

CHAPTER FOUR

ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

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5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

**In the previous
classes.....**

- ✓ **Theory of compaction**
- ✓ **Compaction in the lab.**
- ✓ **Factors Affecting**

Compaction:

- ✓ **Control of Compaction**

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

In this chapter we will discuss.....

- ✓ develop the **basic concepts** of **consolidation**
- ✓ show how to **calculate** the **consolidation settlement** from applied loads.
- ✓ we will **formulate** the theory of

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Introduction

- ✓ Under load, all soils will settle, causing settlement of structures founded on or within them.
- ✓ If the settlement is not kept to a tolerable limit:-
 - ❖ the desired use of the structure may be impaired and
 - ❖ the design life of the structure may be reduced.

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Introduction

The **total settlement** usually consists of **three parts**

- ✓ immediate or elastic compression
- ✓ primary consolidation, and

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Definitions of Key Terms

- ✓ **Consolidation** is the time-dependent settlement of soils resulting from the expulsion of water from the soil pores.
- ✓ **Primary Consolidation** is the change in volume of a fine-grained soil caused by the expulsion of water from the voids and the transfer of load from the excess pore water pressure to the soil particles.
- ✓ **Secondary Consolidation** is the change in volume of a fine-grained soil caused by the adjustment of the soil fabric (internal structure) after primary consolidation has been completed.
- ✓ **Drainage path, H_{dr}** , is the longest vertical path that a water particle will take to reach the drainage surface.

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Definitions of Key Terms

- ✓ **Pre-consolidation Stress** is **past maximum effective stress** in a soil. (σ_{zc})
- ✓ **Normally Consolidated Soil** is one that has never experienced vertical effective stresses greater than its current vertical effective stress (σ_{z0})
- ✓ **Over-consolidated Soil** is one that has experienced vertical effective stresses greater than its current (σ_{z0})
- ✓ **Over-consolidation ratio, OCR**, is the ratio

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Definitions of Key Terms

- ✓ ***Compression Index, C_c*** , is the slope of the normal consolidation line on a plot of the logarithm of vertical effective stress versus void ratio.
- ✓ ***Unloading/reloading index or recompression index, C_r*** , is the average slope of the unloading/reloading curves in a plot of the logarithm of vertical effective stress versus void ratio.
- ✓ ***Modulus of volume compressibility,***

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Primary consolidation

In our development of the various ideas on consolidation settlement, we will assume:

- ✓ A homogeneous, saturated soil.
- ✓ The soil particles and the water to be incompressible.
- ✓ Vertical flow of water.
- ✓ The validity of Darcy's law.
- ✓ Small strains

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Primary consolidation

- ❖ We will conduct a *simple experiment* to establish the *basic concepts* of the *one-dimensional consolidation settlement* of *fine-grained soils*.
 - ✓ Let us take a *thin, soft, saturated sample* of *clay* and place it between *porous stones* in a *rigid, cylindrical container* whose *inside wall* is *frictionless* (Fig. 6.1a).
 - ✓ The *porous stones* are *used* to *facilitate drainage* of the *pore water* from the *top* and *bottom faces* of the *soil*.
 - ✓ A *platen* on the *top* of the *top porous stone* *transmits applied loads* to the *soil*.
 - ✓ *Expelled water* is *transported* by *plastic tubes* to a *burette*.

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Primary consolidation

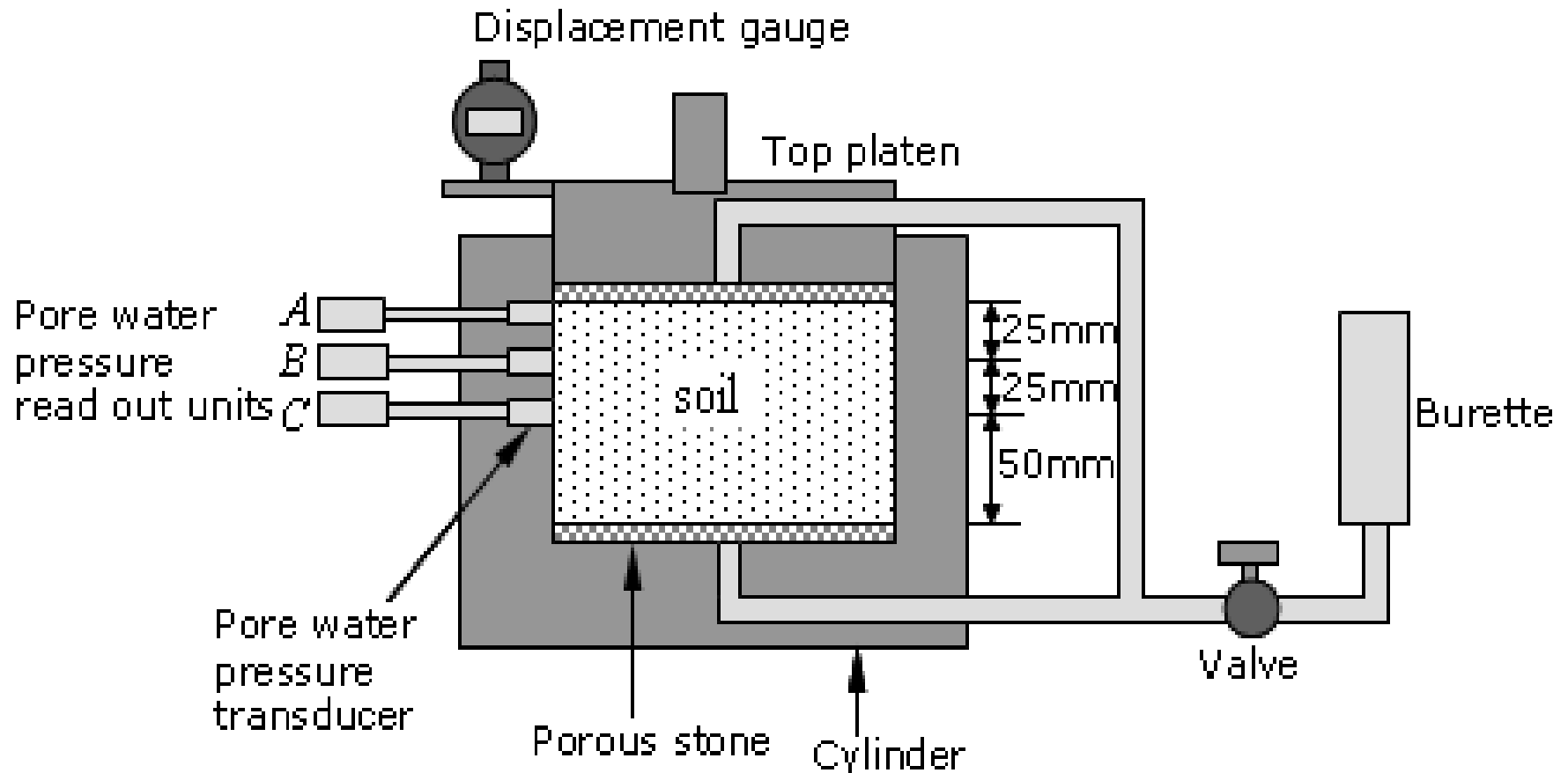


Figure 6.1a: Experimental setup for illustrating basic concepts on consolidation.

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Primary Consolidation

- ✓ *Three pore water transducers* are mounted in the *side wall* of the *cylinder* to *measure* the *excess pore water pressure*
- ✓ A *displacement gauge* with its stem on the *platen* *keeps track* of the *vertical settlement of the soil*.
- ❖ We will *assume* that the *pore water* and the *soil particles* are *incompressible* and the *initial pore water pressure* is *zero*.
- ❖ The *volume of excess pore water* that *drains* from the *soil* is then a *measure* of the *volume change* of the *soil resulting* from the *applied loads*.

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Primary consolidation

- ❖ Since the *side wall* of the *container* is *rigid, no radial displacement* can *occur*.
- ❖ The *lateral* and the *circumferential strains* are then *equal* to *zero* ($\epsilon_r = \epsilon_\theta = 0$) and the *volumetric strain* ($\epsilon_p = \epsilon_z + \epsilon_r + \epsilon_\theta$) is *equal to* the *vertical strain* ($\epsilon_z = \Delta z / H_0$),

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Primary consolidation

- ❖ Let us now *apply a load P* to the *soil* through the *load platen* and *keep the valve closed*.
- ❖ Since *no excess pore water* can *drain* from the *soil*, the *change in volume* of the *soil* is *zero* $\Delta V = 0$
- ❖ The *pore water carries the total head*.
- ❖ The *initial excess pore water pressure* in the *soil* () is then *equal* to the *change in applied vertical stress*, $\Delta u_0 = \Delta \sigma'_z = P/A$
- ❖ For our *thin soil layer*, we will *assume* that the *initial excess pore water pressure* will be *distributed uniformly* with *depth* so that at every point in the soil layer, the *initial excess pore water pressure* is *equal* to the *applied stress*.

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Primary consolidation

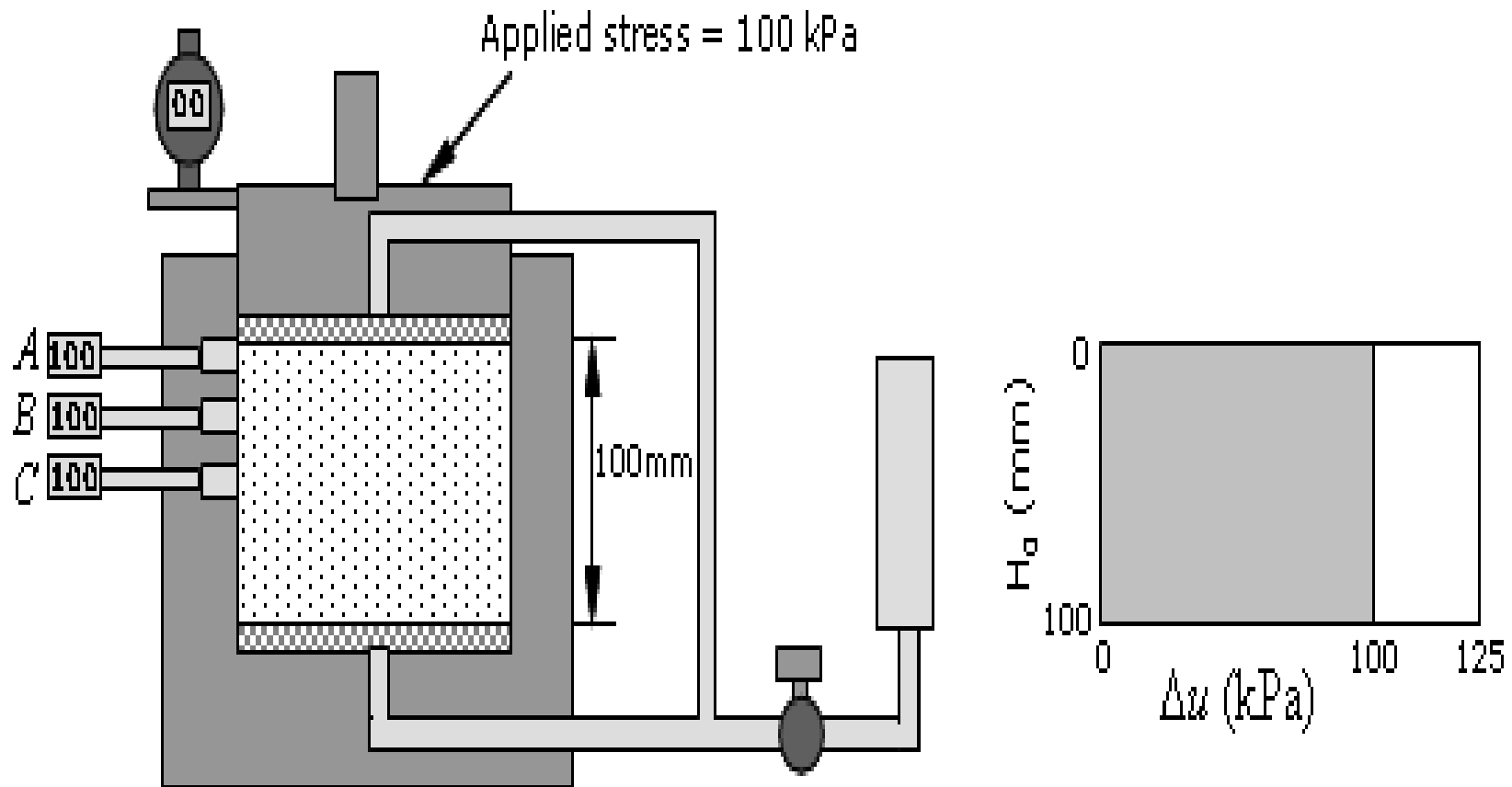


Figure 6.1b: Instantaneous or initial excess pore water pressure when a vertical load is applied.

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Primary consolidation

- ❖ Let us now *open* the *valve* and *allow the initial excess pore water to drain*.
- ❖ The *total volume* of *soil* at *time t_1* *decreases* by the amount of *excess pore water* that *drains* from it as indicated by the *change* in *volume* of *water* in the *burette* (Fig. 6.1c).
- ❖ At the *top* and *bottom* of the *soil sample*, the *excess pore water pressure* is *zero* because these are *drainage boundaries*.
- ❖ The *decrease of initial excess pore pressure* at the *middle* of the *soil* (*point C*) is the *slowest* because a *water particle* must *travel* from the *middle* of the *soil* to *either* the *top* or *bottom boundary* to exit the system.

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Primary consolidation

- ❖ You may have *noticed* that the *settlement* of the *soil* (ΔZ) with *time* t (Fig. 6.1 c) is *not linear*.
- ❖ *Most* of the *settlement occurs shortly* after the *valve* was *opened*.
- ❖ ***Primary consolidation*** is the *change* in *volume* of the *soil* caused by the *expulsion of water* from the *voids* and the *transfer* of *load* from the *excess pore water pressure* to the *solid particles*.

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Primary consolidation

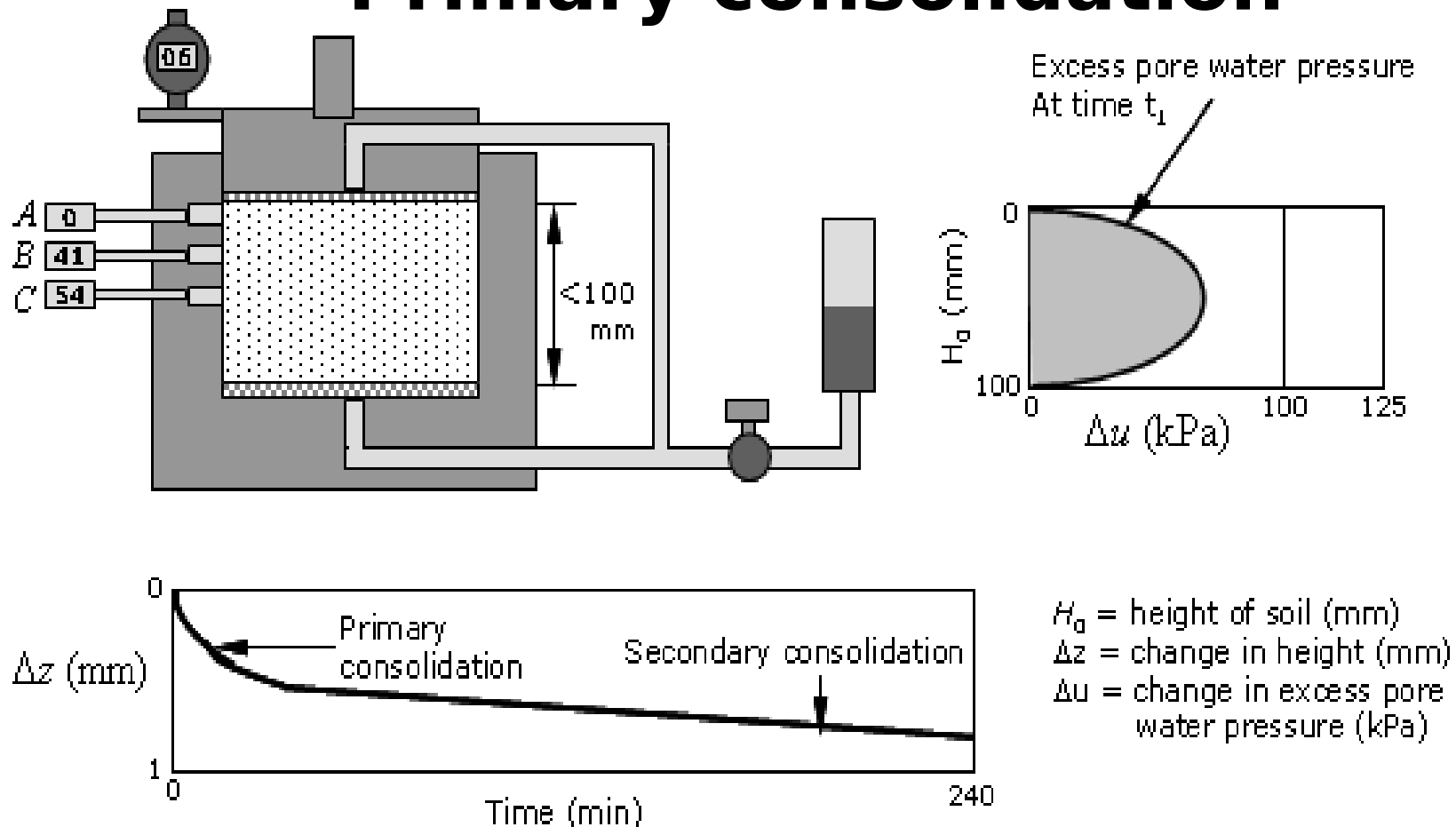


Fig 6.1c: Excess pore water pressure distribution and settlement during consolidation.

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Secondary Compression

- ❖ *Primary consolidation ends* with $\Delta u = 0$
- ❖ The *later time settlement* response is called ***secondary compression or creep***.
- ❖ *Secondary compression* is the *change* in *volume* of *fine-grained soils* caused by the *adjustment* of the *soil fabric* (*internal structure*) after *primary consolidation* has been *completed*.
- ❖ The *rate of settlement* from *secondary compression* is *very slow* compared with *primary consolidation*.

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Drainage Path

- ❖ The *distance* of the *longest vertical* path *taken* by *water* to *exit* the *soil* is called the *length of the drainage path*.
- ❖ *Because* we *allowed* the *soil* to *drain* on the *top* and *bottom faces* (*double drainage*), the *length* of the *drainage path*, H_{dr} , is

$$\boxed{H_{dr} = \frac{H_{av}}{2} = \frac{H_0 + H_f}{4}} \quad (6.1)$$

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Rate of Consolidation

- ❖ The *rate of consolidation* for a *homogeneous* soil *depends* on the *soil's permeability*, the *thickness*, and the *length of the drainage path*.
- ❖ A *soil* with a *coefficient of permeability lower than* that of *our current soil* will *take longer to drain*, the *initial excess pore water* and *settlement* will *proceed* at a *slower rate*.

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Effective Stress Changes

- ❖ Since the *applied vertical stress (total stress) remains constant*, then according to the *principle* of the $\Delta\sigma_z = \Delta\sigma_z - \Delta u$ () *any reduction of initial excess pore water pressure must be balanced by a corresponding increase in vertical effective stress.*
- ❖ *Increases in vertical stresses lead to soil settlement* caused by *changes* to the *soil fabric*.
- ❖ As *time increases*, the *initial excess water pressure continues* to *dissipate* and the *soil continues* to *settle* (Fig. 6.1c).

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Void Ratio and Settlement Changes Under a

❖ The *initial volume* (*Constant Volume*) of a *soil* is $V = 1 + e_0$

❖ Any *change in volume* of the *soil* () is *equal* to the *change* in *void ratio* (), volumetric strain is equal to,

$$\varepsilon_p = \frac{\Delta V}{V} = \frac{\Delta e}{1 + e} \quad (6.2)$$

❖ Since for *one-dimensional consolidation*, we can write a *relationship* between *settlement* and the *change* in the *void ratio* as

$$\varepsilon_z = \frac{\Delta z}{H_0} = \frac{\Delta e}{1 + e} \quad (6.3)$$

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Void Ratio and Settlement Changes Under a Constant Load

- ❖ We can rewrite Eq. (6.3) as:

$$\Delta z = H_0 \frac{\Delta e}{1 + e} \quad (6.4)$$

- ❖ We are going to *use* ρ_{pc} to *denote primary consolidation settlement* rather than Δz

$$\rho_{pc} = H_0 \frac{\Delta e}{1 + e} \quad (6.5)$$

- ❖ The *void ratio* at the *end* of the *consolidation* under *load P* is

$$e = e_0 - \Delta e = e_0 - \frac{\Delta z}{H_0} (1 + e_0) \quad (6.6)$$

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Effects of Vertical Stresses on Primary Consolidation

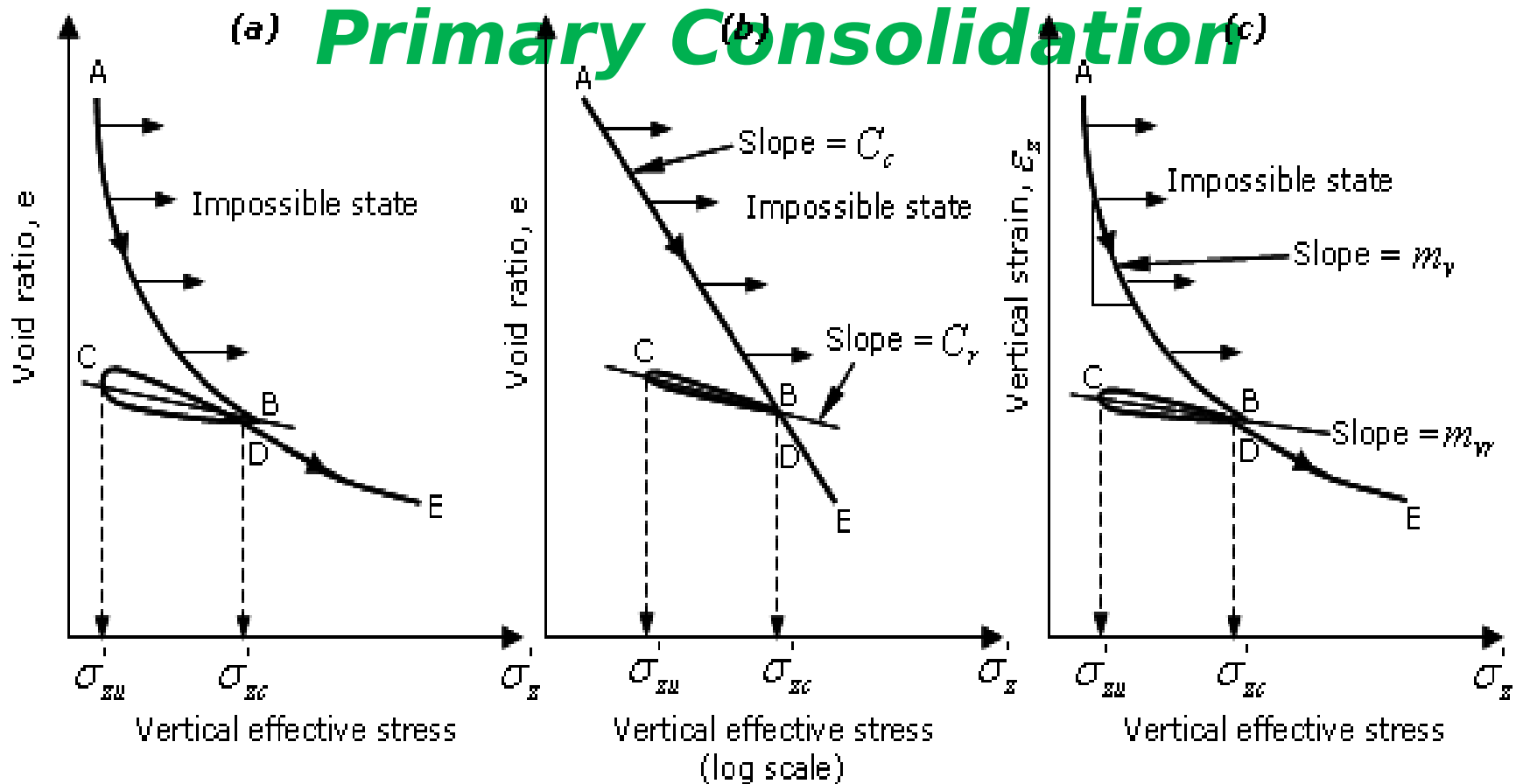


Figure 6.2: Three plots of settlement data from soil consolidation.

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Primary Consolidation

- ❖ One is called the **Coefficient of Compression** or **Compression Index**, C_c , and is obtained from the plot of e versus $\log \sigma'_z$ (Fig. 6.2b).

$$C_c = - \frac{e_2 - e_1}{\log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}} = \frac{|\Delta e|}{\log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}} \quad (\text{no units}) \quad (6.7)$$

- ❖ The other is called The **Modulus of Volume Compressibility**, m_v , and is obtained from the plot of ϵ_z versus σ'_z (Fig. 6.2c).

$$m_v = - \frac{(\epsilon_z)_2 - (\epsilon_z)_1}{(\sigma'_z)_2 - (\sigma'_z)_1} = \frac{|\Delta \epsilon_z|}{(\sigma'_z)_2 - (\sigma'_z)_1} \left(\frac{\text{m}^2}{\text{kN}} \right) \quad (6.8)$$

Where: subscripts 1 and 2 denote two arbitrarily selected points on the NCL

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Primary Consolidation

- ❖ Similarly, we can define the slope BC in Fig.6.2b as the **Recompression Index, C_r** , which we can express as:

$$C_r = - \frac{e_2 - e_1}{\log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}} = \frac{|\Delta e_{zr}|}{\log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}} \quad (6.9)$$

Where: subscripts 1 and 2 denote two arbitrarily selected points on the URL

- ❖ The slope BC in Fig.6.2c is called the **Modulus of Volume Recompressibility, m_{vr}** , and is expressed as:

$$m_{vr} = - \frac{(\varepsilon_z)_2 - (\varepsilon_z)_1}{(\sigma'_z)_2 - (\sigma'_z)_1} = \frac{|\Delta \varepsilon_{zr}|}{\log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}} \left(\frac{\text{m}^2}{\text{kN}} \right) \quad (6.10)$$

Where: subscripts 1 and 2 denote two arbitrarily selected points on the URL

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Primary Consolidation

- ❖ From *Hook's law*, we know that *Young's modulus of elasticity* is

$$E'_c = \frac{\Delta \sigma'_z}{\Delta \varepsilon_z} \quad (6.11)$$

$$E'_c = \frac{1}{m_{vr}} \quad (6.12)$$

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Effects of Loading History

❖ Consolidation Type

1. **Normal consolidation**

- ✓ Preconsolidation pressure (P_c) just equals the existing effective vertical overburden pressure (P_o)

2. **Over consolidation**

- ✓ If the soil whose preconsolidation pressure (P_c) is greater than the existing overburden pressure

❖ Overconsolidation Ratio

$$\text{OCR} = \frac{\sigma'_{zc}}{\sigma'_{z0}}$$

(6.13)

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Calculation of Primary Effects of Unloading/Reloading of a Sample Taken from Field

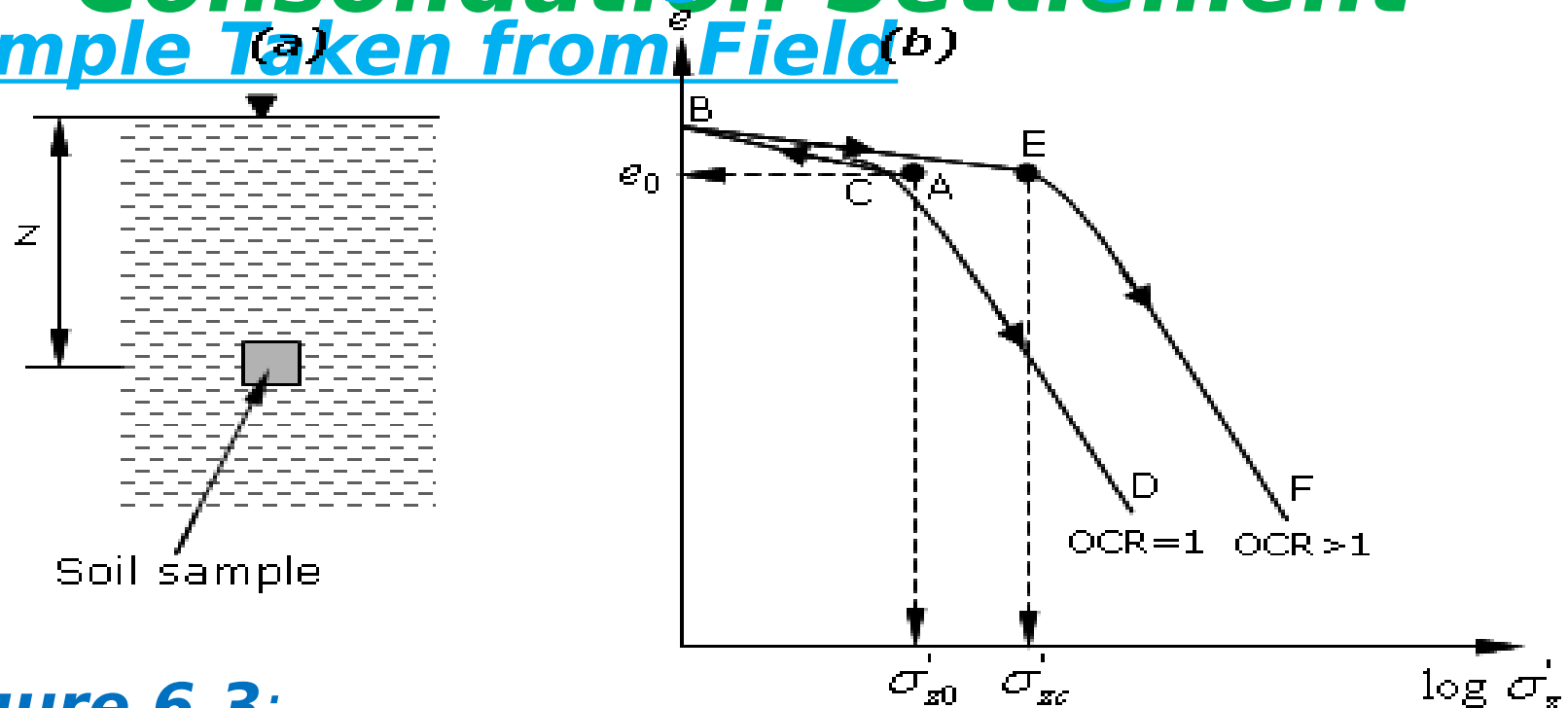


Figure 6.3:

(a) Soil sample at a depth z below ground surface.

(b) Expected one-dimensional response.

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Primary Consolidation Settlement of Normally Consolidated Fine-grained Soils

- ❖ The *increase in vertical stress* due to the *building* at depth z , where we took our soil sample, is $\Delta\sigma_z$
 - ❖ The *final vertical stress* is $\sigma'_{fin} = \sigma'_{z0} + \Delta\sigma_z$
 - ❖ The *increase in vertical stress* will *cause* the soil to *settle* following the *NCL* and the *Primary Consolidation Settlement* is (6.14)
- $$s_{pc} = H_0 \frac{\Delta e}{1 + e_0} = \frac{H_0}{1 + e_0} C_c \log \frac{\sigma'_{fin}}{\sigma'_{z0}}, \text{OCR} = 1$$

where $\Delta e = C_c \log(\sigma'_{fin} / \sigma'_{z0})$

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Primary Consolidation Settlement of Overconsolidated Fine-grained Soils

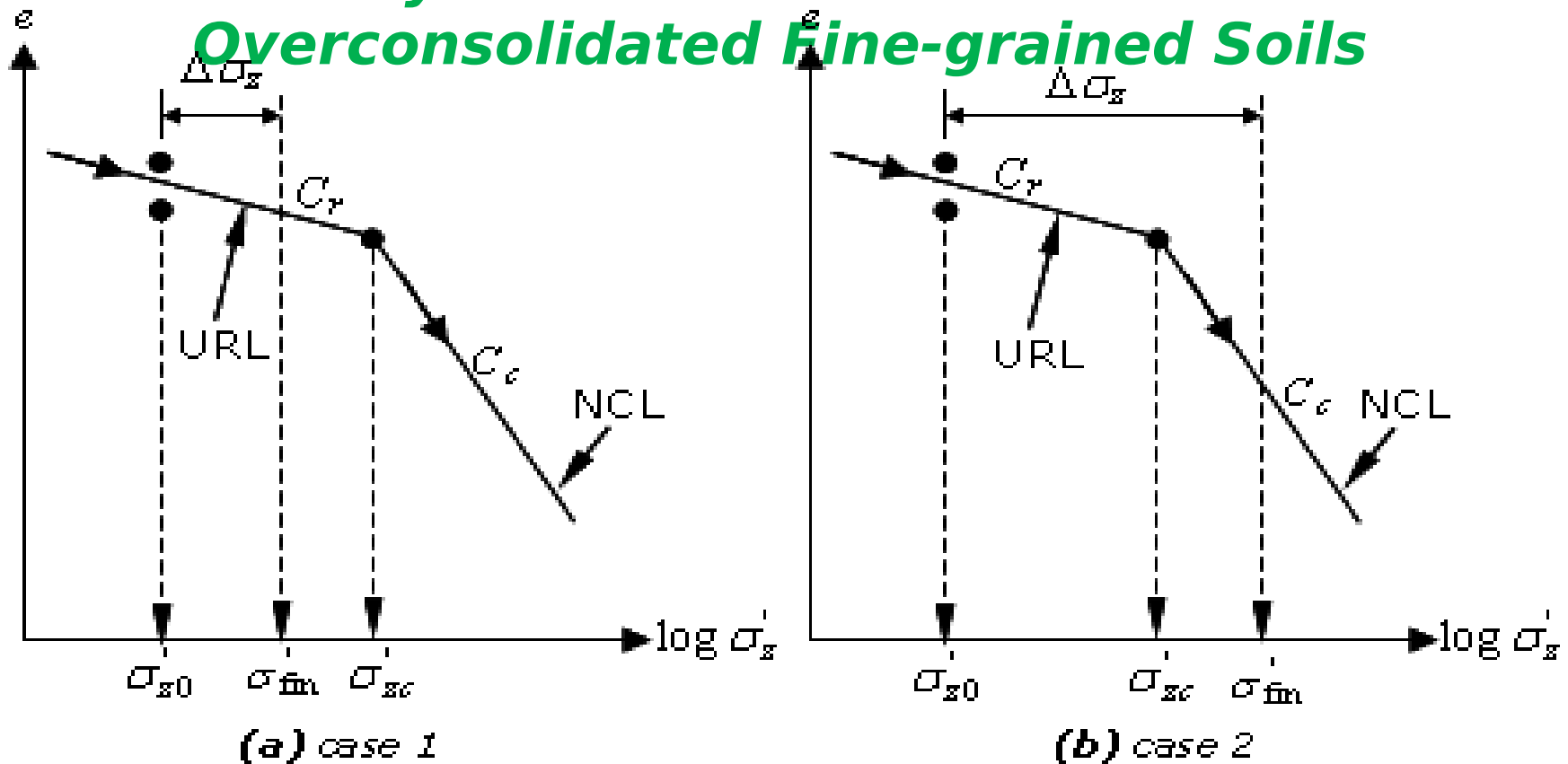


Figure 6.4: Two cases to consider for calculating settlement of overconsolidated

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Primary Consolidation Settlement of Overconsolidated Fine-grained Soils

In case 1, the increase in $\Delta\sigma_z$ is such that $\sigma'_{fin} = \sigma'_{z0} + \Delta\sigma_z$ is less than σ'_{zc} (Fig.6.4a). In this case, consolidation occurs along the URL and

$$\rho_{pc} = H_0 \frac{\Delta e}{1 + e_0} = \frac{H_0}{1 + e_0} C_r \log \frac{\sigma'_{fin}}{\sigma'_{z0}}; \sigma'_{fin} < \sigma'_{zc} \quad (6.15)$$

In case 2, the increase in $\Delta\sigma_z$ is such that $\sigma'_{fin} = \sigma'_{z0} + \Delta\sigma_z$ is greater than σ'_{zc} (Fig.6.4b). In this case, we have to consider two equations, one along the URL and the other along the NCL. The equation to use in case 2 is

$$\rho_{pc} = \frac{H_0}{1 + e_0} \left(C_r \log \frac{\sigma'_{zc}}{\sigma'_{z0}} + C_c \log \frac{\sigma'_{fin}}{\sigma'_{zc}} \right); \sigma'_{fin} > \sigma'_{zc} \quad (6.16)$$

or

$$\rho_{pc} = \frac{H_0}{1 + e_0} \left(C_r \log(\text{OCR}) + C_c \log \frac{\sigma'_{fin}}{\sigma'_{zc}} \right); \sigma'_{fin} > \sigma'_{zc} \quad (6.17)$$

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Procedure to Calculate Primary Consolidation Settlement

- 1** Calculate the current vertical effective stress (σ'_{z0}) and the current void ratio (e_0) at the center of the soil layer for which settlement is required.
- 2** Calculate the applied vertical stress increase ($\Delta\sigma_z$) at the center of the soil layer using the appropriate method in section 5.10.
- 3** Calculate the final effective vertical stress $\sigma_{fin} = \sigma'_{z0} + \Delta\sigma_z$.
- 4** Calculate the primary consolidation settlement.
 - a.** If the soil is normally consolidated ($OCR=1$), use Eq. (6.14).
 - b.** If the soil is overconsolidated ($OCR>1$) and $\sigma_{fin} < \sigma'_{zc}$, use Eq. (6.15).
 - c.** If the soil is overconsolidated ($OCR>1$) and $\sigma_{fin} > \sigma'_{zc}$, use Eq. (6.16 or 6.17).

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Procedure to Calculate Primary Consolidation Settlement

- ❖ You can also calculate the primary consolidation settlement using m_v .
- ❖ However, *unlike C_c , which is constant, m_v varies with stress levels.*
- ❖ You should *compute an average value of m_v over the stress ranges σ_{z0}' to σ_{fin}*
- ❖ The *primary consolidation settlement, using m_v , is*

$$\Delta s_{pc} = H_0 m_v \Delta \sigma_z \quad (6.18)$$

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Terzaghi One-dimensional

6.3.1 Derivation of Governing Equation

- ❖ The *general equation* for *one-dimensional consolidation* is:

$$\boxed{\frac{\partial u}{\partial t} = C_v \frac{\partial^2 u}{\partial z^2}} \quad (6.29)$$

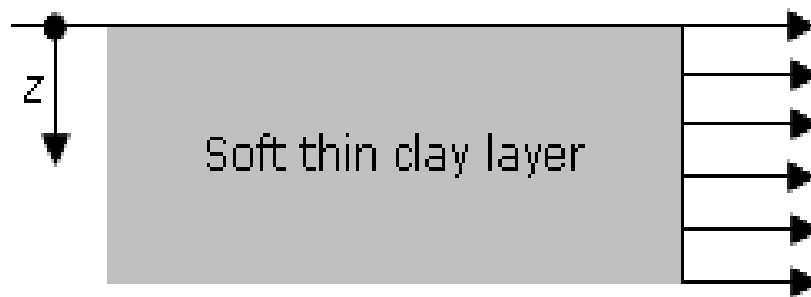
Where: C_v is called the coefficient of consolidation

$$C_v = \frac{k_z}{m_v \gamma_w}$$

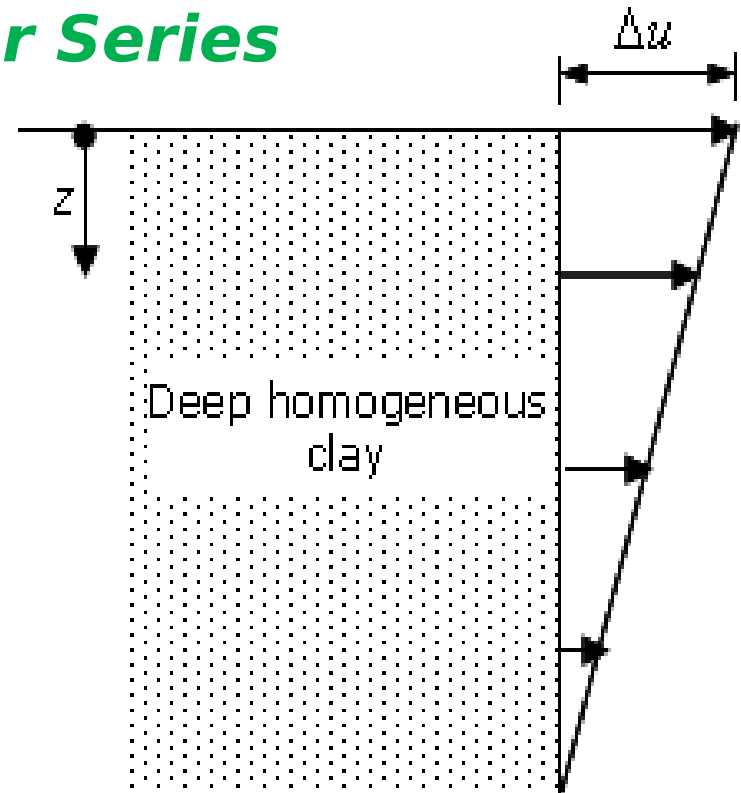
- ❖ Eq. (6.29) is often called the **Terzaghi one-dimensional consolidation equation** because Terzaghi (1925) developed it.

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Solution of Governing Consolidation Equation Using Fourier Series



(a) Uniform distribution



(a) Triangular distribution

Figure 6.6: Two types of excess pore water pressure distribution with depth

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Solution of Governing Consolidation Equation Using Fourier Series

The boundary conditions for a uniform distribution of initial excess pore water pressure in which double drainage occurs are

When $t = 0$, $\Delta u = \Delta u_0 = \Delta u_z$.

At the top boundary, $z = 0$, $\Delta u = 0$.

At the bottom boundary, $z = 2H_{dr}$, $\Delta u = 0$, where H_{dr} is drainage path length.

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Solution of Governing Consolidation Equation Using Fourier Series

A solution for the governing consolidation equation (6.29), which satisfies these boundary conditions, is obtained using the Fourier series,

$$\Delta u(z,t) = \sum_{m=0}^{\infty} \frac{2\Delta u_0}{M} \sin\left(\frac{Mz}{H_{dr}}\right) \exp(-M^2 T_v) \quad (6.30)$$

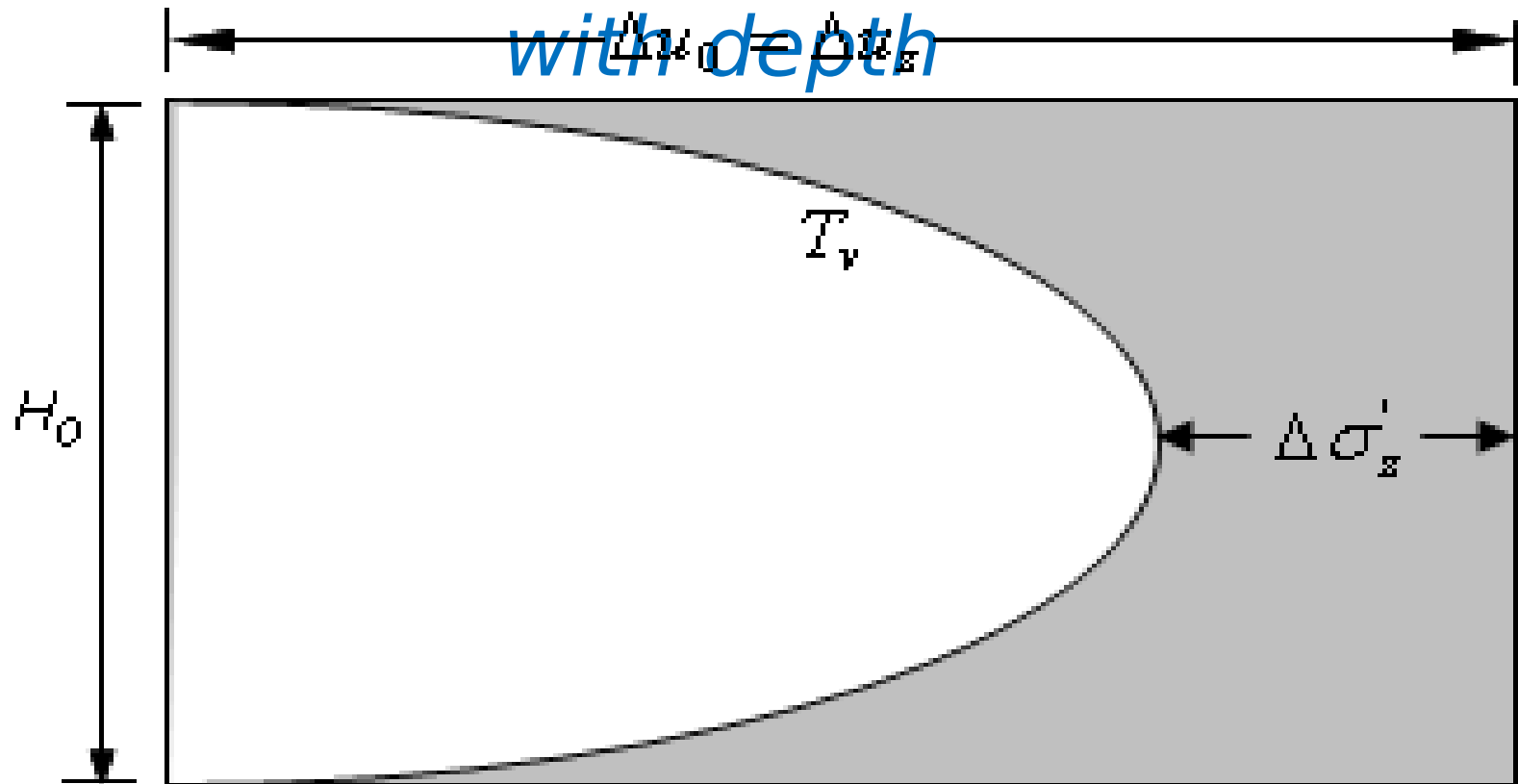
where $M = (\pi/2)(2m+1)$ and m is a positive integer with values from 0 to ∞ and,

$$T_v = \frac{C_v t}{H_{dr}^2} \quad (6.31)$$

where T_v is known as the **time factor**, it is a dimensionless term.

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*An isochrone illustrating the theoretical
excess pore water pressure distribution
with depth*



5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

An isochrone illustrating the theoretical excess pore water pressure distribution

- ❖ **The degree of consolidation** or **consolidation ratio**, U_z , gives us the *amount* of *consolidation* *completed* at a *particular time* and *depth* and is given

by:

$$U_z = 1 - \frac{\Delta u_z}{\Delta u_0} = 1 - \sum_{m=0}^m \frac{2}{M} \sin\left(\frac{Mz}{H_{dr}}\right) \exp(-M^2 T_v) \quad (6.32)$$

- ❖ The **average degree of consolidation**, U , can be expressed *mathematically* from the *solution* of the *one-dimensional consolidation equation* as

$$U = 1 - \sum_{m=0}^m \frac{2}{M^2} \exp(-M^2 T_v) \quad (6.33)$$

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An isochrone illustrating the theoretical excess pore water pressure distribution with depth

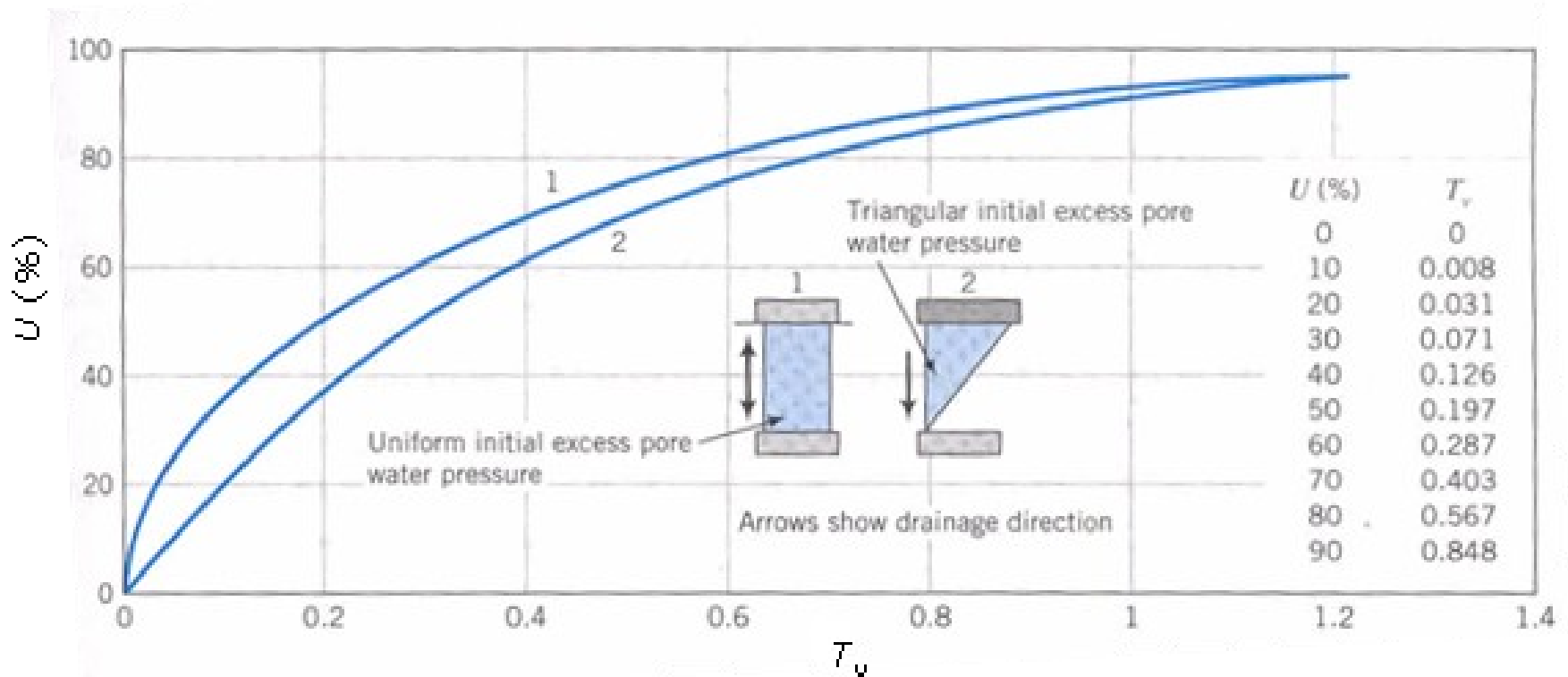


Fig 6.8: *R/ship between time factor and average degree of consolidation*

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

An isochrone illustrating the theoretical excess pore water pressure distribution with depth

- ❖ Figure 6.8 shows the *variation* of the *average degree* of *consolidation* with *time factor* T_v for a *uniform* and *triangular distribution* of *excess pore water pressure*.

- ❖ A *convenient set* of *equations* for *double drainage* found by curve fitting Fig. 6.8, is

$$T_v = \frac{\pi}{4} \left(\frac{U}{100} \right)^2 \quad \text{for } U < 60\% \quad (6.34)$$

$$T_v = 1.781 - 0.933 \log(100 - U) \quad U \geq 60\% \quad (6.35)$$

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Secondary Compression Settlement

- ❖ You will recall that *consolidation settlement* consisted of *two parts*.
- ❖ The *first part* is *primary consolidation*, which *occurs* at *early times due to expulsion of water*.
- ❖ The *second part* is *secondary compression*, or *creep*, which *takes place* under a *constant effective stress*.
- ❖ *Primary consolidation* is *assumed* to *end* at the *intersection* of the *projection* of the *two straight parts* of the *curve* as shown in Fig. 6.9.

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Secondary Compression Settlement

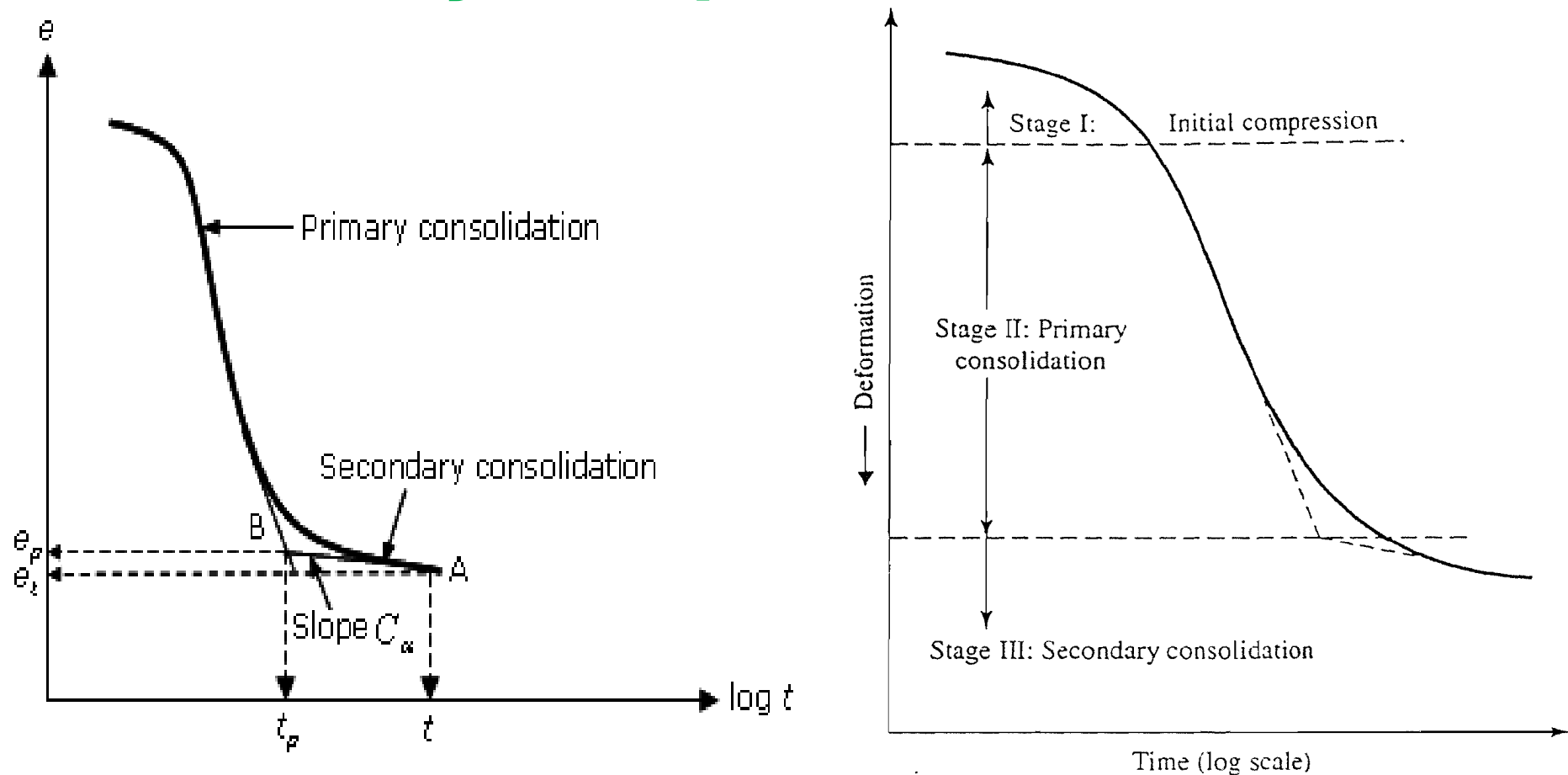


Figure 6.5: Secondary compression.

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Secondary Compression Settlement

- ❖ The *secondary compression index* is given by:

$$C_{\alpha} = - \frac{(e_t - e_p)}{\log(t / t_p)} = \frac{|\Delta e|}{\log(t / t_p)}; t > t_p \quad (6.36)$$

- ❖ *Overconsolidated soils do not creep significantly* but *creep settlements* in *normally consolidated soils* can be *very significant*.

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

One-dimensional Consolidation *Oedometer Test*

- ❖ The *one-dimensional consolidation test*, called the *oedometer test*, is used to find C_c , C_r , C_α , m_v , and σ'_{zc} .
- ❖ The *coefficient of permeability* k_z , can also be *calculated* from the *test data*
- ❖ *Incremental loads*, including *unloading sequences*, are applied to the *platen* and the *settlement* of the *soil* at *various fixed times*, under each *load increment*, is measured by a *displacement gauge*.
- ❖ *Each loading increment* is allowed to *remain* on the *soil until* the *change* in *settlement* is *negligible* and the *excess pore water pressure developed* under the *current load increment* has *dissipated*. (For many soils, this usually occurs with in 24 hours)

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

One-dimensional Consolidation

❖ **Laboratory Test**
The data obtained from the one-dimensional consolidation test are as follows:

1. *Initial height* of the soil, H_0 , which is fixed by the height of the ring.
2. *Current height* of the *soil* at various *time intervals* under *each load* (time-settlement data).
3. *Water content* at the *beginning* and at the *end* of the *test*, and the *dry weight* of the *soil* at the *end* of the *test*.

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Determination of the Coefficient of Consolidation

1. Root Time Method

$$C_v = \frac{0.848 H_{dr}^2}{t_{90}}$$

2. Log Time Method

$$C_v = \frac{0.197 H_{dr}^2}{t_{50}}$$

(6.37)

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Determination of the Coefficient of Consolidation

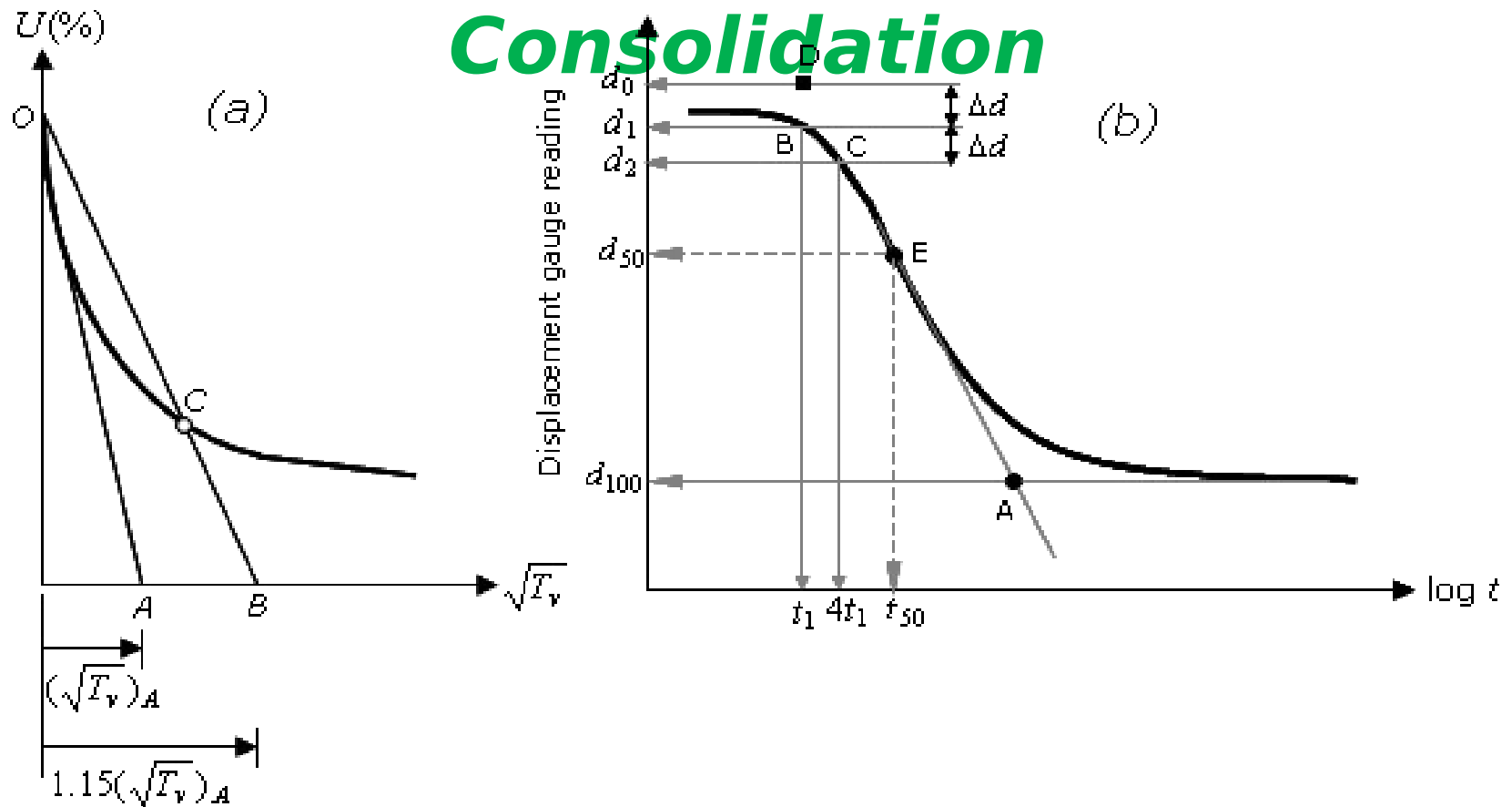


Fig 6.10: (a) Root time method and (b) Log time method for determining the coefficient of consolidation.

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Determination of Void Ratio at the End of a Loading Step

- ❖ The *void ratio* at the *end* of the *consolidation* under *load P* is:

$$e = e_0 - \Delta e = e_0 - \frac{\Delta z}{H_0} (1 + e_0) \quad (6.6)$$

$$e_0 = \frac{e_{\text{fin}} + \frac{(\Delta z)_{\text{fin}}}{H_0}}{1 - \frac{(\Delta z)_{\text{fin}}}{H_0}}$$

$$\Delta e = \frac{(\Delta z)_{\text{fin}}}{H_0} (1 + e_0)$$

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Determination of the preconsolidation stress

The procedure, with reference to Fig. 6.11a, is as follows:

1. Identify the point of maximum curvature, point D , on the initial part of the curve.
2. Draw a horizontal line through D .
3. Draw a tangent to the curve at D .
4. Bisect the angle formed by the tangent and the horizontal line at D .
5. Extend backward the straight portion of the curve (the normal consolidation line), BA , to intersect the bisector line at F .

The abscissa of F is the preconsolidation effective stress, σ'_{zc} .

A simpler method that is also used in practice is to project the straight portion of the initial recompression curve to intersect the backward projection of the normal consolidation line at F as shown in Fig. 6.11b. The abscissa of F is σ'_{zc} .

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Determination of the preconsolidation stress

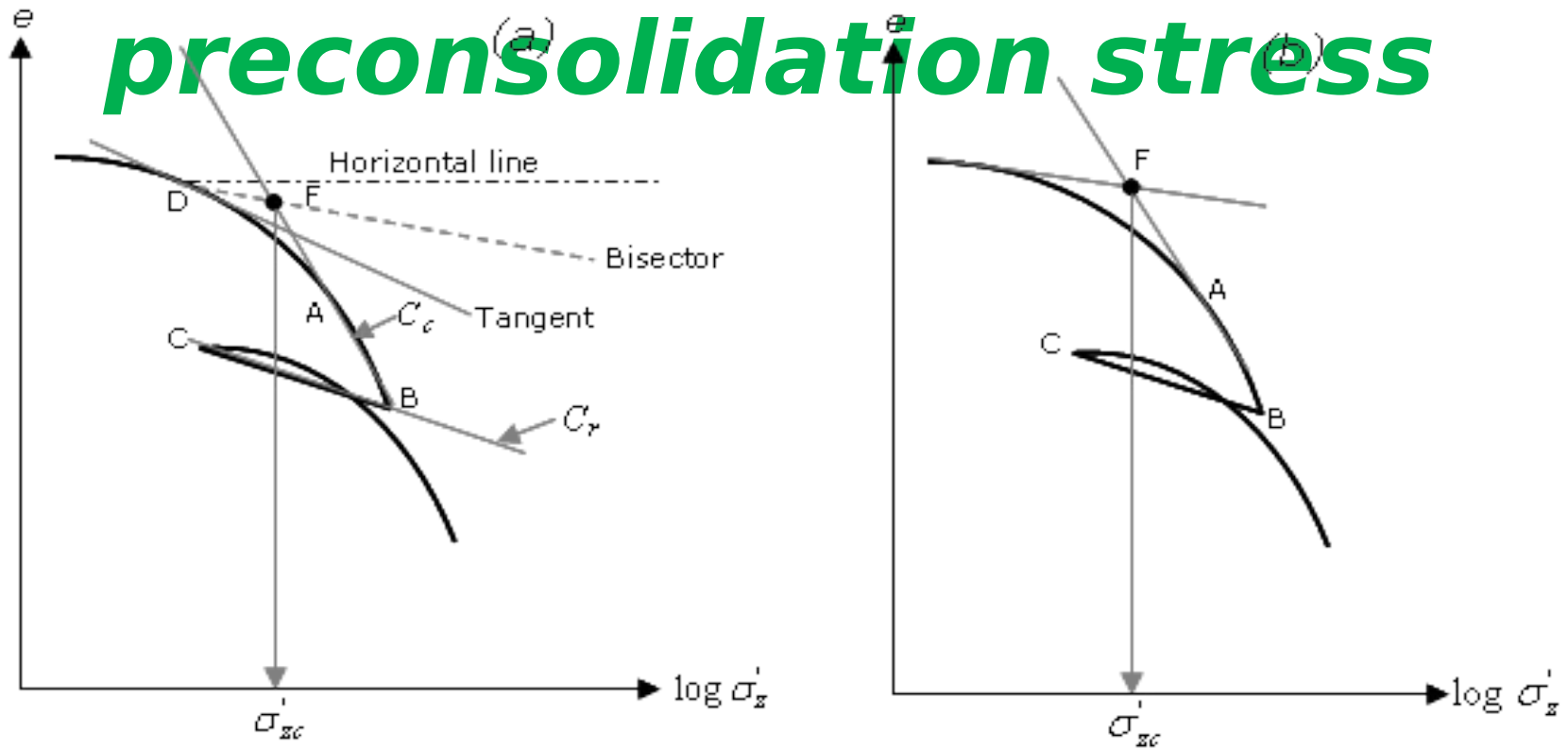


Figure 6.11: Determination of the preconsolidation stress using (a) Casagrande's method and (b) Simplified

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Evaluation of Total Soil Settlement

In general, the total settlement ρ_{total} of a foundation can be given as:

$$\rho_{\text{total}} = \rho_e + \rho_{\text{pc}} + \rho_{\text{sc}}$$

(6.38)

where, ρ_e = immediate settlement.

ρ_{pc} = primary consolidation settlement.

ρ_{sc} = secondary compression settlement.

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Relationship Between Laboratory and Field Consolidation

- ❖ The *time factor* (T_v) provides a *useful expression* to *estimate* the *settlement* in the *field* from the *results* of a *laboratory consolidation test*.
 - ❖ If *two layers* of the *same clay* have the *same degree* of *consolidation*, then their *time factors* and *coefficients of consolidation* are the *same*. Hence (6.39)
- $$T_v \frac{(C_v t)_{lab}}{(H_{dr}^2)_{lab}} = \frac{(C_v t)_{field}}{(H_{dr}^2)_{field}}$$

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

EXAMPLE

A laboratory consolidation test on a normally clay showed the following result :

Load, p (kN/m ²)	Void ratio at the end of consolidation, e
140	0.92
212	0.86

The specimen thickness was 25.4mm and drained on both sides. The time required for the specimen to reach 50% consolidation was 4.5 min.

A similar clay layer in the field, 2.8 m thick and drained on both sides, is subjected to similar average pressure increase that is $p_o = 140$ kN/m² and $p_o + \Delta p = 212$ kN/m². Determine the following :

1. The expected maximum consolidation settlement in the field

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Solution

➤ Question no.1

$$C_c = \frac{e_1 - e_2}{\log\left(\frac{p_2}{p_1}\right)} \quad C_c = \frac{0.92 - 0.86}{\log\left(\frac{212}{140}\right)} = 0.333$$

$$S_c = \frac{C_c}{1 + e_o} H_c \log \frac{p_o + \Delta p}{p_o}$$

$$S_c = \frac{0.333}{1 + 0.92} * 2.8 * \log \frac{212}{140} = 87.5 \text{ mm}$$

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Solution

➤ Question no.2

- ✓ Determine the coefficient of consolidation (C_v)

From laboratory testing

$$C_v = T_v \frac{H^2}{t} \quad \text{where :}$$

$$T_v = \pi / 4 (U^2) = 0.197 \quad (U = 50\%)$$

$$H = H_c / 2 = 25.4 / 2 = 12.7 \text{ mm}$$

$$t = 4.5 \text{ min}$$

$$\text{We get } C_v = 0.197 * \frac{12.7^2}{4.5} = 7.061 \text{ mm}^2/\text{min}$$

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Solution

➤ Question no.2

- ✓ Determine field consolidation

coefficient

$$U = \frac{S_c}{S_{c, \text{max}}} \times 100\% = \frac{40}{87.5} \times 100\% = 45.7\%$$

$$t = \frac{T_v \cdot H^2}{C_v}$$

- ✓ Calculate consolidation time

$$T_v = \pi / 4 (U^2) = 0.164 \quad (U = 45.7\%)$$

$$H = H_c / 2 = 1.4 \text{ m} = 1400 \text{ mm}$$

$$C_v = 7.061 \text{ mm}^2/\text{min}$$

$$t = \frac{0.164 \times 1400^2}{7.061} = 45,523 \text{ min} = 31.6 \text{ days}$$

We

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Solution

➤ Question no.3

○ Calculate consolidation time

Where: $U = 45.7\%$

$$t = \frac{T_v \cdot H^2}{C_v} \quad T_v = \frac{\pi}{4} (U^2) = 0.164 \quad (U = 45.7\%)$$

$$H = H_c = 2.8 \text{ m} = 2800 \text{ mm}$$

$$C_v = 7.061 \text{ mm}^2/\text{min}$$

$$t = \frac{0.164 \times 2800^2}{7.061} = 182,093 \text{ min} = 126.5 \text{ days}$$

We
got

5. ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT OF FINE SOILS

Thank
you!!!