential components are N and T respectively.

EFFECTIVE STRESS

Then the effective Normal stress is interpreted as the sum of all the components N within the area A, divided by the area A, i.e.,

$$\sigma' = \frac{\sum N'}{A}$$

The total Normal stress is given by

$$\sigma = \frac{P}{A}$$

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EFFECTIVE STRESS

If a point contact is assumed between the particles the pore water pressure will act on the plane over the entire area A. Then for equilibrium in the direction Normal to XX

$$P = \sum N' + uA \quad \text{OR} \quad \frac{P}{A} = \frac{\sum N'}{A} + u \quad \text{OR} \quad \sigma = \sigma' + u$$

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

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Critical points to note on effective stress

The pore water pressure which acts equally in every direction will act on the entire surface of any particle but is assumed not to change the volume of the particle; also the pore water pressure does not cause particles to be pressed together.

The error involved in assuming point contact between particles is negligible in soils, since the total contact area normally being between 1 and 3 % of the cross-sectional area A.

Effective stress is a concept that summation of normal load through the contact point divided by the total area. Hence it does not represent the true contact stress between two particles, actual contact stress N/a, which is much higher than the the effective stress so defined.

Effective vertical stress due to Self Weight of Soil

Consider a soil mass having a horizontal surface and with the water table at surface level. The total vertical stress (i.e., the total normal stress on a horizontal plane) at a depth z is equal to the weight of all material (solids + water) per unit area above that depth

$$\sigma_v = \gamma_{sat} z$$

EFFECTIVE STRESS

The pore water pressure at any depth will be hydrostatic since the void space between the solid particles is continuous, so depth z

$$u = \gamma_w z$$

Hence from the equation of effective stress derived previously

$$\sigma_v{}' = \sigma_v - u = (\gamma_{sat} - \gamma_w) z = \gamma' z$$

Example

A layer of saturated clay 4 m thick is overlain by sand 5 m deep. The water table being 3 m below the ground surface. The saturated unit weights of the clay and sand are 19 and 20 kN/m3, respectively; above the water table the unit weight of the sand is 17 kN/m3. If sand to a height of 1 m above the water table is saturated with capillary water, how are the above stresses affected?

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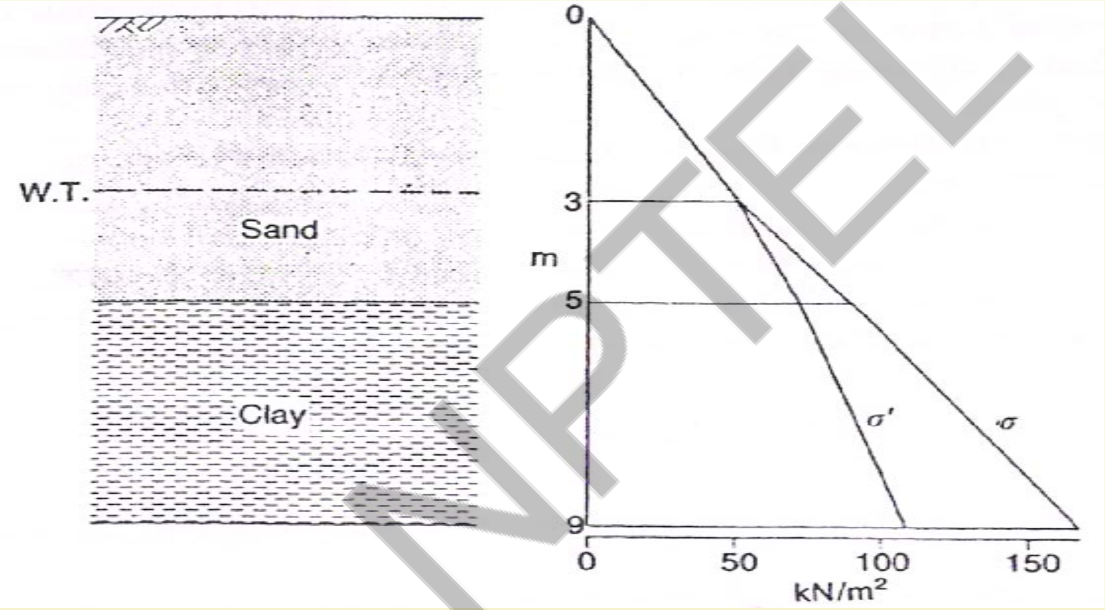
EFFECTIVE STRESS



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EFFECIVE STRESS CONCEPT

Variation in Effective stress With the Shift in Ground Water Table

For water table below the ground surface, a rise in the water table causes a decrease in the effective stress, and a fall in the water table produces an increase in the effective stress

For water level above the ground surface, a fluctuation in the exposed water level does not alter the effective stress

The effect of a shift of in the ground surface will cause a change in the effective stress of magnitude equal to the change in the overburden pressure

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EFFECTIVE STRESS CONCEPT

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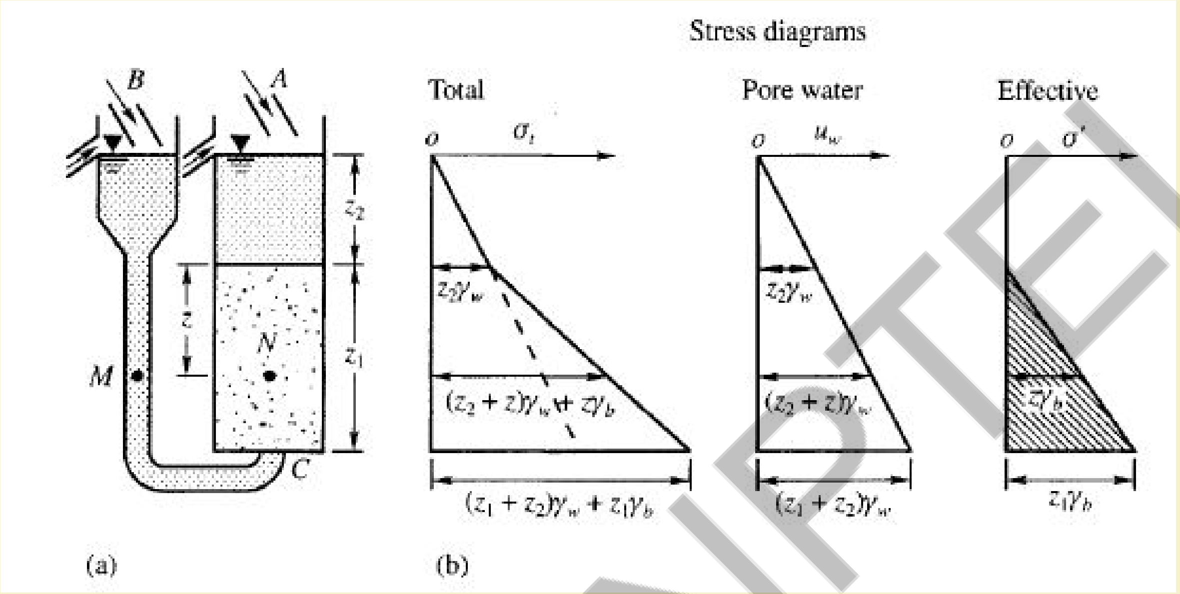
EFFECTIVE STRESS CONCEPT



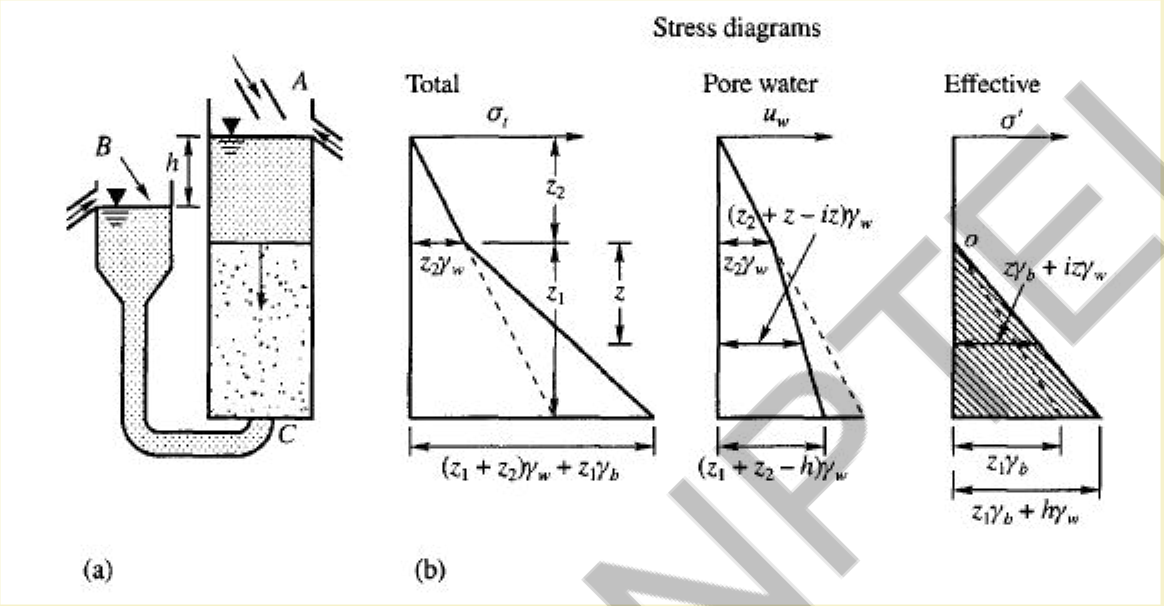
At any depth z of the soil in A hydrostatic pressure = $u_z = (z + z_2)\gamma_w$

At any depth z total stress,

$$\sigma_z = z\gamma_{sub} + (z + z_2)\gamma_w$$

$$\sigma_z' = \sigma_z - u_z = z\gamma_{sub} + (z + z_2)\gamma_w - (z + z_2)\gamma_w = z\gamma_{sub}$$

EFFECTIVE STRESS CONCEPT



$$u_b = (z_1 + z_2 - h)\gamma_w$$

$$u_a = (z_1 + z_2)\gamma_w$$

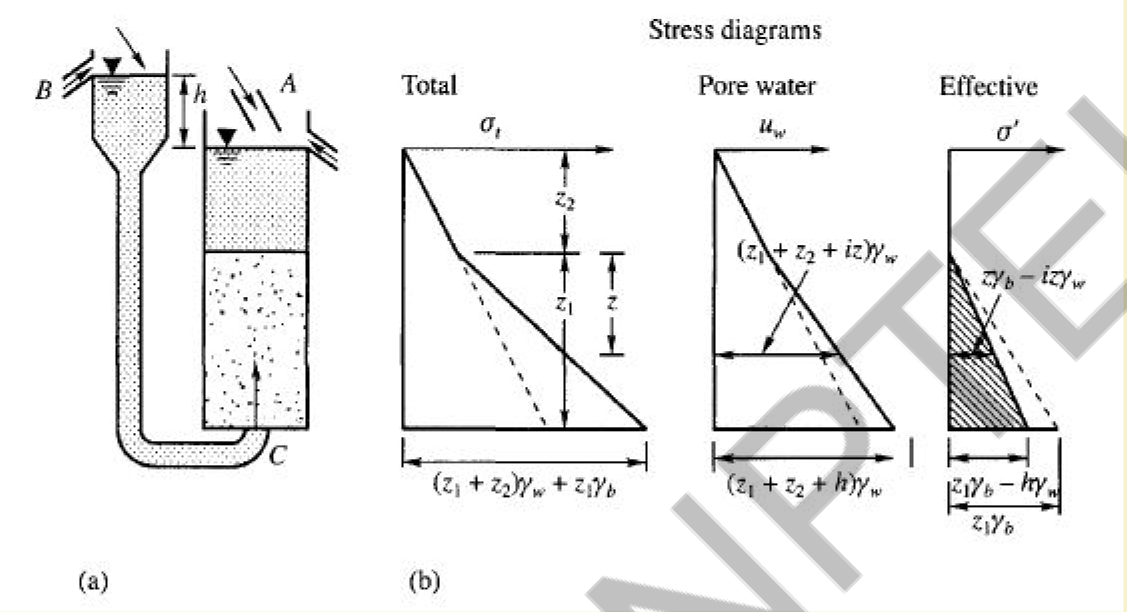
$$\sigma_a = (z_1 + z_2)\gamma_w + z_1\gamma_{sub}$$

EFFECTIVE STRESS CONCEPT

$$\sigma_a{}' = \sigma_a - u_a = (z_1 + z_2)\gamma_w + z_1\gamma_{sub} - (z_1 + z_2 - h)\gamma_w = z_1\gamma_{sub} + h\gamma_w$$

$$\sigma_z{}' = \sigma_a{}'\frac{z}{z_1} = (z_1\gamma_{sub} + h\gamma_w)\frac{z}{z_1} = z\gamma_{sub} + \frac{hz\gamma_w}{z_1} = z\gamma_{sub} + iz\gamma_w$$

EFFECTIVE STRESS CONCEPT



$$u_a = u_b = (z_1 + z_2 + h)\gamma_w$$

$$\sigma_a = (z_1 + z_2)\gamma_w + z_1\gamma_{sub}$$

$$\sigma_a{}' = \sigma_a - u_a = (z_1 + z_2)\gamma_w + z_1\gamma_{sub} - (z_1 + z_2 + h)\gamma_w = z_1\gamma_{sub} - h\gamma_w$$

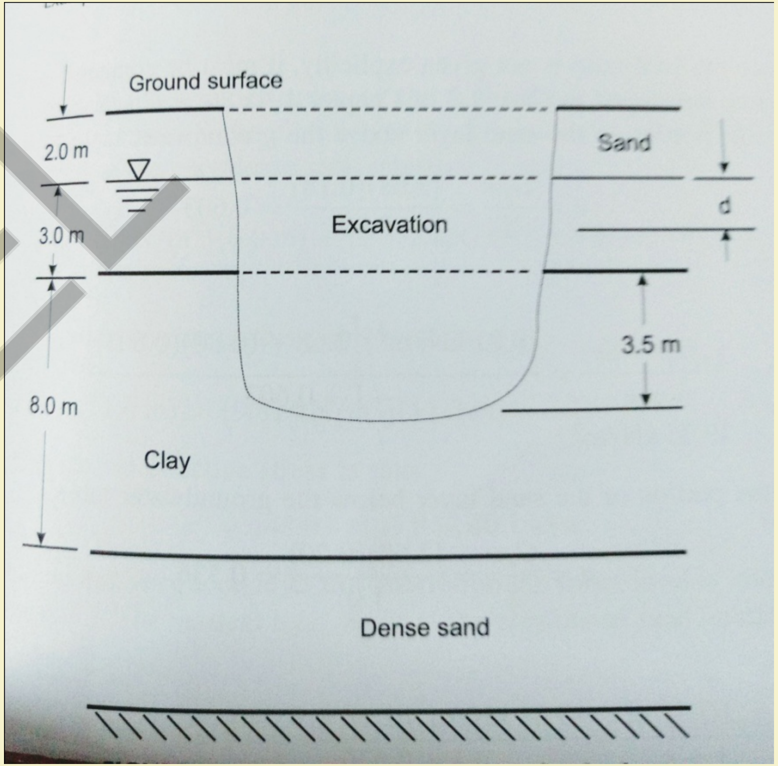
EFFECTIVE STRESS CONCEPT

$$\sigma_z{}' = z\gamma_{sub} - iz\gamma_w$$

$$i_c = i = \frac{\gamma_{sub}}{\gamma} = \frac{G_s - 1}{1 + e}$$

EFFECTIVE STRESS CONCEPT

Sand above water table w=18% and S = 80% G = 2.7
Below water Table w= 20% G = 2.7
Clay w= 40% G – 2.7
(i)Determine effective stress at sand clay interface before excavation
(Ii)Effective stress immediately after excavation
(iiI)How much the water level can be lowered without causing the effective stress at the clay sand interface to go to zero



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SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

EFFECTIVE STRESS CONCEPT: APPLICATION

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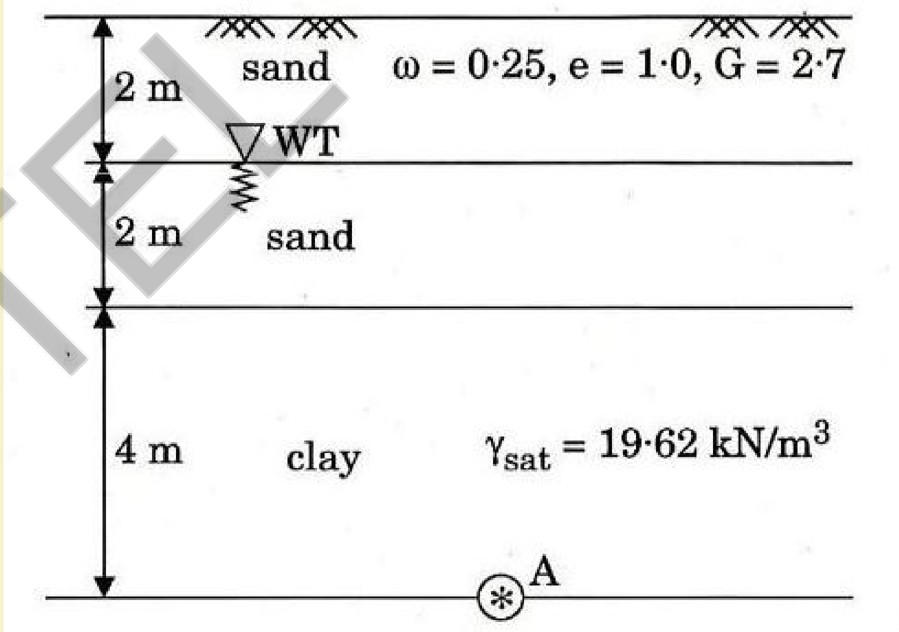
EFFECTIVE STRESS

For the soil profile given below, determine the total and effective stresses at point A. What will be the total, neutral, and effective stresses at point A if the ground water table rises to the ground surface? Will there be any change in effective stress at point A if the water table rises 2 m above the ground surface?



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EFFECTIVE STRESS CONCEPT

An excavation is to be performed in a stratum of clay 9 m thick, underlain by a bed of sand. In a trial bore hole the ground water is observed to rise up to an elevation of 3m below the ground surface. Find the depth to which the excavation can be safely carried out without the bottom becoming unstable under uplift pressure of ground water. The specific gravity of clay particles is 2.7 and the void ratio is 0.7.

If the excavation is to be safely carried to a depth of 7 m, how much should the water table be lowered in the vicinity of the trench.

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EFFECTIVE STRESS CONCEPT

Water is flowing vertically up a 2 m thick layer of sand. The head lost in the flow is 0.8 m of water. Calculate the effective vertical stress at the mid-height of the sand layer if the saturated unit weight of sand is 19.5 kN/m3 and there is no other head over the sand.

EFFECTIVE STRESS CONCEPT

In a deposit of fine sand the water table was at 3m below the ground surface but the sand up to a height of 1m above the water table was saturated by capillary rise. The sand above this height can be considered as dry. For the sand Gs = 2.65 and n = 40%. Calculate the effective stress at a depth 8 m below the ground surface.

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