EWCE 341

Principles of Soil Mechanics

Compressibility and Settlement

Distortion Settlement

- When **heavy loads are applied** over a small area, **soil can deform laterally.**

- **Lateral deformations produce additional settlement at ground surface**, which is called **distortion settlement,** δ_d.

- Distortion settlement is generally **much smaller than consolidation settlement, and can be ignored**.

- It is sometimes **considered in the design of spread footing foundations.**

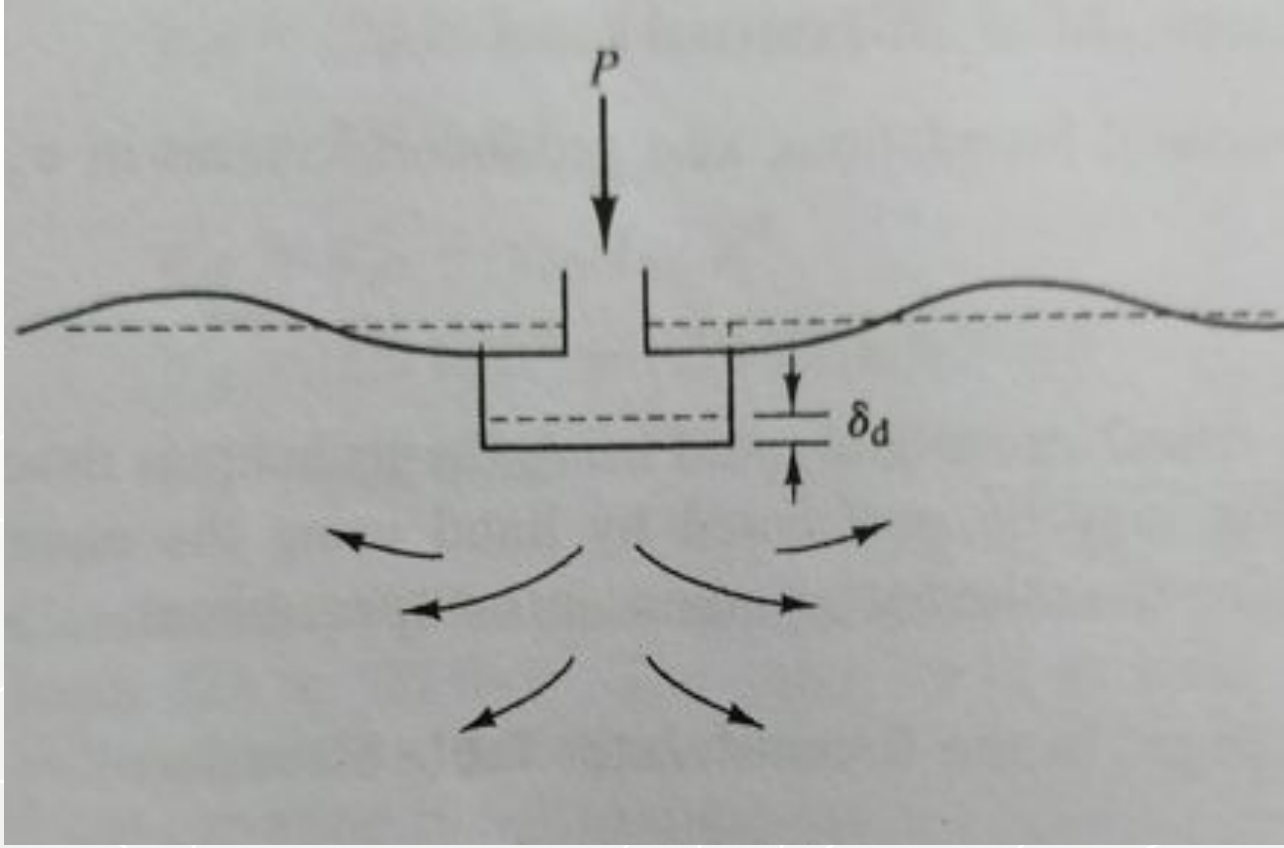




Figure: Distortion settlement beneath a small loaded area.

Consolidation Settlement:

- Term ***consolidation*** is used to described the **pressing of soil particles into a tighter packing** in response to in increase in effective stress.
- It is assumed that the **volume of solids remain constant** ie **the compression of individual particles is negligible**; only the **volume of voids changes.**

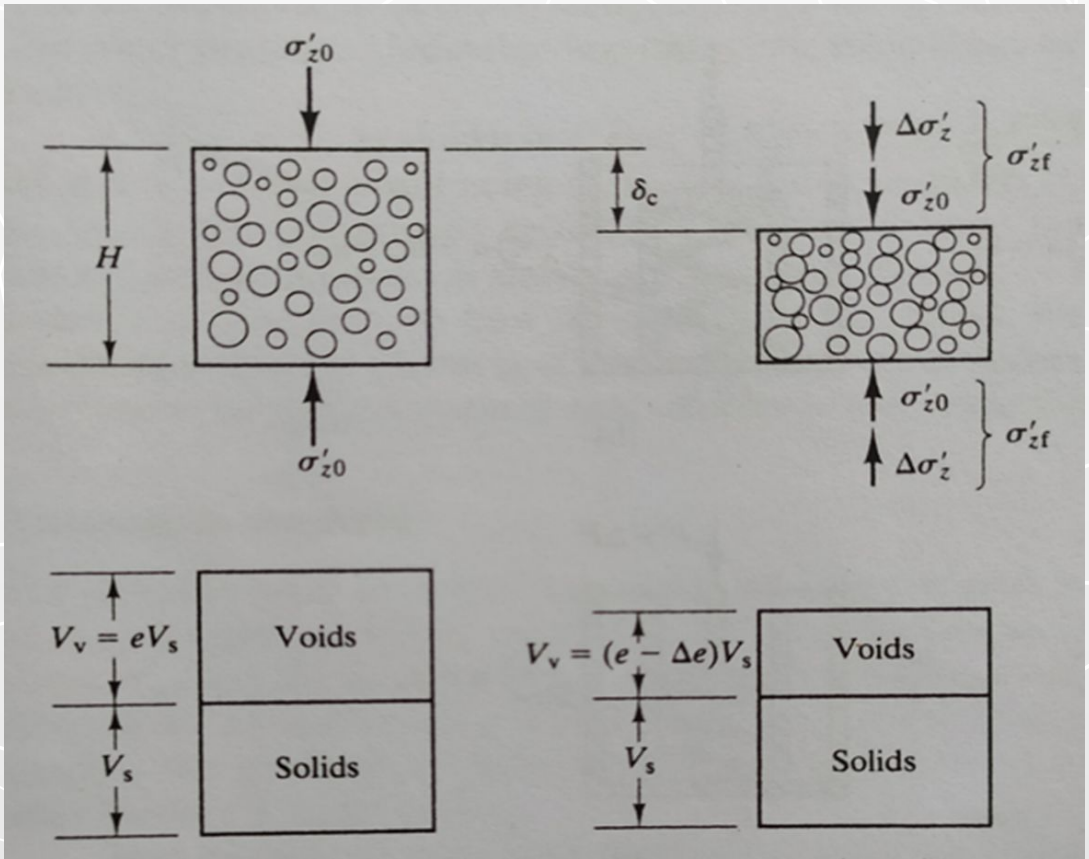


Figure: Consolidation of soil particles under the influence of an increasing vertical effective stress.

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

Consolidation Settlement (cont..)

- Resulting settlement is known as ***consolidation settlement*** δ_c.
- **Most important source of settlement in soils** and its analysis is an important cornerstone of geotechnical engineering.

Question: What is consolidation settlement in soils? Why it is important to geotechnical engineering?

Understanding the Consolidation analyses.

- Consolidation analyses usually **focus on saturated soils (S=100%)**, which means the **voids are completely filled** with water.
- Both the **water and solids are virtually incompressible**.
- So consolidation **can occur only as some of the water is squeezed out of the voids**.
- Process can be **demonstrated by taking a saturated kitchen sponge and squeezing it**; the sponge compresses, the water is pushed out.

Question: Explain the physical process of consolidation and its relationship with the flow of pore water.

Physical process of consolidation and its relationship with the flow of pore water:

Piston and Spring Analogy:

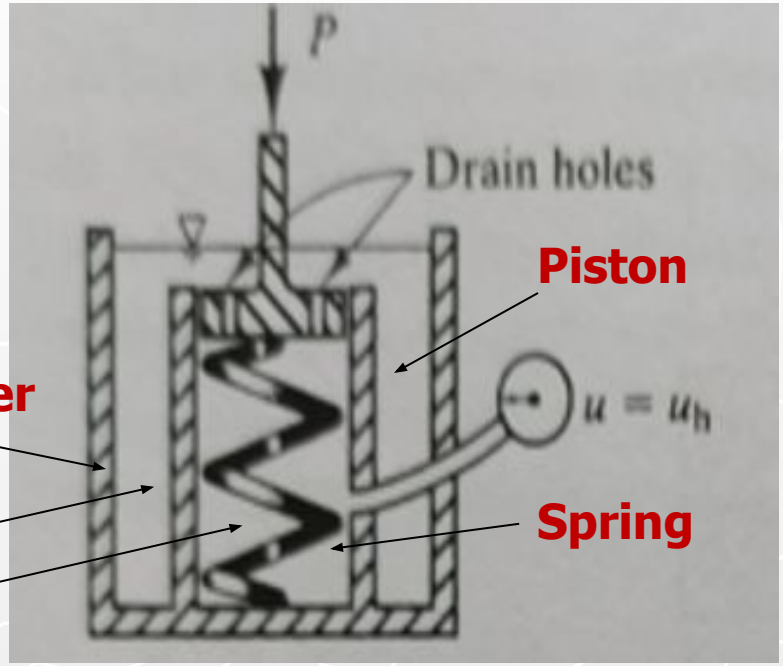
- Consider the mechanical piston and spring analogy.

- **Device consists of a piston and spring located inside a cylinder.**

- **Cylinder** is filled with **water** and a **small drain hole** present in the **piston.**

Piston and Spring Analogy (cont…):

- **Components represent an element of soil** at some depth in the ground.
- **Spring** representing the soil solids.



- **Water** representing the pore water, and
- **Drain holes** representing the soil voids through which the pore water must flow.

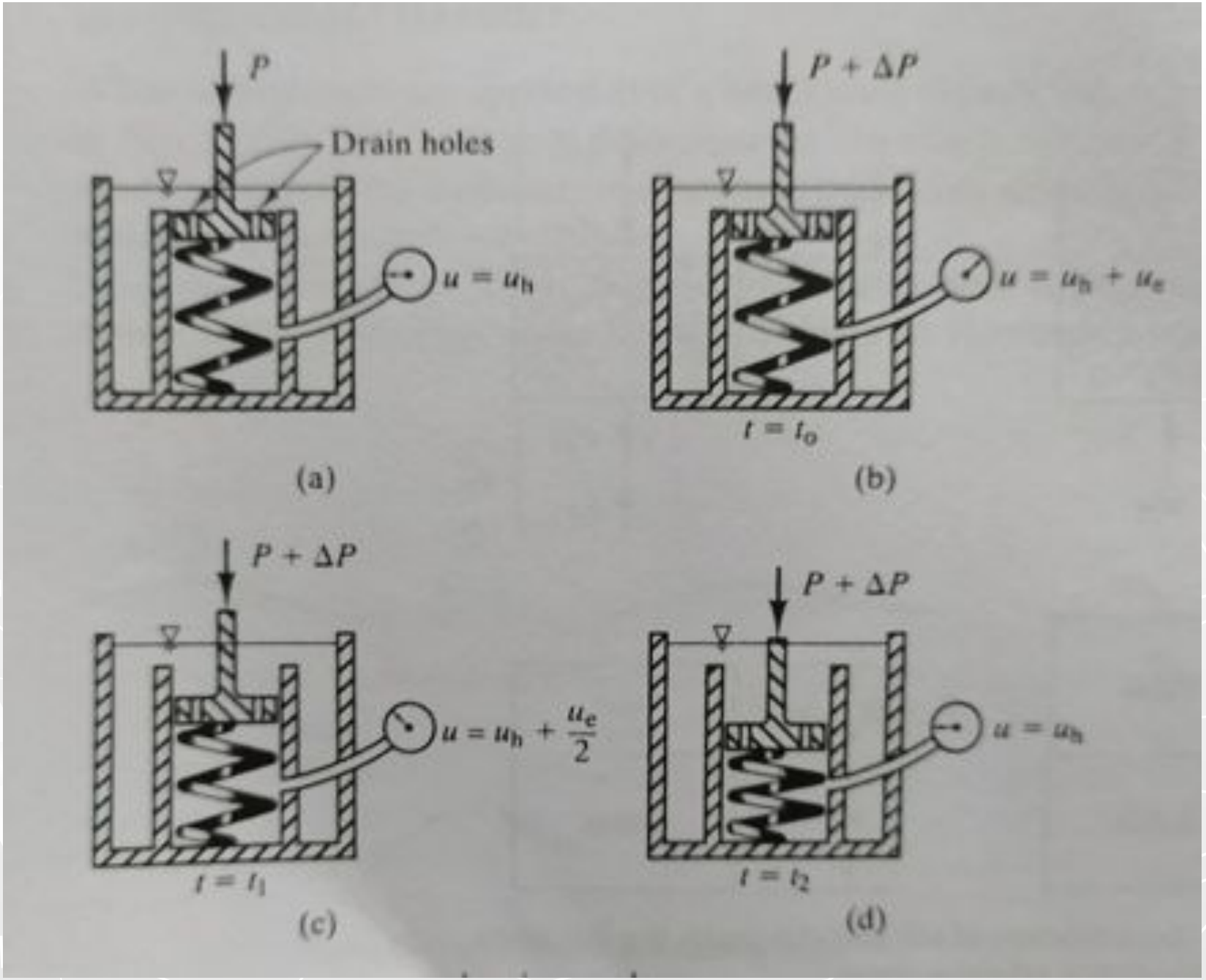


Figure: Piston and Spring Analogy.

Figure (a).

- Piston is in **static equilibrium at top** under a certain vertical load P.

- Assembly is **submerged in a cylinder**, so the water is subjected to a hydrostatic pressure that represents the **hydrostatic pore water pressure** u_h, in the soils.

- **Water pressure** on top and bottom are equal, so that applied **load on piston is carried entirely by the spring**.

- Load divided by the cross-sectional area of the cylinder represents the **initialvertical effective stress**, σ'_{z0}.

$$\sigma'_{z0} = \frac{Load}{\quad}$$

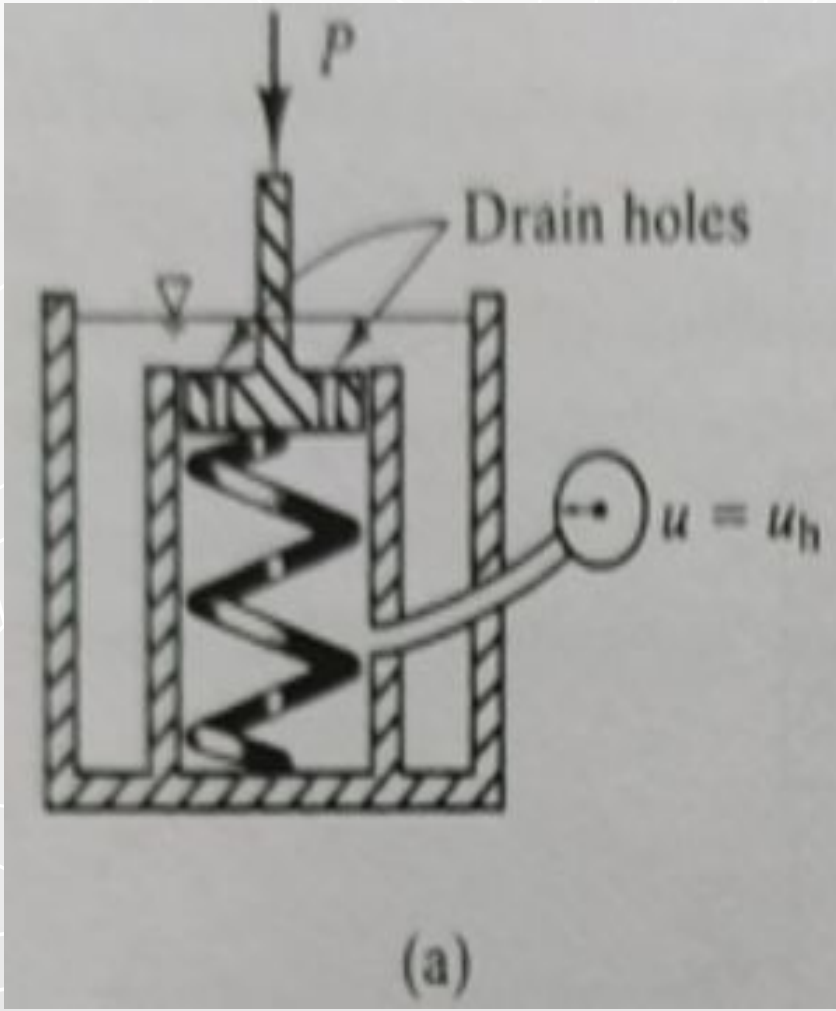
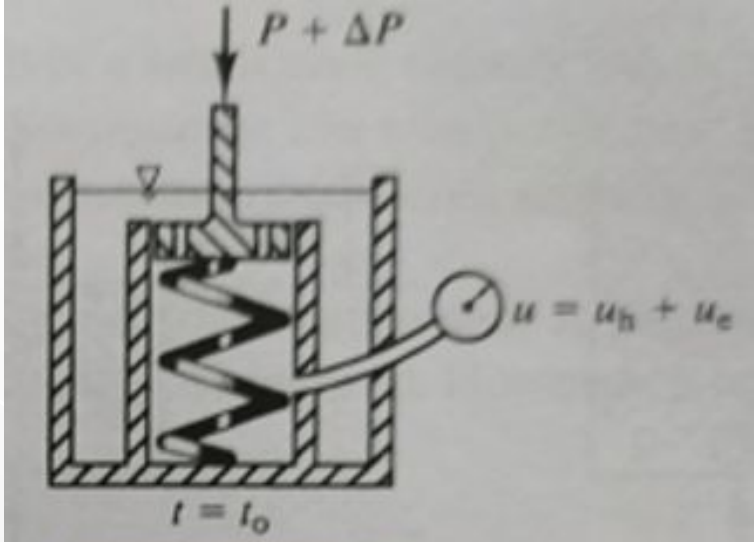


Figure (b):



Figure; (b)

- At time **$t=t_0$** an additional load **ΔP** is applied to the piston, which represent additional total vertical stress **$\Delta\sigma_z$** in a soil, such as induced **by a new fill**.

- Causes a very small **downward movement** of the piston, but this movement is **resisted** by **both the spring (soil)** and **water (pore water)**.

- **Water** is much stiffer than spring, it **carries virtually all the additional load** and the **water pressure increases**.

- Additional pressure is known as *excess pore water pressure,* **u_e**.

- *Water pressure* ***u*** **in side the cylinder** now equals to **$u = u_h + u_e$.**

- **Water pressure inside the cylinder is now greater than outside**, so some of the **water began to flow** through the holes.

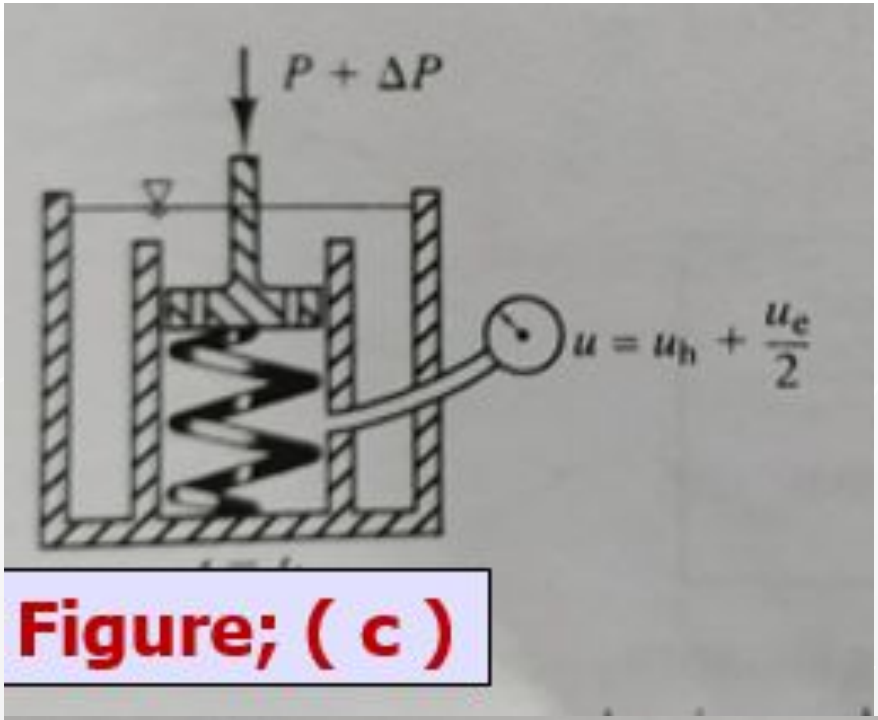
Piston and Spring Analogy: (cont..)

- Holes are very small, so the **flow rate through them is also small**, but eventually **a certain quantity of water passes through.**
- **Outward flow of water allows the piston to move further downward,** thus **compressing the spring** and **relieving some of the load from water**.
- **Process represents** the **gradual transfer of stress from** the pore water to the soil solids**.**

Question: Understanding the relationship between compression of the spring and dissipation of water is key to solving the consolidation problems. explain

Figure (c):

- At time t=t_1, **half of $\Delta\sigma_z$** has been transferred to the soil solids and **half of them** is still being carried by pore water.



Figure; (c)

Figure (d):

- Process continues until the **spring has compressed sufficiently** to **accommodate the original effective stress** plus **the additional effective stress** at **t=t_2**.

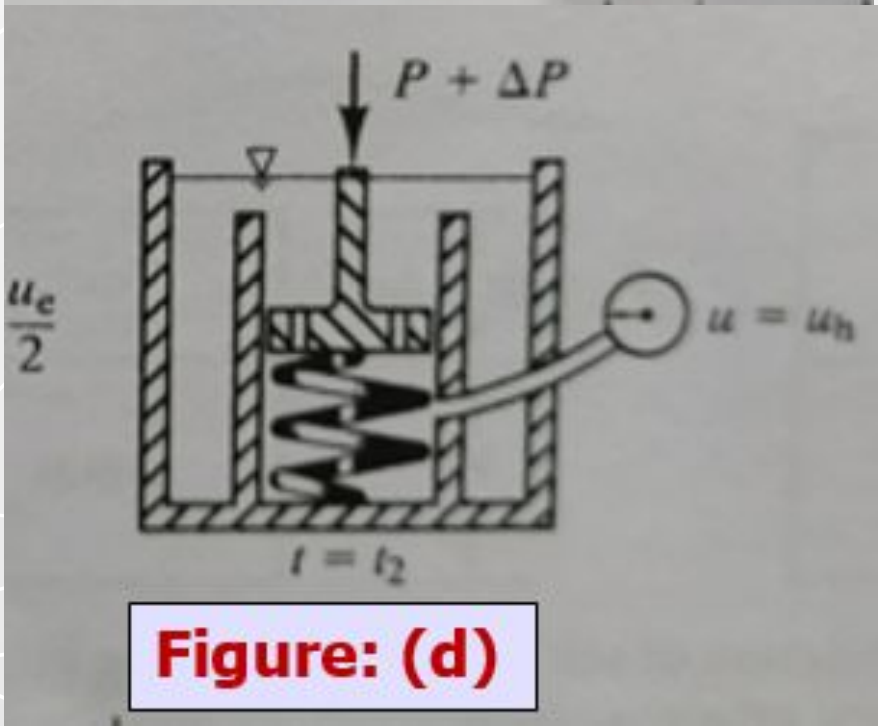


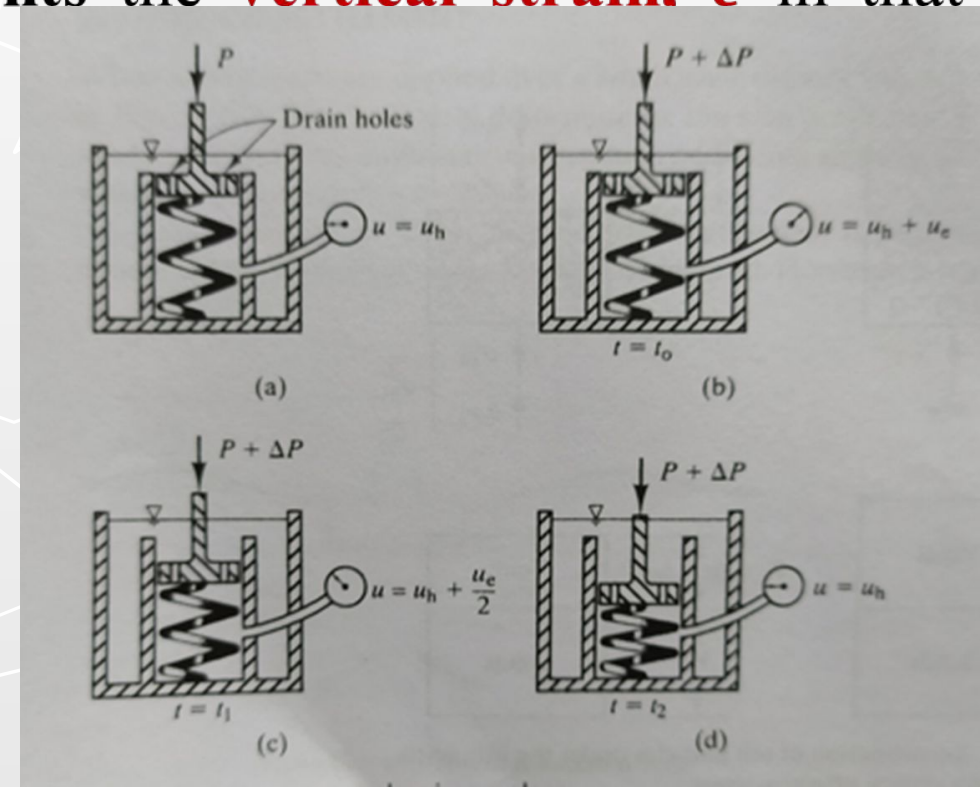
Figure: (d)

Figure (d):

- Excess pore water pressure is now zero **(u_e=0),** so flow through the holes ceases.

- Components returned to **static equilibrium**, but **the piston is in lower position and $u=u_h$.**

- **Change in position represents** the **vertical strain, ϵ** in that element of soil in the field.



Question: Describe the consolidation processes in the field.

Processes in the field:

- **Initial build up of excess pore water pressures** in soils is **more complex** because it depends on the changes of **normal stress** and **deviator stress**.

- Problems can be **simplified** by **assuming the excess pore water pressure** u_e, immediately after loading is equal to $\Delta\sigma_z$. $(u_e=\Delta\sigma_z)$

- **Increase in pore water pressure produces** a **hydraulic gradient in the soil**, causing some of the **pore water to flow away.**

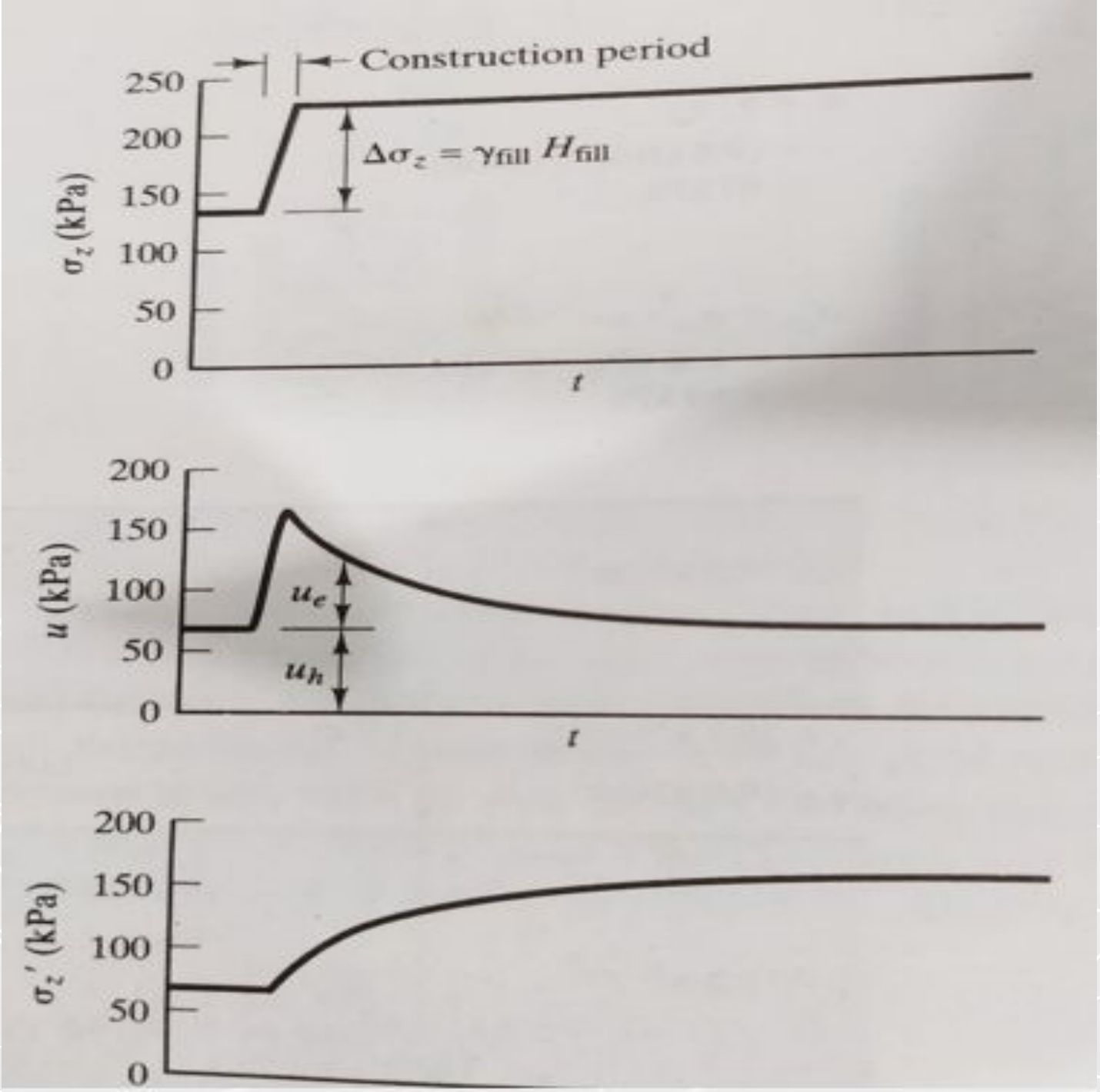
Describe the consolidation processes in the field (cont..).

- As each **increment of stress, water is discharged**, **the solid particles consolidate** and **begin to carry part of the new load.**

- Thus, $\Delta\sigma_z$ **is gradually transferred** from the **pore water to the soil solids**, and the vertical effective stress $\Delta\sigma'_z$ **rises**.

- **Eventually, all of the new load is carried by the solids**, the **pore water pressure returned to its hydrostatic value** u_h, and the **flow of pore water ceases**.

Question: The transfer of load from water to solids is one of the most important processes in geotechnical engineering. Explain.


Construction period
250
200
150
100
50
0
σ_z (kPa)
$\Delta\sigma_z = \gamma_{fill} H_{fill}$
t
200
150
100
50
0
u (kPa)
u_e
u_h
t
200
150
100
50
0
σ_z' (kPa)

Ex. 2: Find out the **vertical effective stress** in soil element at point A, when a 5-m deep fill is placed shown in the following figure; after the consolidation is complete. Explain the consolidation process in the field.

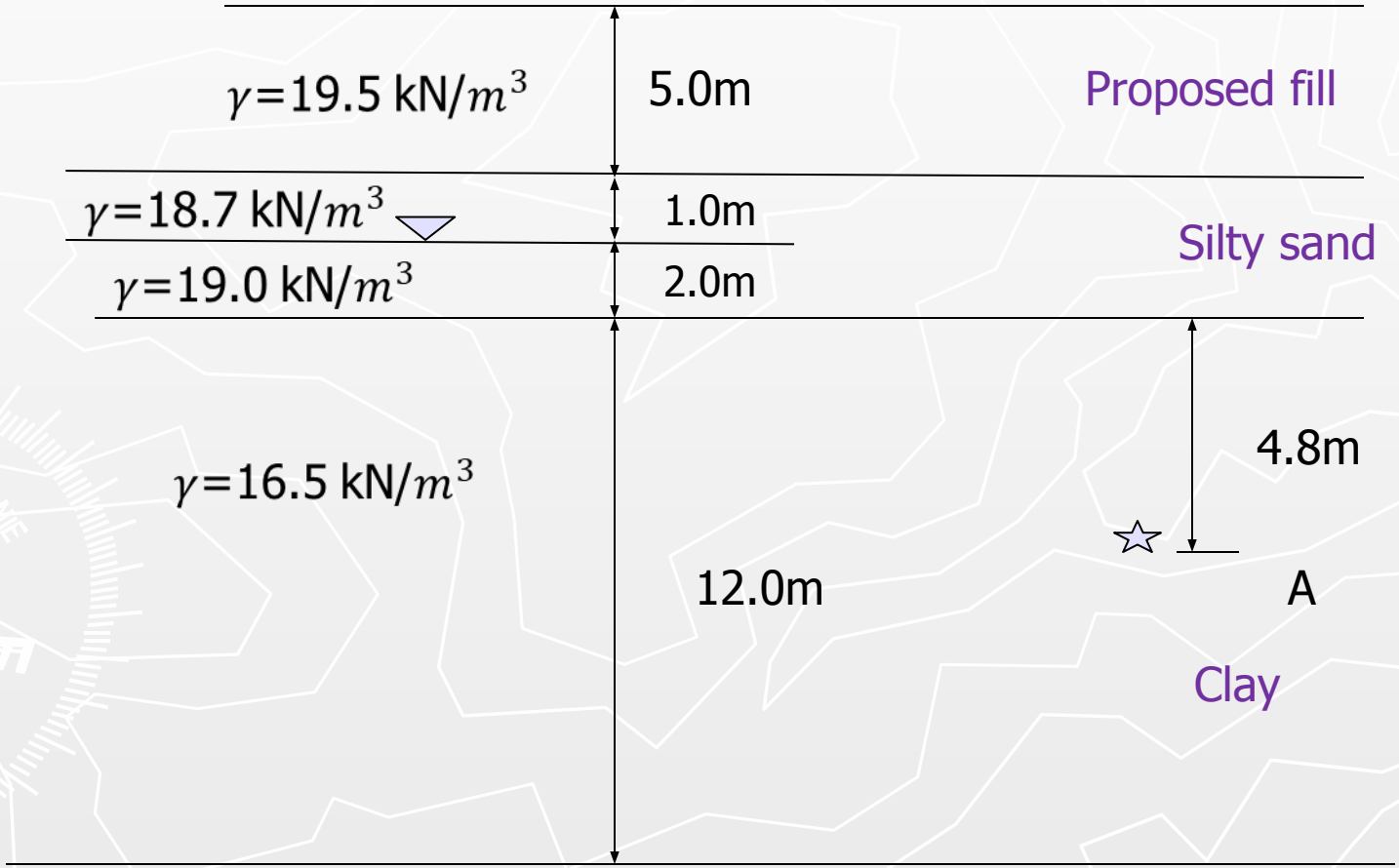


Figure: Soil Profile

Solution:

- Soil element is initially subjected to the following stresses:

$$\sigma'_{z0} = \sigma_{z0} - u$$

$$\sigma_{z0} = \sum \gamma H$$

$$= 18.7 \times 1.0 + 19.0 \times 2.0 + 16.5 \times 4.8$$

$$= 136 \text{ kPa}$$

$$u = \gamma_w z_w$$

$$= 9.8 \times (2.0 + 4.8)$$

$$= \mathbf{67.0 \text{ kPa}}$$

$$\sigma'_{z0} = \sigma_{z0} - u$$

$$= 136 - 67 = \mathbf{69 \text{ kPa}}.$$

Solution (cont..):

- **5-m deep fill has been placed**. These increases the vertical total stress:

$$\sigma_{zf} = \sigma_{z0} + \gamma_{fill} H_{fill}$$

$$= 136\text{kPa} + 19.5\text{x}5.0 = 234\ \text{kPa}$$

- **Initially the applied load** (fill) is carried entirely by the **pore water**. So the pore water pressure becomes:

$$\mathbf{u} = u_h + u_e$$

$$= 67\text{kPa} + 19.5\text{x}5$$

$$(\sigma_{zf} = u_e, \textit{excess load carried by pore water})$$

$$67 + 47.5 = 165\text{kPa}$$

Solution (cont…)

- But the **vertical effective stress remain unchanged**,

σ'_z $= \sigma_z$- u (ie σ_{zf} -u)

=234 – 165

=**69 kPa**

- As some of the pore water drains away, soil element consolidates and $\Delta\sigma_z$ **is gradually transferred from the pore water to the solids.**

- After sufficient long time, u_e=0 and consolidation complete.

u $= u_h + u_e$ = 67kPa + 0 =**67kPa**

σ'_z $= \sigma_z$- u

=234 – 67 = **167 kPa (Answer).**

Thank you