University of Baghdad
College of Engineering
Civil Engineering Department

Title: Lecture 2: One-Dimensional consolidation Theory

Subject: Soil Mechanics II

Year: Third

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Speaker: Prof. Dr. Nesreen Kurdy Al-Obaidy

References:

Principles of Geotechnical Engineering, Textbook by Das,2010

Fundamentals of Geotechnical-Engineering-Third-Edition, Textbook by Das

Consolidation

Assumptions of Terzaghi's Consolidation Theory

Fundamentals of Consolidation

Spring-Cylinder Model

Variation of total stress, pore water pressure, and effective stress

Solved Problem

Consolidation

A Consolidation is a **gradual** process of ***reduction of volume under static loading***, due to **squeezing out of water from soil**. It is a process which occurs in ***nature*** when the saturated soil deposits are subjected to static loading caused by the weight of the building and other structures. The ***theoretical concepts*** of the ***consolidation*** process was developed by ***Terzaghi.*** (1923).

Fill in the blanks

1. Every process involving a decrease in the water content of a saturated soil without replacement of water by air is called ____ **consolidation** _____
2. The compression resulting from a long term static load and consequent escape of pore water is ______ **consolidation** _______
3. Compression of soil, under short duration of moving or vibratory loads is _____**compaction**____

Assumptions of Terzaghi's Theory of One Dimensional Consolidation:

- 1) The **soil** is **homogeneous, isotropic** and **fully saturated**.
- 2) **Soil particles** and **water** are **incompressible**
- 3) The **load** and **flow** are one – dimensional 1D (**vertical**)
- 4) **Strains** are **small**
- 5) **Darcey's law** is **valid** at all hydraulic gradients.
- 6) Coefficient of permeability **'k', ** Coefficient of volume compressibility **'mv' , and** the coefficient of consolidation remain **constant** throughout the process.
- 7) There is a **unique relationship**, **independent of time**, between 'e' and '$\bar{\sigma}$'
- 8) The **time taken for consolidation** is entirely depends upon the **permeability of soil**
- 9) **Excess pore water** drains out only in the **vertical** direction.

Fundamentals of Consolidation in sandy soils

When a saturated soil layer is subjected to ***a stress increase***, **the pore water pressure is increased suddenly**. **In sandy** soils that are highly permeable, the ***drainage*** caused by the ***increase in the pore water pressure*** is ***completed immediately***. Pore water drainage is accompanied by a reduction in the volume of the soil mass, which results in settlement. Because of rapid drainage of the pore water in sandy soils, **elastic settlement and consolidation occur simultaneously.**

Fundamentals of Consolidation in Clay

When a saturated compressible **clay** layer is subjected to ***a stress increase***, **elastic settlement occurs immediately**. Because the hydraulic conductivity of clay is significantly smaller than that of sand, the ***excess pore water pressure*** generated by loading gradually ***dissipates over a long period***. Thus, the associated volume change (that is, the consolidation) in the clay may **continue long after** the elastic settlement. The **settlement** caused by consolidation in clay may be **several times greater than the elastic settlement**.

MCQ Slow vertical deformation occurs when a compressive load is applied to a laterally confined layer of sand.
a) True
b) False **ans. false**

The Degree of Saturation throughout the Consolidation Process

- **The degree of saturation (S)** of soil is the ratio of the volume of water (V_w) to the volume of voids (V_v), expressed as a percentage, i.e., **S = (V_w / V_v) × 100.**
- **During consolidation**, while the volume of voids decreases, the volume of water in the voids also decreases because the water is being pushed out. Therefore, **the degree of saturation remains constant throughout the consolidation process**, so long as no air enters the voids i.e., the soil remains fully saturated.

Spring-Cylinder Model

P: *applied load*

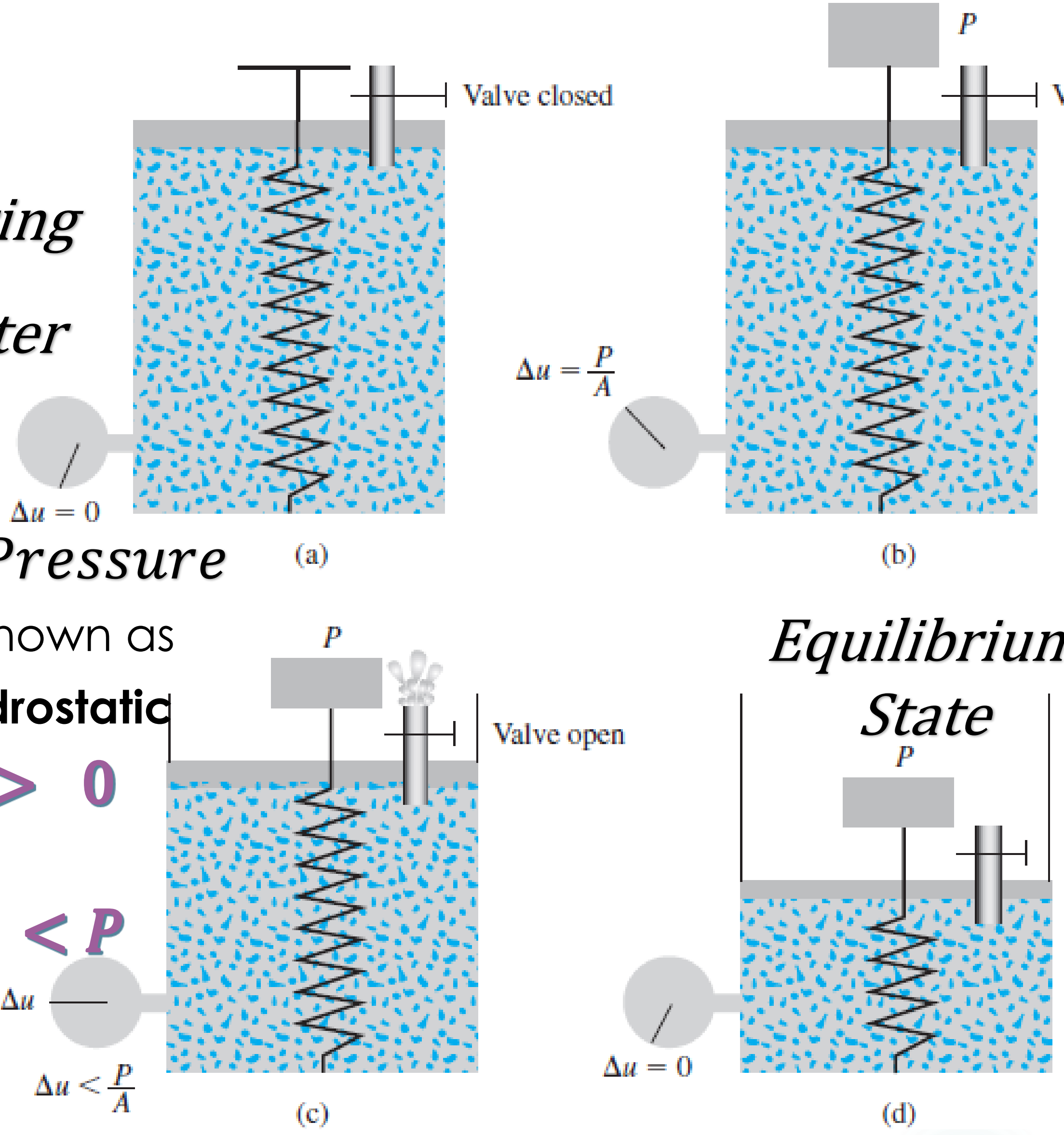
Ps: *load carried by the spring*

Pw: *load carried by the water*

$$P = Ps + Pw$$

$$\Delta u = Excess\ Pore\ Water\ Pressure$$

(Excess pore pressure is also known as **hydrodynamic pressure** or **hydrostatic pressure**)



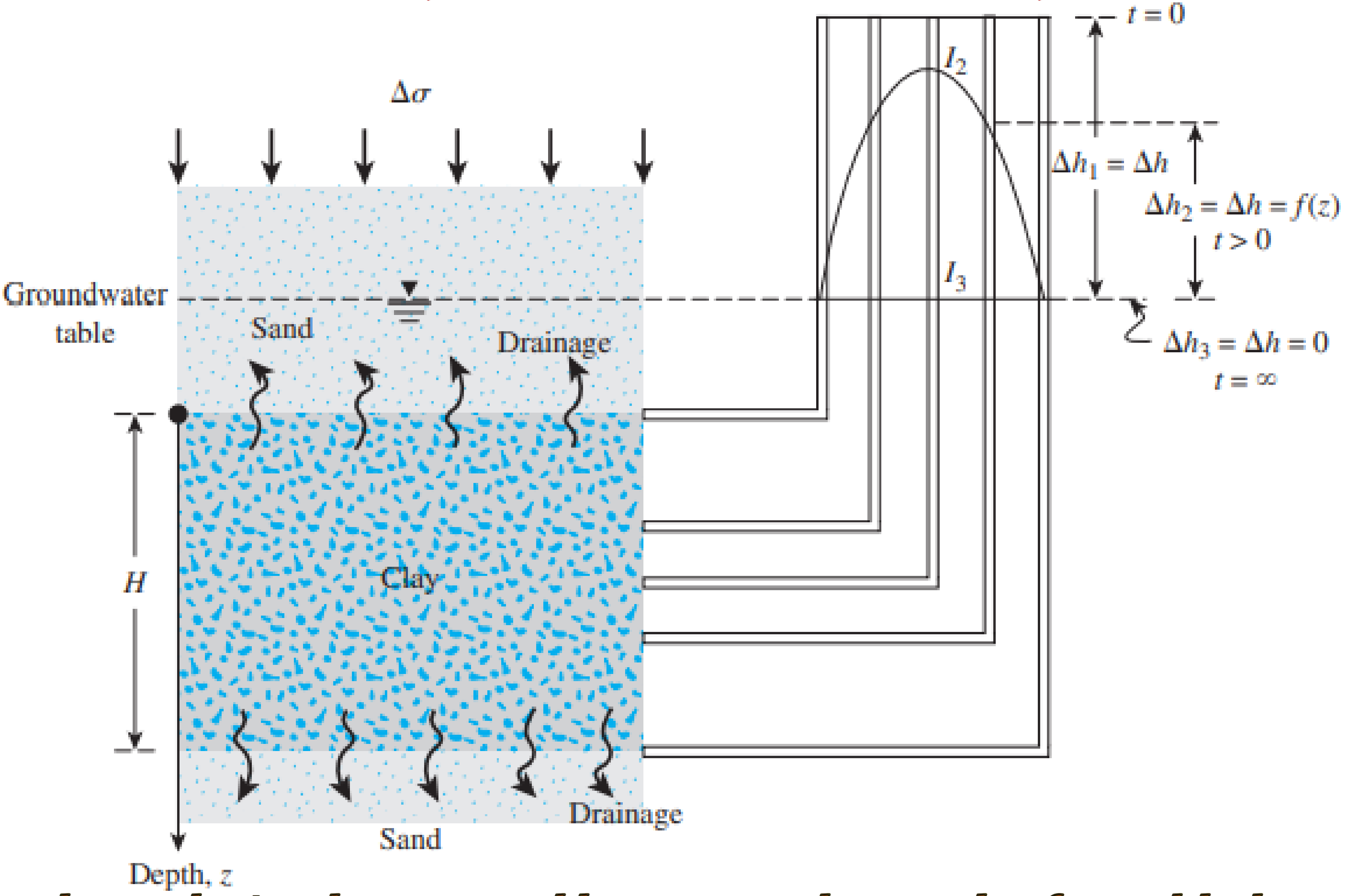
Ps =0 and Pw= P

Ps > 0 and Pw < P

Equilibrium State

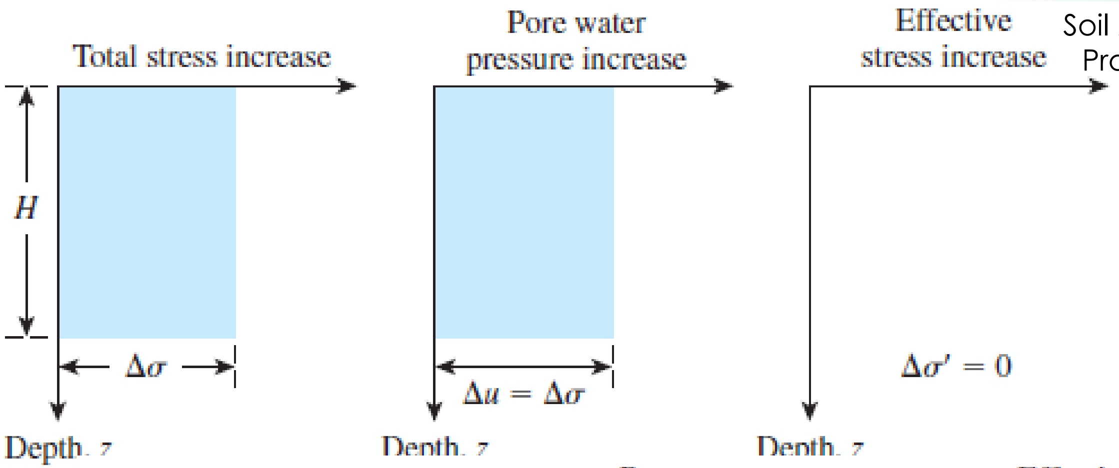
Ps = P and Pw = 0

Variation of Total Stress, Pore Water Pressure, and Effective Stress

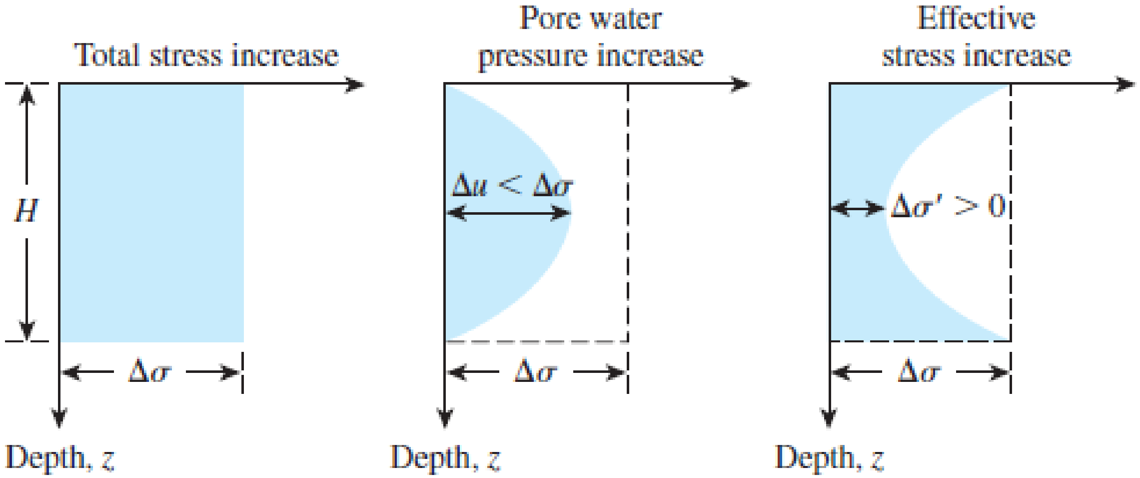


in a clay layer drained at top and bottom as the result of an added stress,

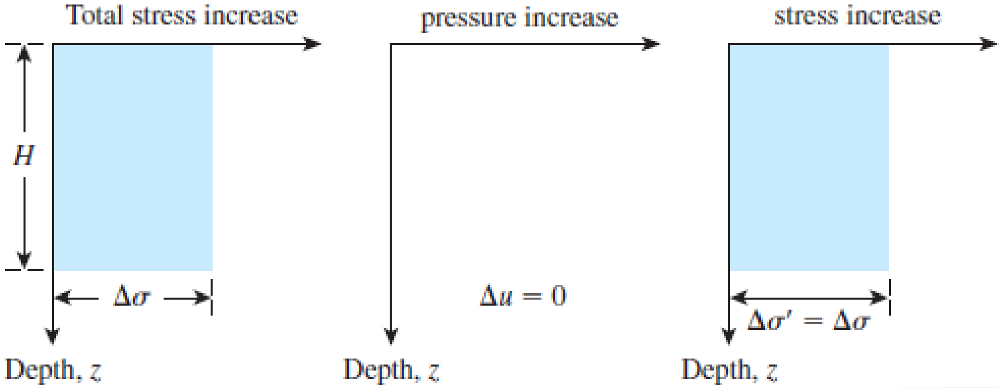
So at time =0 $\Delta u = \Delta\sigma$ while $\Delta\sigma' = 0$



but after a time t
$\Delta u < \Delta\sigma$ while $\Delta\sigma' > 0$



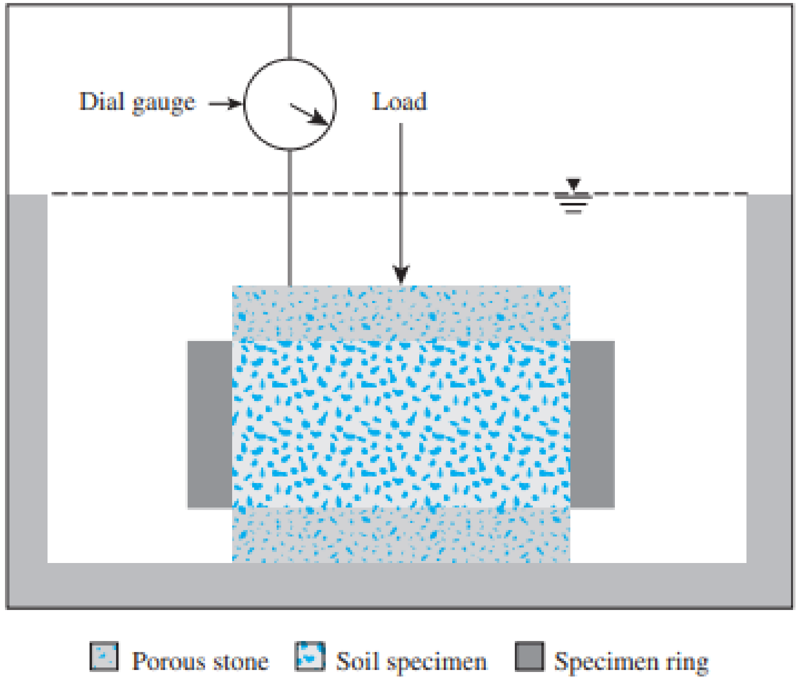
after very long time
$(t \approx \infty)$ $\Delta u = 0$ while $\Delta\sigma = \Delta\sigma'$



One-Dimensional Laboratory Consolidation Test

- The one-dimensional consolidation testing procedure was first suggested by Terzaghi. This test is performed in a **consolidometer** (sometimes referred to as an **oedometer**.

The soil specimen which is laterally **confined** (**restrained**)is placed inside a metal ring with **two porous stones**, one at the top of the specimen and another at the bottom.



The specimens are usually 64 mm in diameter and 25 mm thick (Das). or dia=75 mm and thick=14-20 mm

One-Dimensional Laboratory Consolidation Test

One-Dimensional Laboratory Consolidation Test

The load on the specimen is applied through a **lever arm**, and **compression is measured** by a micrometer **dial gauge**.

The specimen is kept under water during the test. Each load usually is kept for **24 hours**. After that, the load usually is **doubled**, and the compression measurement is continued. At the end of the test, the dry weight of the test specimen is determined.

The loading machine of the consolidometer is generally capable of applying the vertical pressure of 800-1000 kPa

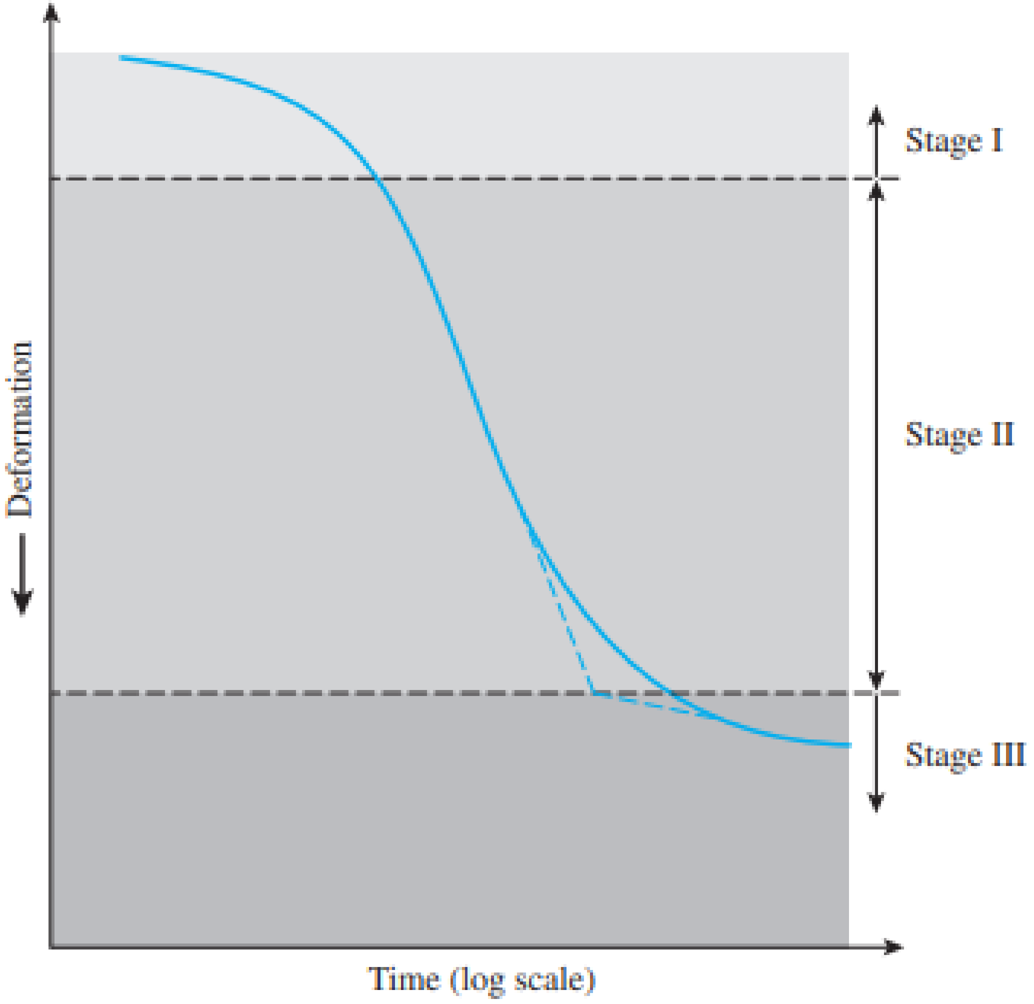
Deformation of the specimen against time for a given load increment is shown,

we can observe three distinct stages, which may be described as follows:

Stage I: Initial compression, which is caused mostly by **preloading**

Stage II: Primary consolidation, during which excess pore water pressure gradually is transferred into effective stress because of the **expulsion of pore water**

Stage III: Secondary consolidation, which occurs after complete dissipation of the excess pore water pressure, when some deformation of the specimen takes place because of **the plastic readjustment of soil fabric**



Void Ratio–Pressure Plots

Step 1: Calculate the height of solids, Hs, in the soil specimen using the equation

$$H_s = \frac{W_s}{AGs\gamma_w} = \frac{M_s}{AGs\rho_w}$$

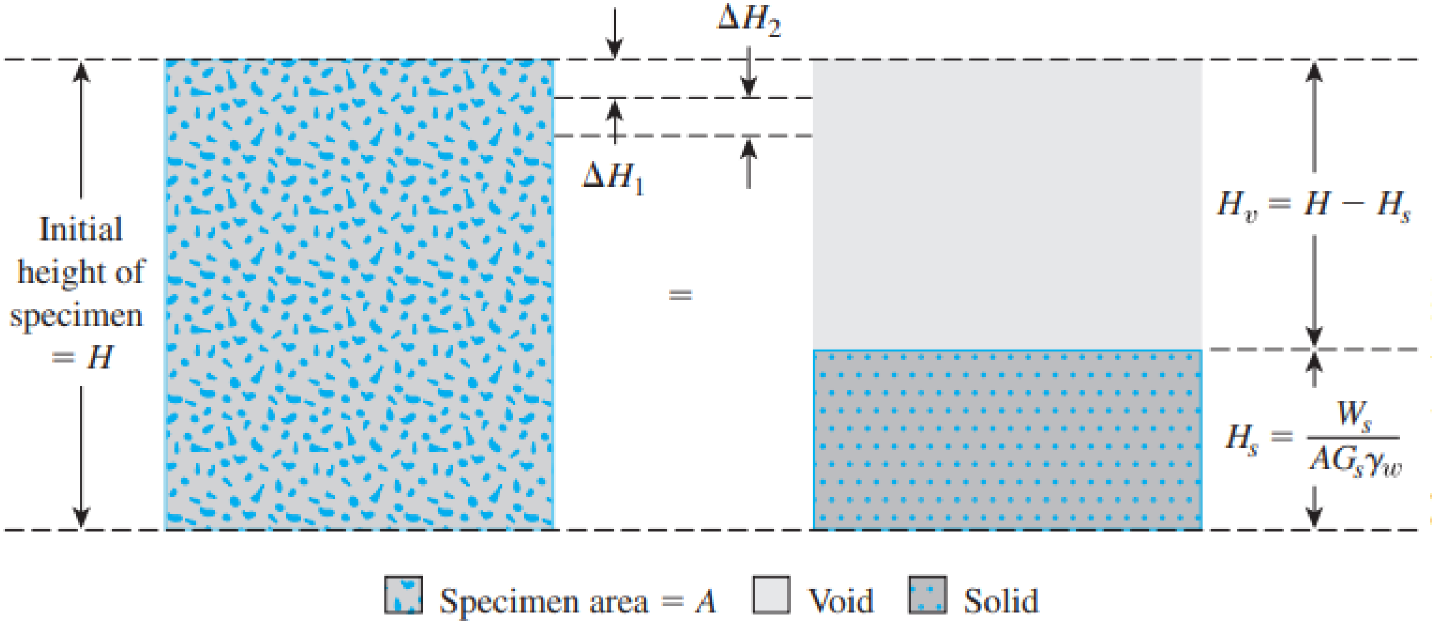
where W_s dry weight of the specimen, M_s dry mass of the specimen A area of the specimen Gs specific gravity of soil solids γ_w :unit weight of water ρ_w density of water

Step 2: Calculate the initial height of voids as $H_v = H - H_s$

where H initial height of the specimen

Step 3: Calculate the initial void ratio, e_o, of the specimen, using the equation

$$e_o = \frac{V_v}{V_s} = \frac{H_v A}{H_s A} = \frac{H_v}{H_s}$$



Void Ratio–Pressure Plots

Step 4: For the first incremental loading, σ_1 (total load/unit area of specimen), which causes a deformation ΔH_1, calculate the change in the void ratio as

$$\Delta e_1 = \frac{\Delta H_1}{H_s}$$

(ΔH_1 is obtained from the initial and the final dial readings for the loading)

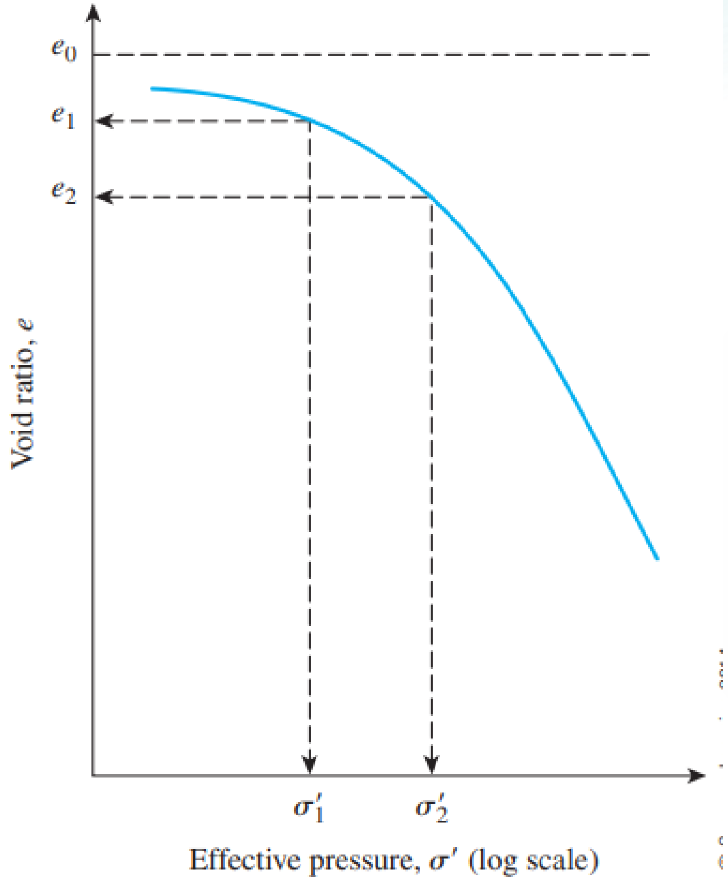
It is important to note that, at the end of consolidation, total stress σ_1 is equal to effective stress σ_1'

Step 5: Calculate the new void ratio after consolidation caused by the pressure increment

$$e_1 = e_o + \Delta e_1$$

Void Ratio–Pressure Plots

For the next loading, σ_2 (note: σ_2 equals the cumulative load per unit area of specimen), which causes additional deformation , ΔH_2 the void ratio at the end of consolidation can be calculated as



$$e_2 = e_1 + \frac{\Delta H_2}{H_s}$$

The effective stress and the corresponding void ratios (e) at the end of consolidation are plotted on semilogarithmic graph paper. The typical shape of such a plot is shown in Figure

Example

Following are the results of a laboratory consolidation test on a soil specimen obtained from the field: Dry mass of specimen 128 g, height of specimen at the beginning of the test 2.54 cm, Gs 2.75, and area of the specimen 30.68 cm^2 . Make necessary calculations and draw an *e* versus log σ' curve.

Effective Pressure σ' (kN/m^2)	Final height of specimen at the end of consolidation (cm)
0	2.540
50	2.488
100	2.465
200	2.431
400	2.389
800	3.324
1600	2.225
3200	2.115

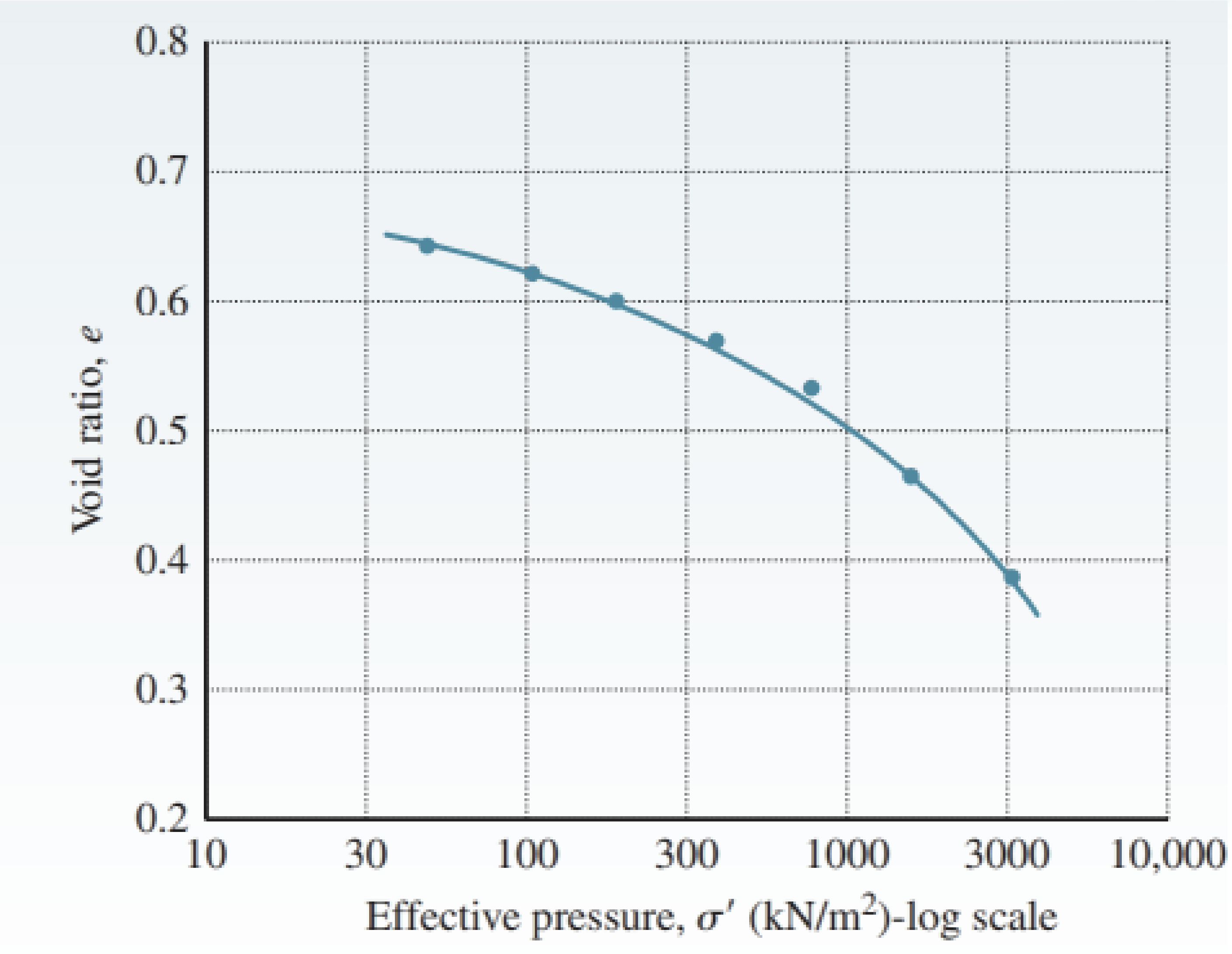
Solution

$$H_s = \frac{W_s}{AGs\gamma_w} = \frac{M_s}{AGs\rho_w}$$

$$H_s = \frac{128\text{ g}}{30.68\text{ cm}^2\,(2.75) * (1g/cm^3)}$$

$$H_s = 1.52\text{ cm}$$

Effective Pressure σ' (kN/m²)	Final height of specimen at the end of consolidation H (cm)	H_v=H-H_s	$e = H_v/H_s$
0	2.540	2.540-1.52=1.02	1.02/1.52 =0.671
50	2.488	0.968	0.637
100	2.465	0.945	0.622
200	2.431	0.911	0.599
400	2.389	0.869	0.572
800	3.324	0.804	0.529
1600	2.225	0.705	0.464
3200	2.115	0.595	0.390


0.8
0.7
0.6
0.5
0.4
0.3
0.2
Void ratio, e
10
30
100
300
1000
3000
10,000
Effective pressure, σ′ (kN/m²)-log scale

Thank you