EWCE 341

Principles of Soil Mechanics

Compressibility and Settlement

Compressibility and Settlement

- **Settlement and Subsidence**
- **Issues of Geotechnical Engineers**
- **Criteria to compute the Magnitude of Settlement**
- **Different Types of Settlement:**
- **Changes in Vertical Effective Stress**

Compressibility and Settlement

Settlement and Subsidence:

Settlement:

- Many civil engineering projects **impart loads** onto the ground, which produce corresponding **increase in the vertical effective stress, σ'_z.**
- Stress increases **induce vertical strains, ε_z** in the soils, which cause the **ground surface to move downward**.
- Downward movement is called **Settlement**.

Subsidence

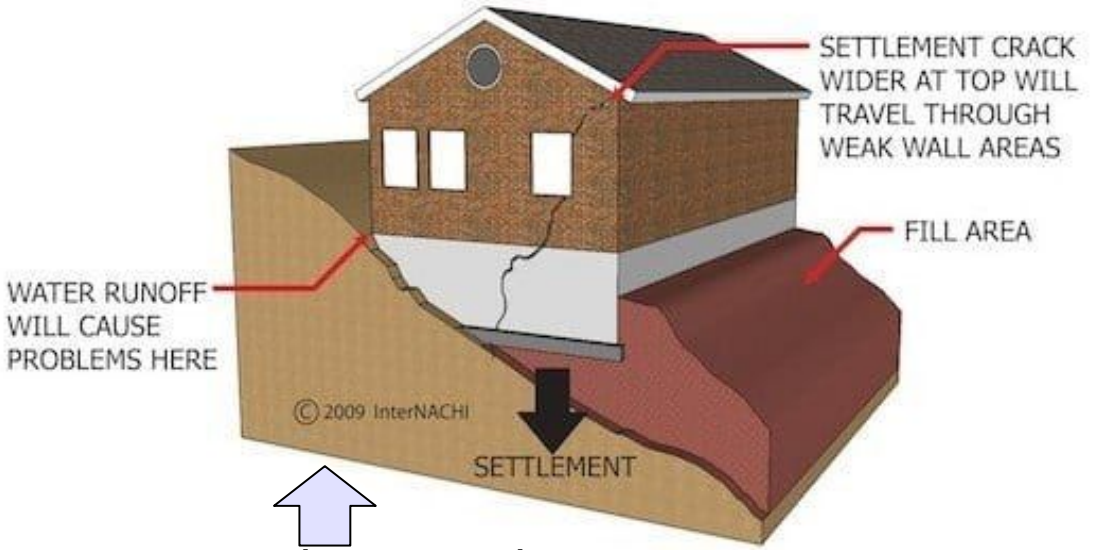
- Whenever **settlement occurs over a large area**, it is sometimes called **subsidence**.
- **Land subsidence** is a **gradual settling** or sudden sinking of the Earth's surface
- Often caused by **human activities** like excessive groundwater pumping or **natural events** such as earthquakes or soil compaction.

Indonesia - July 21 2019 : land subsidence



Building settlement





Foundation Settlement



Subsidence opening up the earth, threatening local infrastructure and people's homes.

Issues of Geotechnical engineers related to soil settlement:

- Whenever σ'_z **increases**, there is always will be a **corresponding settlement** δ.
- **Issue facing a geotechnical engineer is not if settlement will occur,** but rather:

  -magnitudes of these settlements and

  -how they compare with the tolerable limits.

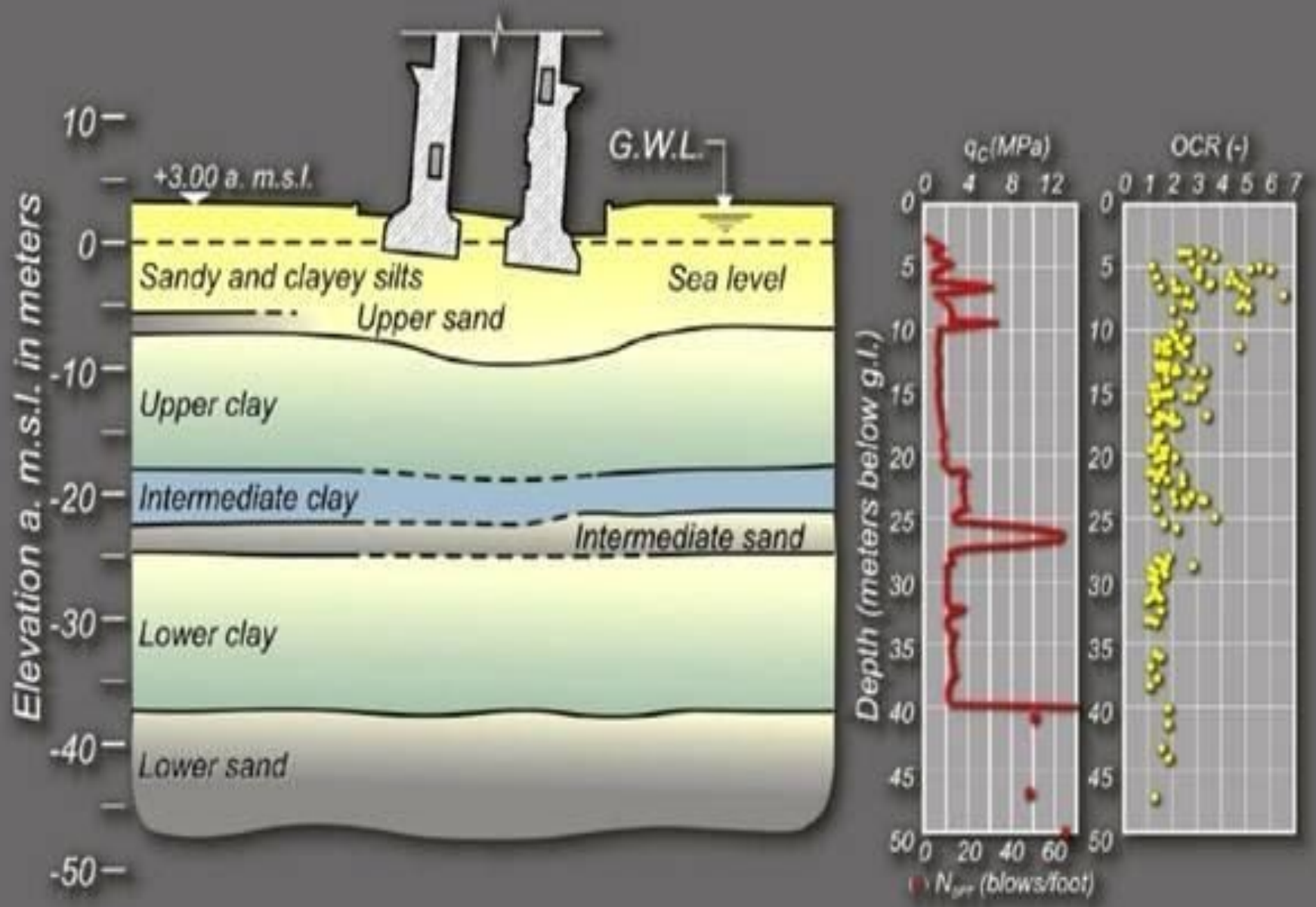
A classic example of **total settlement: Palace of Fine Arts,** cultural center in Mexico City, which has sunk **more than 15 feet (4.6m)** since its construction in the early 20th century.





Example of differential settlement: **Leaning Tower of Pisa**, which leans due to **insufficient bearing capacity** of the soil beneath one side of the **tower**.

SUBSOIL PROFILE AND SOIL PROPERTIES



Criteria to compute the Magnitude of Settlement.

- **Settlement is a displacement** caused by a **change in stress.**

- **Settlement can be computed if we know:**

  -the **magnitude of the change in stress** and

  -the **stress-strain properties of soils**.

Different Types of Settlement:

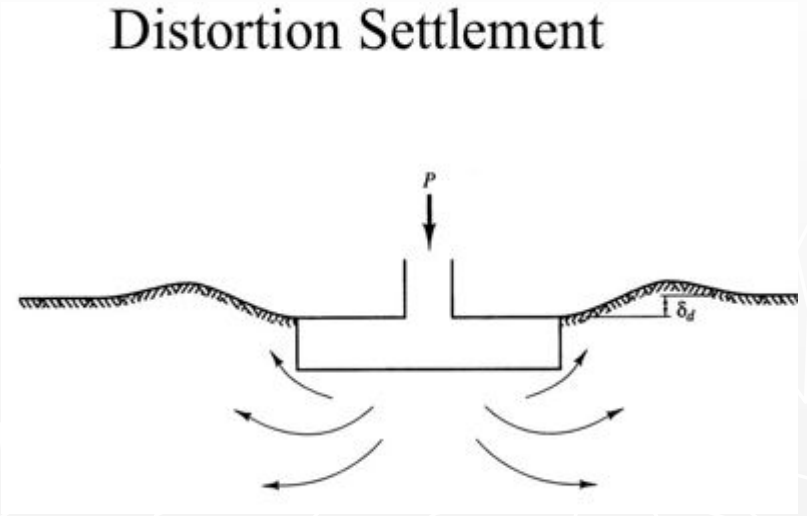
- **Distortion Settlement (δ_d)**
- **Consolidation settlement (δ_c)**)/Primary Consolidation settlement.
- **Secondary Compression Settlement (δ_s).**

Different Types of Settlement:

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Different Types of Settlement:

Distortion Settlement (δ_d):



- Results **from lateral movements of the soils** in response to **changes in σ'_z**.
- Occurs **without volume change**.
- **Similar to Poisson's effect** where an object loaded with in the vertical direction **expands laterally**.
- Primarily occurs when **the load is confined to a small area**, such as **structural foundation** or **near the edges of large loaded areas**, such as **embankment**.

Settlement of Soil



Consolidation settlement (δ_c):

- Also known as **primary consolidation settlement**.
- Occurs when a soli is subjected to an **increase in σ'_z and individual particles respond by arranging into tighter packing.**
- **Volume of the solid particles** themselves remains **virtually unchanged**.
- **Change in total volume** (and the resulting change) is due to a **decrease in the volume of voids, V_v**.
- **If soil is saturated**, the **reduction V_v can occur if some of the pore water is squeezed out of the soils**.

Consolidation Settlement (cont…)

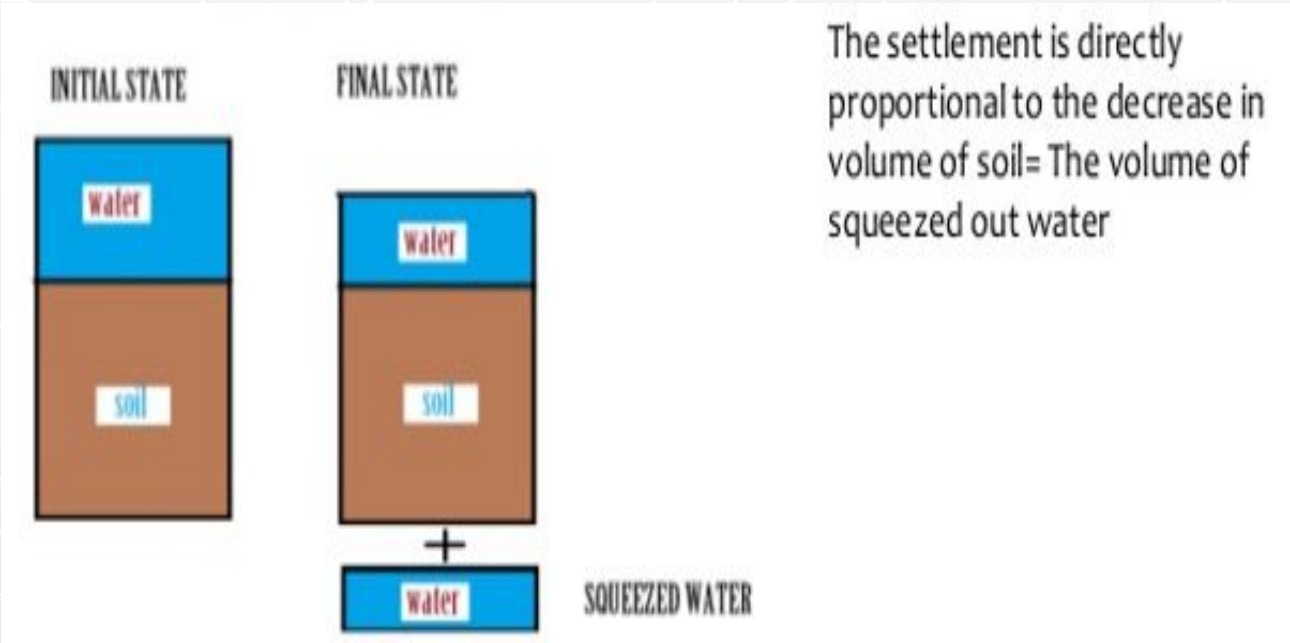
- In some cases, the process occurs as **quickly** as load is applied, but in other situation it occurs **very slowly**.

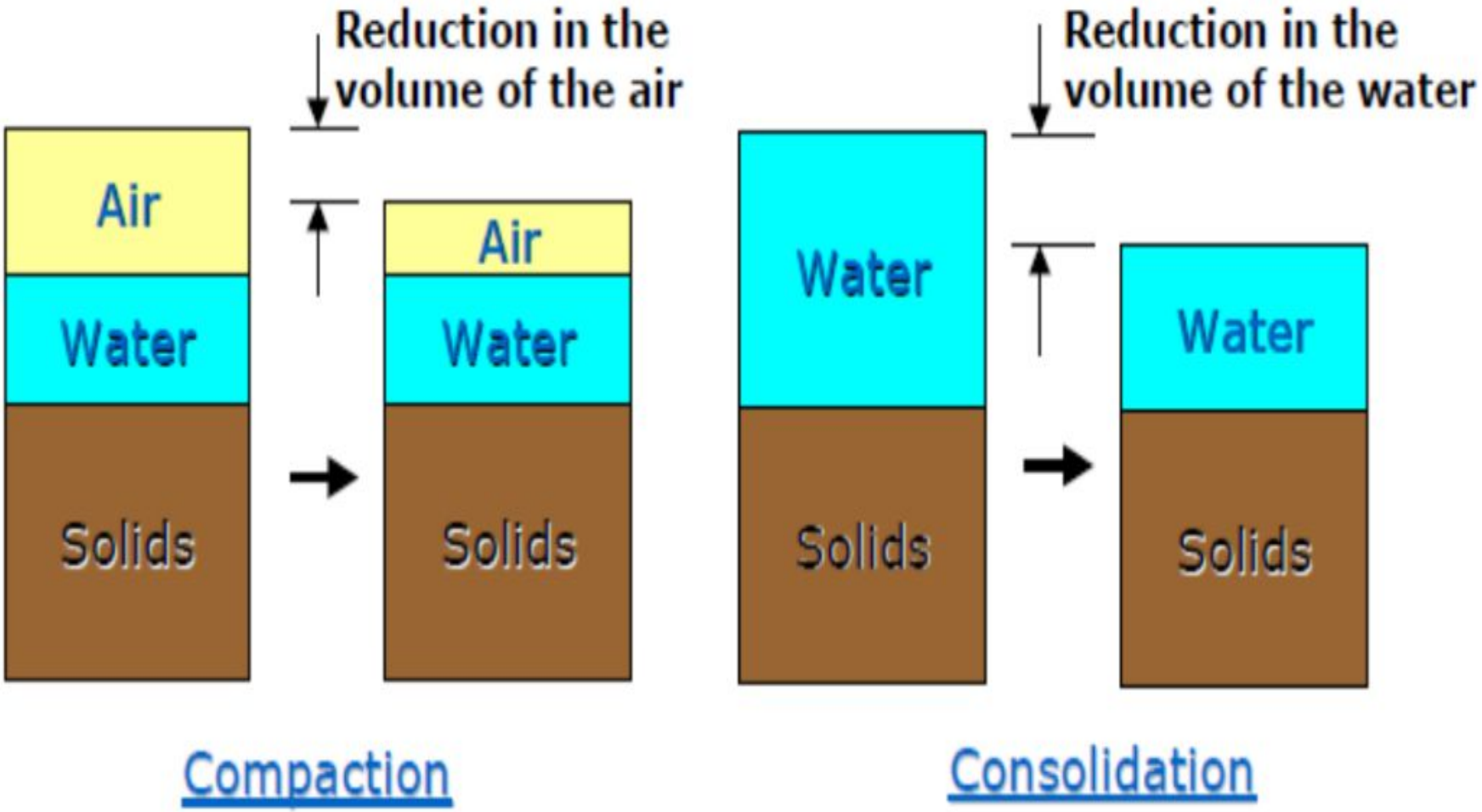
- **Rate of consolidation depends on**:

  -the degree of saturation of soils,

  -its hydraulic properties, and

  -other factors




Reduction in the volume of the air
Air
Water
Solids
Air
Water
Solids
Compaction
Reduction in the volume of the water
Water
Solids
Water
Solids
Consolidation

Secondary Compression Settlement (δ_s):

- Primarily due to **particle reorientation, creep, and decomposition of organic materials.**

- Particle **reorientation cause a reduction in the volume of voids**, like consolidation settlement.

- δ_s is not due change in σ'_z; it **occurs at a constant σ'_z.**

- δ_s is **always time dependent** and can be significant in highly plastic clays, organic soils and sanitary landfills.

Types of Settlement basing on the Duration:

Short-term settlement:

- Also known as *Immediate settlement.*
- Occurs as quickly as the load is applied.

Long-term settlement:

- Also known as delayed settlement.
- Occurs over some longer period.
- Many engineers associate consolidation settlement solely with **the long-term settlement of clay soils**.

Changes in Vertical Effective Stress:

Most Settlement is due to change in the vertical stress.

Initial condition:

- **Initial vertical effective stress, σ'_{z0}**, at a point in the soils **before the event** that causes settlement occurs.
- Initial condition consist of **geostatic stresses only** and estimated using the equation:

$$\sigma'_z = \sum \gamma H - u$$

Final condition:

- **Final vertical effective stress, σ'_{zf}**, is the value after the settlement process is complete.
- Method of computing σ'_{zf} depends on the **kind of event** that is causing the stresses to increase.

Changes in Vertical Effective Stress: (cont…)

- Most common events are:

  -**Placement of fill,**

  -Placement of external load, and

  -Changes in ground water elevation.

Stress Changes Due to Placement of Fill:

- When a **fill is placed** on the ground, σ_z' in the underlying soil increases due to the weight of the fill.

- If the **length and the width of the fill are large compared to the depth of the point** at which stresses to be computed, the fill can be called an **aerial fill and evaluation of the fill to be done as an Point load.**

- When the **point beneath the central area of the fill**, then σ'_{zf} can be computed by simply adding another layer to the $\sum \gamma H$.

$$\sigma'_{zf} = \sigma'_{z0} + \gamma_{fill} H_{fill}$$

$$\sigma'_{z0} = \sum \gamma H - u$$

Stress Changes Due to Placement of Fill (cont…)

Where,

σ'_{z0}= initial vertical effective stress

σ'_{zf}= final vertical effective stress

γ_{fill}= unit weight of the fill

H_{fill}= thickness of the fill

- If the **length or width of the fill are less than the twice the depth to the point** at which the stresses are to be computed as a point load, or

- If this point is **near the edge of the fill**, then **evaluation of the fill to be done as an area load.**

Ex. 1: A **5.0 ft** thick fill to be placed on a site underlain by medium clays as shown in the following figure 1, compute initial vertical effective stress, σ'_{z0} and final vertical effective stress, σ'_{zf} at point A.

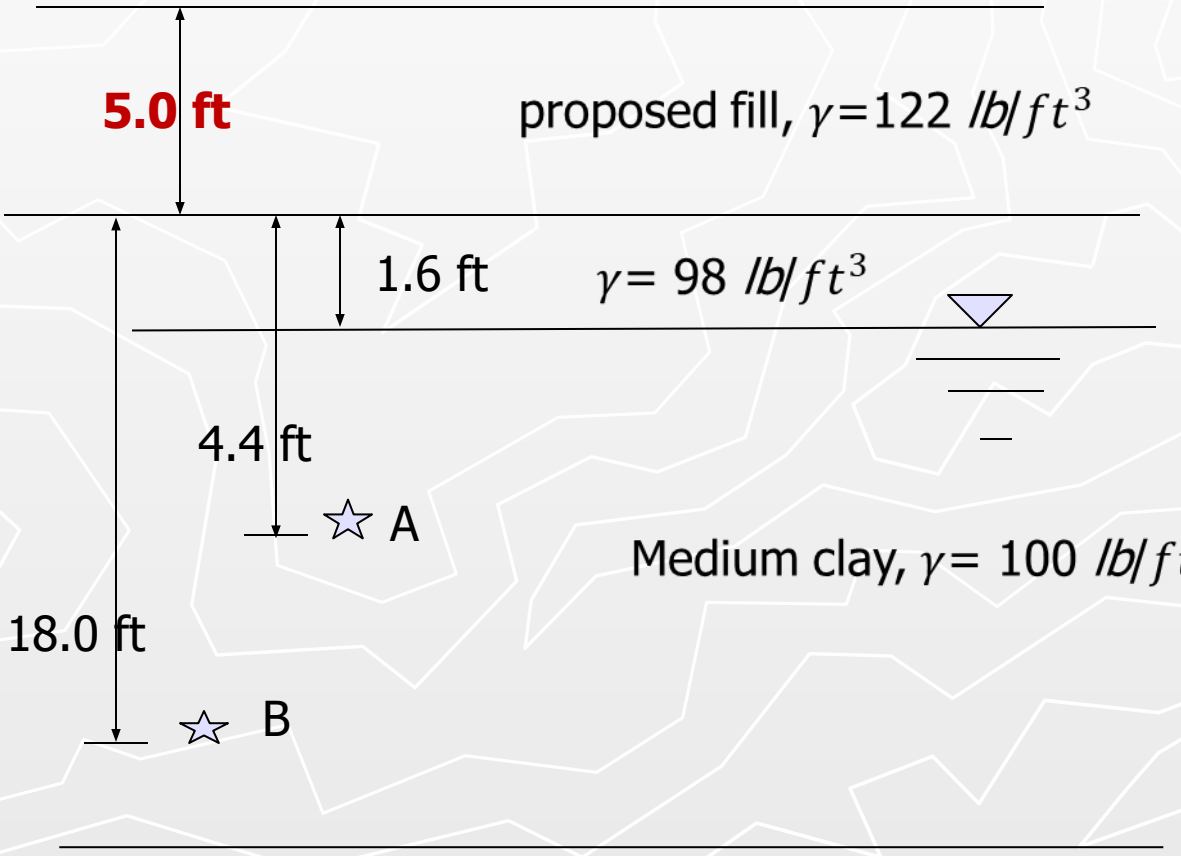


Fig. 1: Soil profile

Solution:

$\sigma'_{z0} = \sum \gamma H - u$

$= (98.0 \text{ lb}/ft^3)x(1.6ft) + (100.0 \text{ lb}/ft^3)x(4.4ft) - (62.4 \text{lb}/ft^3)x(4.4ft)$

$= 322 \text{ lb/ft}^2$ Ans.

$\sigma'_{zf} = \sigma'_{z0} + \gamma_{fill} H_{fill}$

$= 322 \text{ lb/ft}^2 + (122 \text{ lb}/ft^3)x(5.0ft)$

$= 932 \text{ lb/ft}^2$ Ans.

Stress Changes Due to Placement of External Loads:

- External loads such as structural foundations, produce increases in σ'_z.
- In such case: $\sigma'_{zf} = \sigma'_{z0} + \Delta\sigma_z$

where, $\Delta\sigma_z = I_\sigma q$

$\Delta\sigma_z$= induced vertical stress

I_σ= influence factor for vertical stress

q=bearing pressure for vertical stress

$q = \frac{P}{A}$ where, P=applied vertical load

A= area upon which the load acts.

Stress Changes Due to Changes in GWT Elevation:

Change of value of u:

- When the **GW table changes** from one elevation to some **lower elevation**, **u in the underlying soils decreases** and σ_z' increases.

- **More subtle process**, because there is no visible source of loading at the ground surface, and yet it can be and has been the **cause of significant settlements**.

- **Example**: Some of the settlement problems in some City, have been due to excessive pumping from the water supply wells and corresponding drops in GWT.
- Here, $\sigma_z' = \sum \gamma H - u$, with the final GW position.

Stress Changes Due to Changes in GWT Elevation (cont…):

Change of value of γ:

- **Changes in GWT elevation may change the γ of soils.**

- Soils that is now above the GWT will probably have **lower moisture content, have a lower γ than before.**

- Zone of soils between **the initial** and **final** GWTs may have **one γ for the σ'_{z0} computation and another γ for σ'_{zf} computation.**

- Some civil engineering projects include **multiple causes of settlement** acting simultaneously.

Example: A project might include both placement of fill and construction of multiple structural foundation.

Here, σ'_{zf} can be computed by $\sigma'_{zf}=\sum\gamma H + \Delta\sigma_z - u$, with post construction conditions.

Thank you