EWCE 341

Principles of Soil Mechanics

Consolidation

EWCE 341

What we are going to learn today?

- Sample disturbance in consolidation test.
- Adjustments of laboratory consolidation data.
- Compression/recompression index and ratio.
- Consolidation status in the field.
- Problems

Sample Disturbance in Consolidation Test:

Question: Consolidation tests are very sensitive to sample disturbance. Explain

Question: Describe the effects of soil sampling in consolidation test results.

- Consolidation tests are **very sensitive** to sample disturbance.
- **Very high quality samples produce distinct consolidation curves,** shown in the figure:

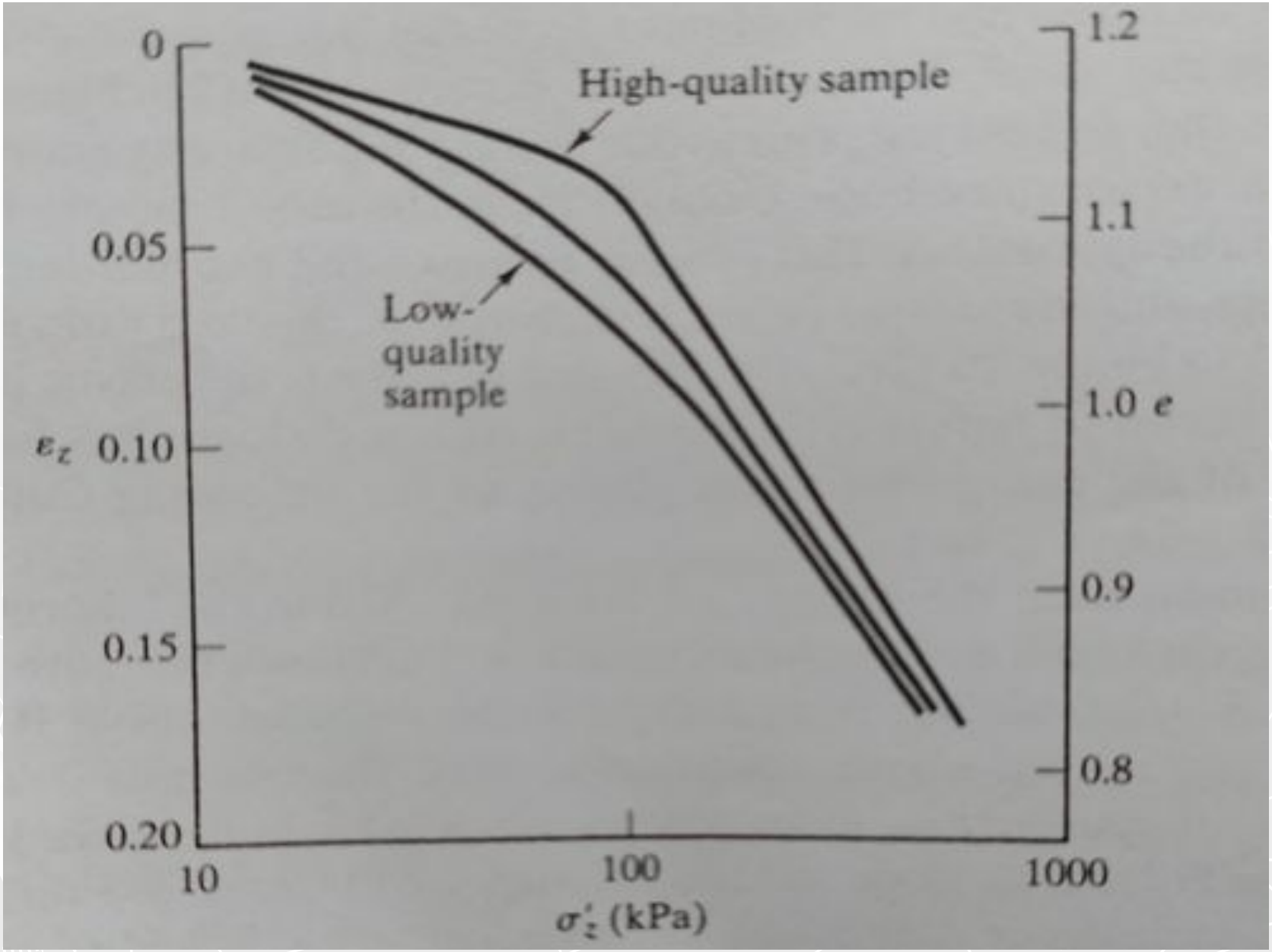


Figure: Effect of sample disturbance on consolidation test results.

Effects of Soil Sampling in Consolidation Test.

- **(a). Less than the ideal sampling**, (b). **handling techniques**, (c). **drying during storage** and (e). **other effects can alter the sample** and **make the test results** more obscure and difficult to interpret.

- (f). Makes **difficult to explain obtained** σ_c' from the poor quality samples because the **curve near the transition** between the **recompression** and **virgin curves becomes much more rounded.**

- Should be **very careful** with samples intended for consolidation tests.

Adjustment of Laboratory Consolidation Data:

Casagrande Procedure (to determine the σ'_c):

Locate the **point of minimum radius** on the consolidation curve (Point A).

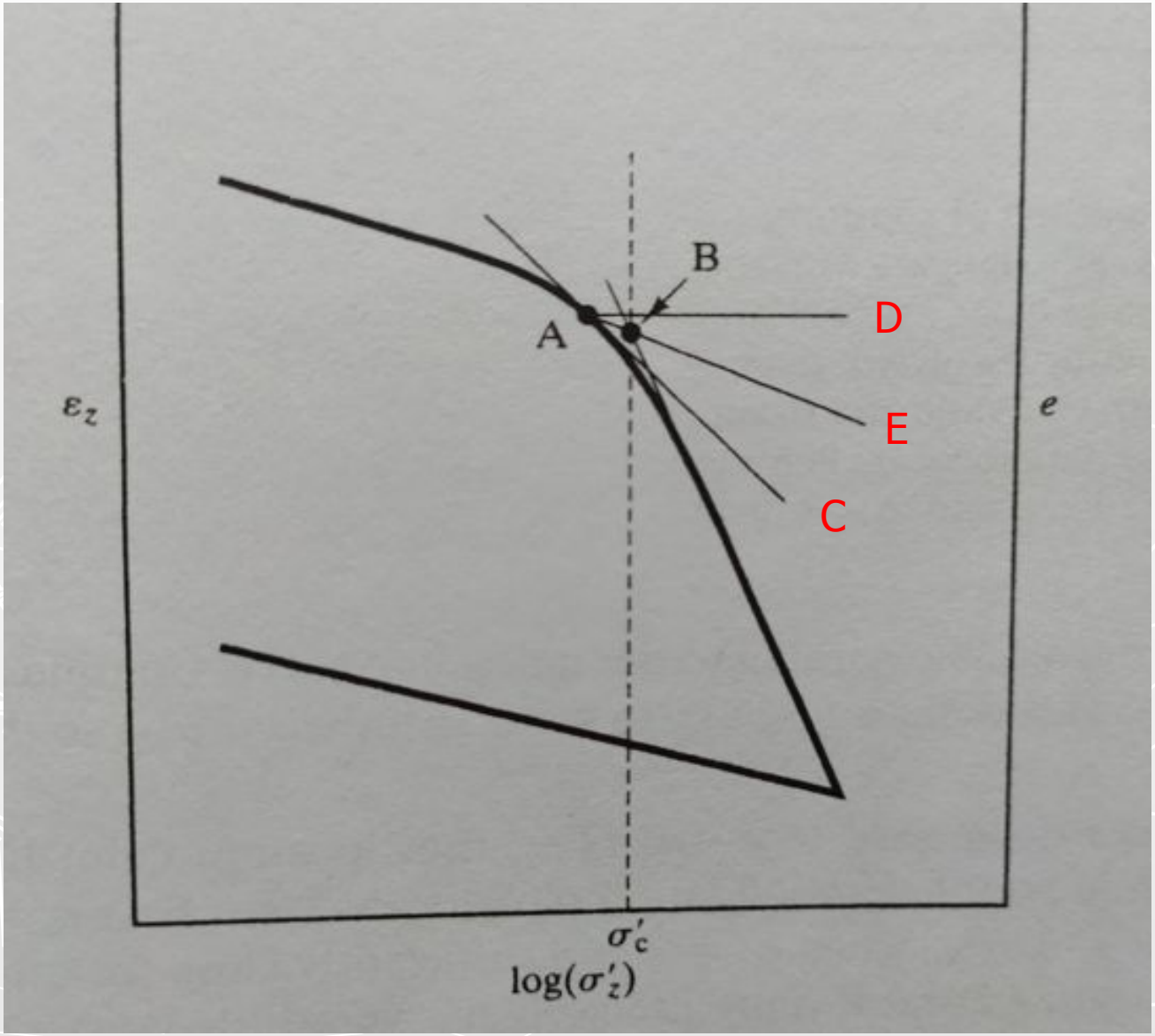
- Draw a **horizontal line** through Point A.
- Draw a **line tangent** to the laboratory curve at Point A.
- Draw the **line that bisects the angle** formed by the lines from upper two steps.

Adjustment of Laboratory Consolidation Data (cont…):

- **Extends the straight portion of the virgin curve** upward until it intersects the line drawn in last steps.
- This **identifies Point B.**
- **Vertical effective stress at Point B** is the **pre-consolidation stress σ_c'.**
- e or ε_z corresponding to point B is not used in any analysis.

Question: Describe the Casagrande's procedure to determine the pre-consolidation stress from laboratory data.

Figure: Casagrande's method of finding the pre-consolidation stress.



Adjustment of Laboratory Consolidation Data:

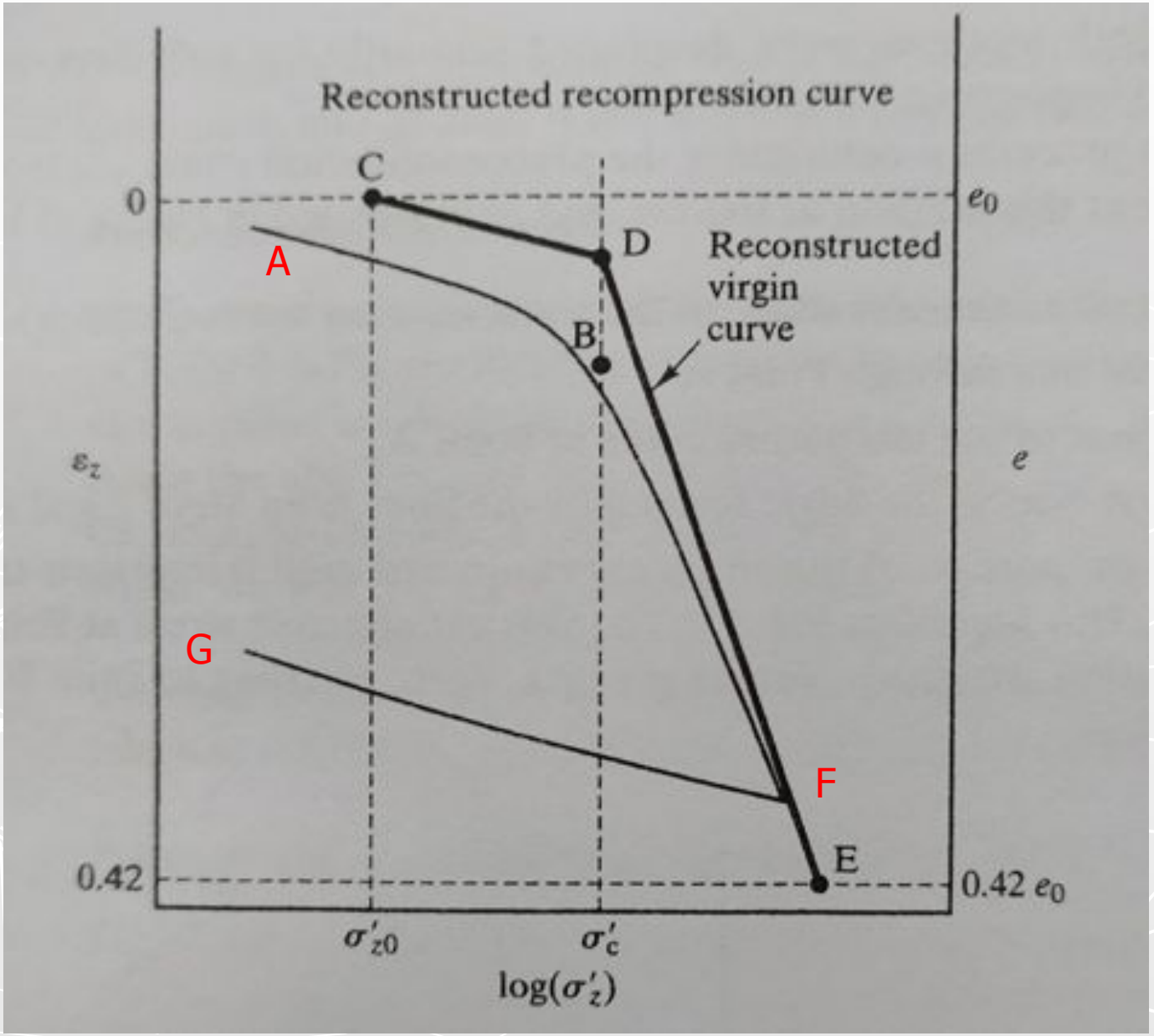
Schmertmann Procedure: (Reconstruction of Field Consolidation Curve)

Sample disturbance affects the slope of the curves, so this procedure is an attempt to **reconstruct the field consolidation curve.**

- **Determine σ'_c**, using Casagrande procedure.
- **Compute the initial vertical effective σ'_{zo}**, at the sample depth. This is the vertical effective stress prior to placement of the proposed load.
- Draw a horizontal line at **e = e_0** or **ε_z=0**, from the vertical axis to **σ'_{zo}**. This locate point C.

Question: Describe the Scmertmann's procedure to reconstruct the field consolidation curve.

Figure: Schmertmann's method of adjusting consolidation test results.



Adjustment of Laboratory Consolidation Data (cont…):

- Beginning at Point C, draw line **parallel to un-loading curve.** Continue to the right until reaching σ'_c line. This defines **Point D**. In some cases, $\sigma'_c \approx \sigma'_{zo}$; this steps is unnecessary.

- Extend the virgin curve downward to **e = 0.42e_0,** when e_0=2, thus locating the Point E or ε_z=0.42.

- **Draw a line connecting points D and E.** This is the **reconstruction of virgin curve.**

Soil Compressibility:

Question: Describe the compressibility of soil in terms of consolidation data plot.

- **Slopes on the consolidation plot reflect the compressibility of the soils.**

- **Highly Compressible**: **Steep slopes mean**, a given increase σ'_z will cause a large strain ε_z (for a large change in **e),** so such soils are said to be *highly compressible*.

- **Slightly Compressible**: **Shallow slopes** indicate that the **same increase** in σ'_z will produce less strain, so the soil is *slightly compressible.*

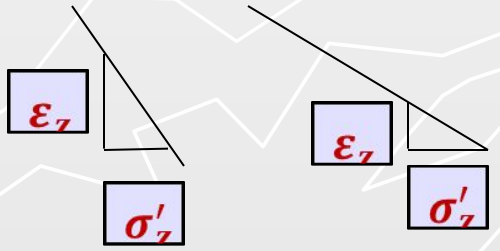
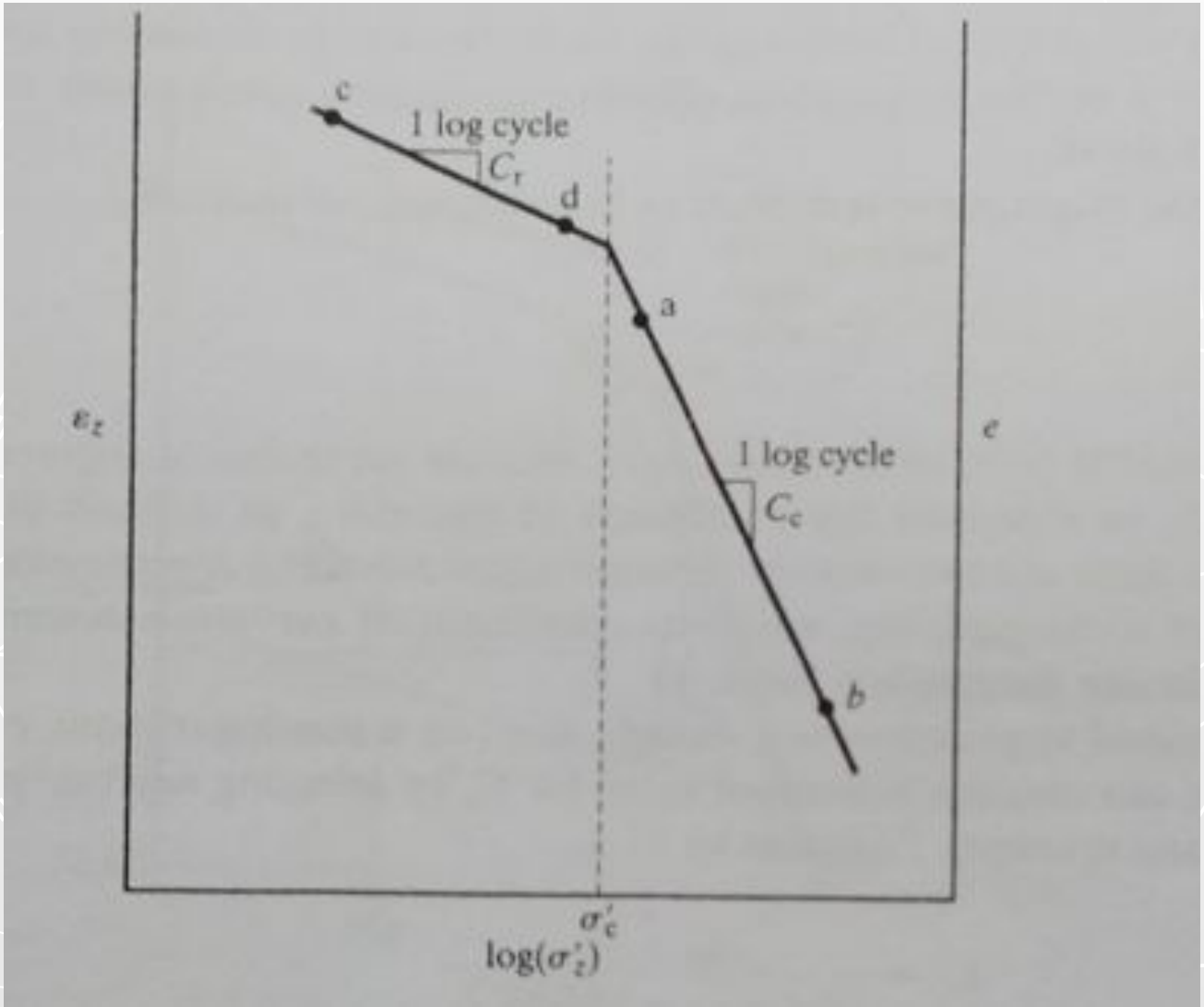


Figure: Slope of consolidation curves.



EWCE 341

What learned in the last class?

- Sample disturbance in consolidation test.
- Adjustments of laboratory consolidation data.

EWC 341

What we are going to learn today?

- Compression/recompression index and ratio.
- Consolidation status in the field.
- Problems

Question: Define compression index and compression ratio.

Compression Index and compression ratio:

Compression Index (C_c):

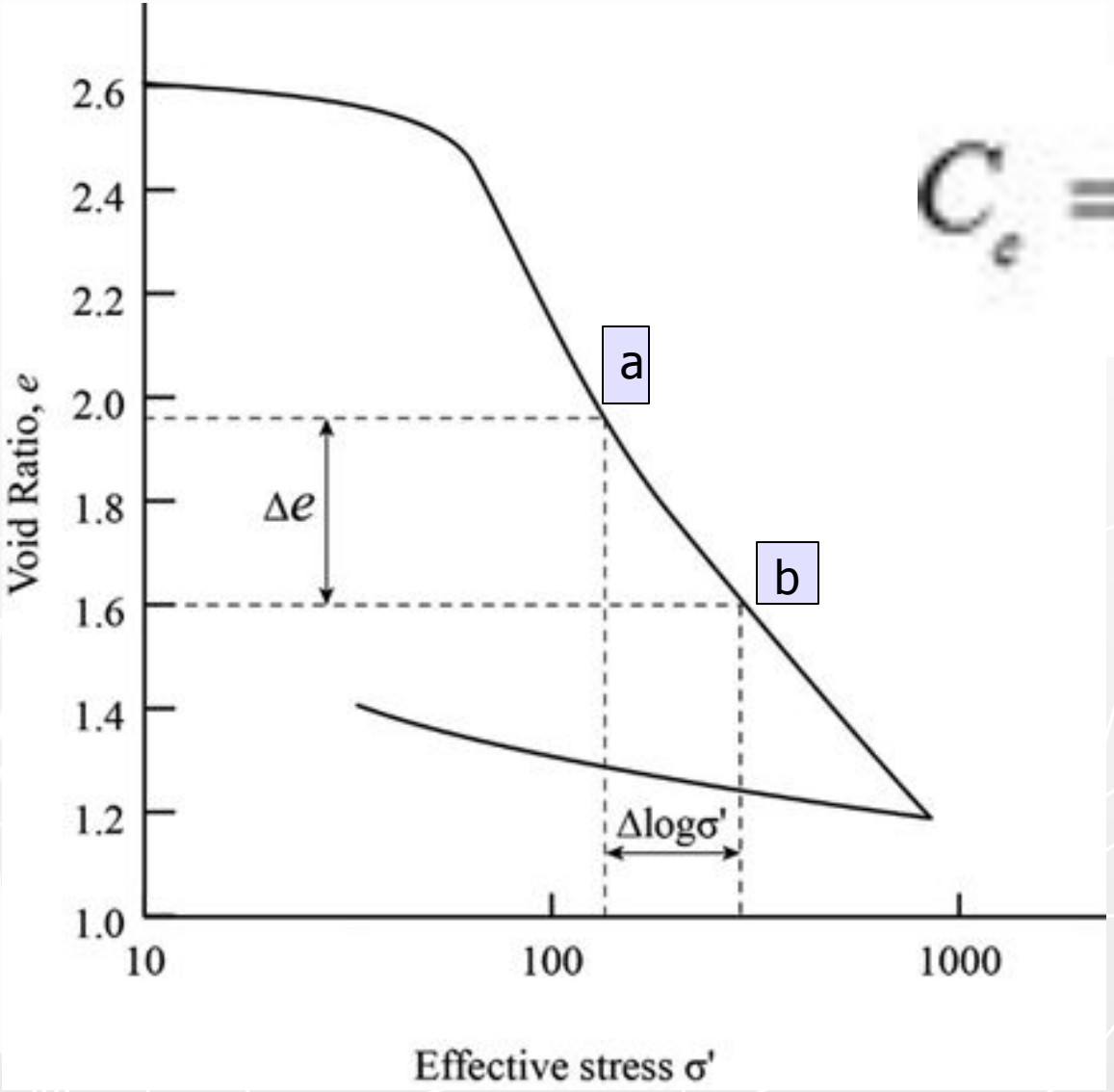
- Slope of the void ratio and log of effective stress in **virgin curve** is defined as the compression index, C_c.

$$C_c = \frac{de}{d \log \sigma'_z} = 0.05 \text{ to } 0.6$$

- For NC clay=0.2 to 0.6 and silts=0.2 to 0.4
- Higher value indicates greater compressibility and settlement potential.

Compression index is a measure of **compressibility of soil** but, **coefficient of curvature** describes the shape of the particle size distribution curve. Both has the same symbol C_c.

- $\mathbf{C_c = (D_{30})^2/D_{60}.D_{10}}$



$$C_e = \frac{\Delta e}{\Delta \log \sigma'}$$

- Reconstruction curve is straight line on a semi logarithmic e vs log σ'_z plot, so we can obtain a numerical value for C_c by selecting any two points, a & b, on the virgin curve.
- Now,

$$C_c = \frac{e_a - e_b}{(\log \sigma'_z)_b - (\log \sigma'_z)_a}$$

Compression Ratio ($\frac{C_c}{1+e_0}$):

- If the consolidation data are plotted only in ε_z - log σ'_z form ie **no void ratio data given**, then the slope of the virgin curve is:

$$\frac{C_c}{1+e_0} = \frac{(\varepsilon_z)_b - (\varepsilon_z)_a}{(\log \sigma'_z)_b - (\log \sigma'_z)_a}$$

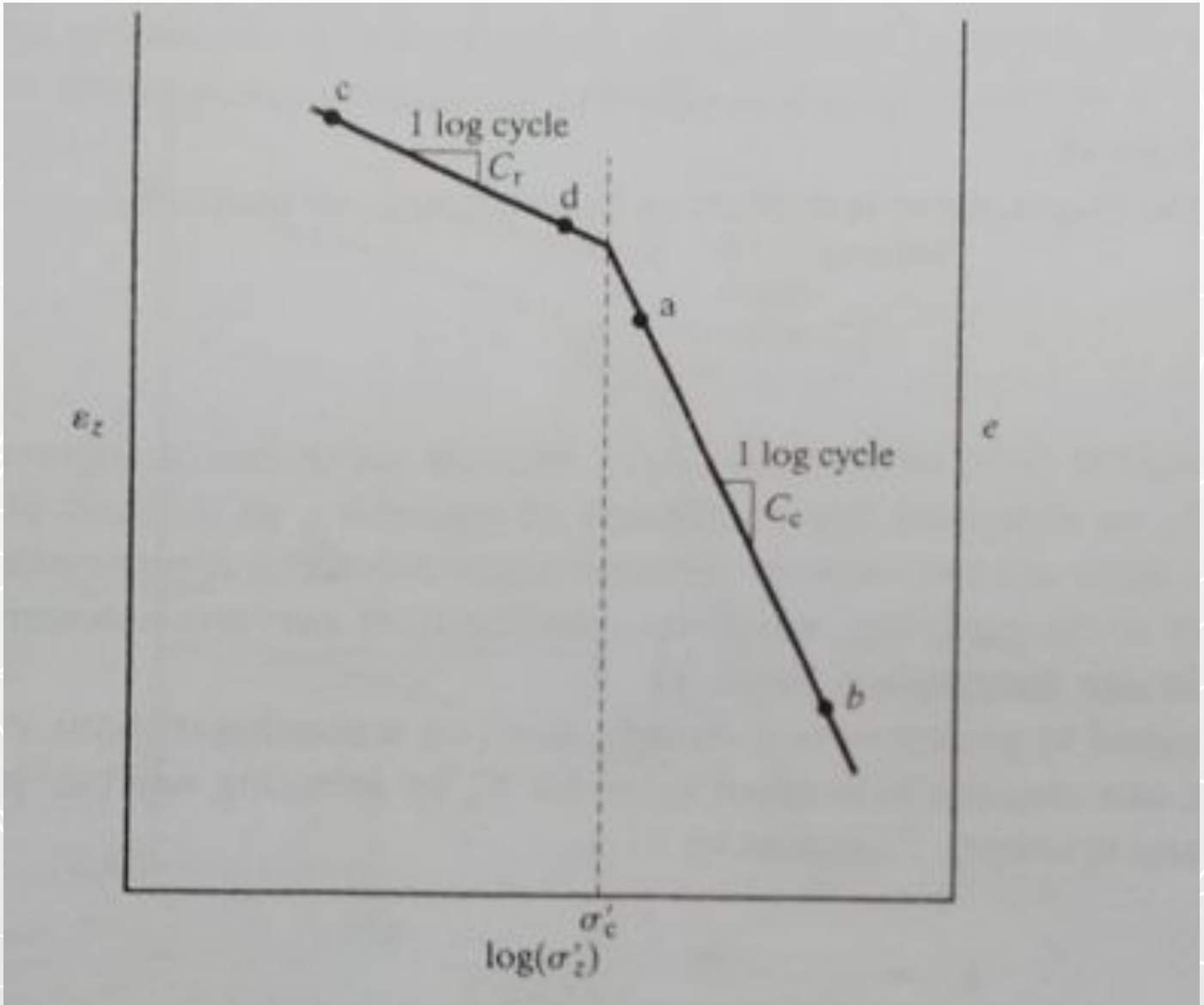
Here the parameter $\frac{C_c}{1+e_0}$ is **called compression ratio**.

If the reconstructed virgin curve is sufficiently long, it is convenient to **select points a and b** such that

$$(log\, \sigma'_z)_b = 10\, (log\, \sigma'_z)_a.$$

- It demonstrates that C_c **could be defined as the reduction in void ratio per 10-fold increase** (one log cycle) in σ'_z.
- Similarly, $\frac{C_c}{1+e_0}$ ie compression ratio is the strain ε_z per 10-fold increase in σ'_z.

Figure: Slope of consolidation curves.



Question: Define recompression index and recompression ratio.

Recompression Index and recompression ratio:

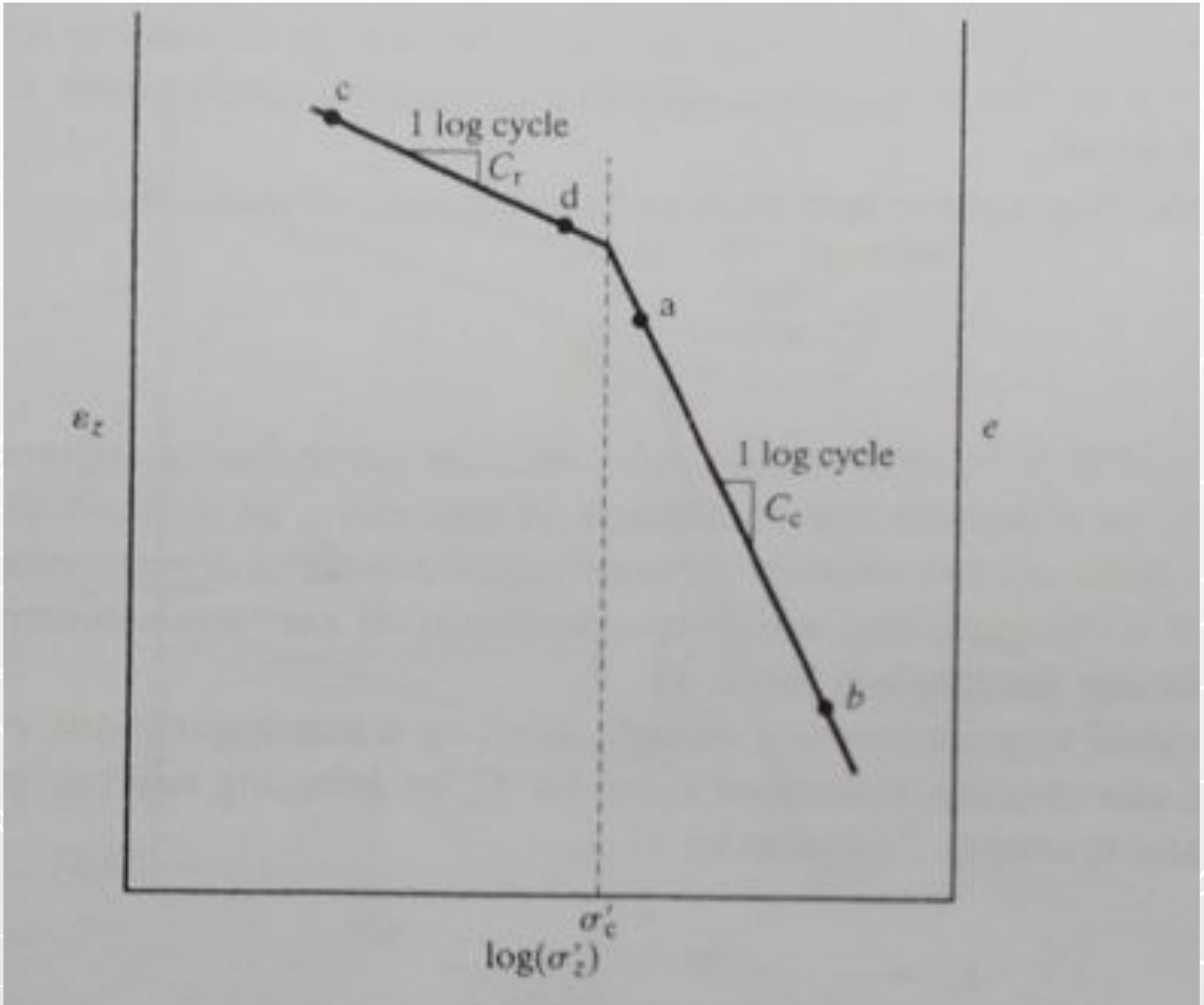
Recompression Index (C_r):

- **Slope of the recompression curve** is defined as the recompression index , C_r.
- We can obtain a numerical value for C_r by selecting any two points, c & d, on the **Re-loading curve**.

$$C_r = \frac{e_c - e_d}{(\log \sigma'_z)_d - (\log \sigma'_z)_c} = 0.04 \text{ to } 0.2$$

Represent stiffness of OC soils, which is less compressible because it has already undergone

Figure: Slope of consolidation curves.



Recompression Ratio ($\frac{C_r}{1+e_0}$):

- If the consolidation data are plotted only in ε_z - σ'_z form ie **no void ratio data given**, then the slope of the recompression curve is:
- $$\frac{C_r}{1+e_0} = \frac{(\varepsilon_z)_d - (\varepsilon_z)_c}{(\log \sigma'_z)_d - (\log \sigma'_z)_c}$$
- Here, the slope is $\frac{C_r}{1+e_0}$, which is called recompression ratio.

Consolidation Status in the Field

- When performing consolidation analyses, need to compare:

  -the pre-consolidation stress σ'_c,

  - with the initial vertical stress σ'_{zo}.

- **Pre-consolidation stress σ'_c,** is determined from the laboratory test data and **initial vertical stress σ'_{zo},** is determined using equation $\sigma_z = \sum \gamma H - u$ with the original field condition (ie without the new load) and original hydrostatic pressure.

- **Both values must be determined at the same depth**, it is the depth of sample on which consolidation test was performed.

Conditions of Soils Exists in the Field:

On the values of σ'_c and σ'_{zo} determined, we need to assess the **three conditions of soils exist in the field**:

Normally Consolidated Soils:

- If $\sigma'_{zo} \approx \sigma'_c$, then the vertical effective stress in the field has **never been higher** than its current magnitude.
- Condition is known as being *normally consolidated* ***(NC).***

Example- soils at the **bottom of lake,** where sediments brought in by a river have slowly accumulated.

- Soils will be normally consolidated if σ'_{zo} and σ'_c are **equal within about $\pm$20%.**

Over-consolidated Soils:

- If $\sigma'_{zo} < \sigma'_c$, then the vertical effective stress in the field was **once higher** than its current magnitude.

- Condition is known as being over-consolidated **(OC).**

Processes that can cause a soil to become over-consolidated:

- **Extensive erosion or excavation** such that ground surface elevation is now much lower than it once was.

- **Surcharge loading from a glacier**, which has since melted.

- **Surcharge loading from a structure**, such as storage tank, **which has since been removed.**

Under-consolidated Soils:

- If $\sigma'_{zo} > \sigma'_c$, the soil is said to be **under-consolidated,** which means the soil is still in the process of consolidating under the previously applied load.

- Soil is still in the **process of losing water** from its pores and its volume is decreasing, which is why it is known as an "under-consolidated" soil.

- Soils include **soft clays, organic-rich soils, and peat** that have not fully settled under their own weight or recent loads.

- Example: **Rapidly deposited sediments in riverbeds** or ocean floors or **soils from recently placed embankments** or landfill fills.

Ex. 2: The element of soil **at point A**, shown in the following Figure 1. A consolidation test has been performed on a sample of soil obtained from Point A. The test results are plotted and adjusted by Casagrande procedure shown in Figure 2. Determine **whether the soil at Point A is normally consolidated or over-consolidated.** The proposed fill in the Figure 1 has not yet been placed. Finally compute C_c and C_r.

Solution:

- Element of soil at point A is initially subjected to following stress:

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

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

$$= (18.7\ \text{kN/m}^3)(1.0\text{m}) + (19.0\ \text{kN/m}^3)(2.0\text{m}) + (16.5\ \text{kN/m}^3)(4.8\text{m}) = \mathbf{136\ kPa}$$

Solution:

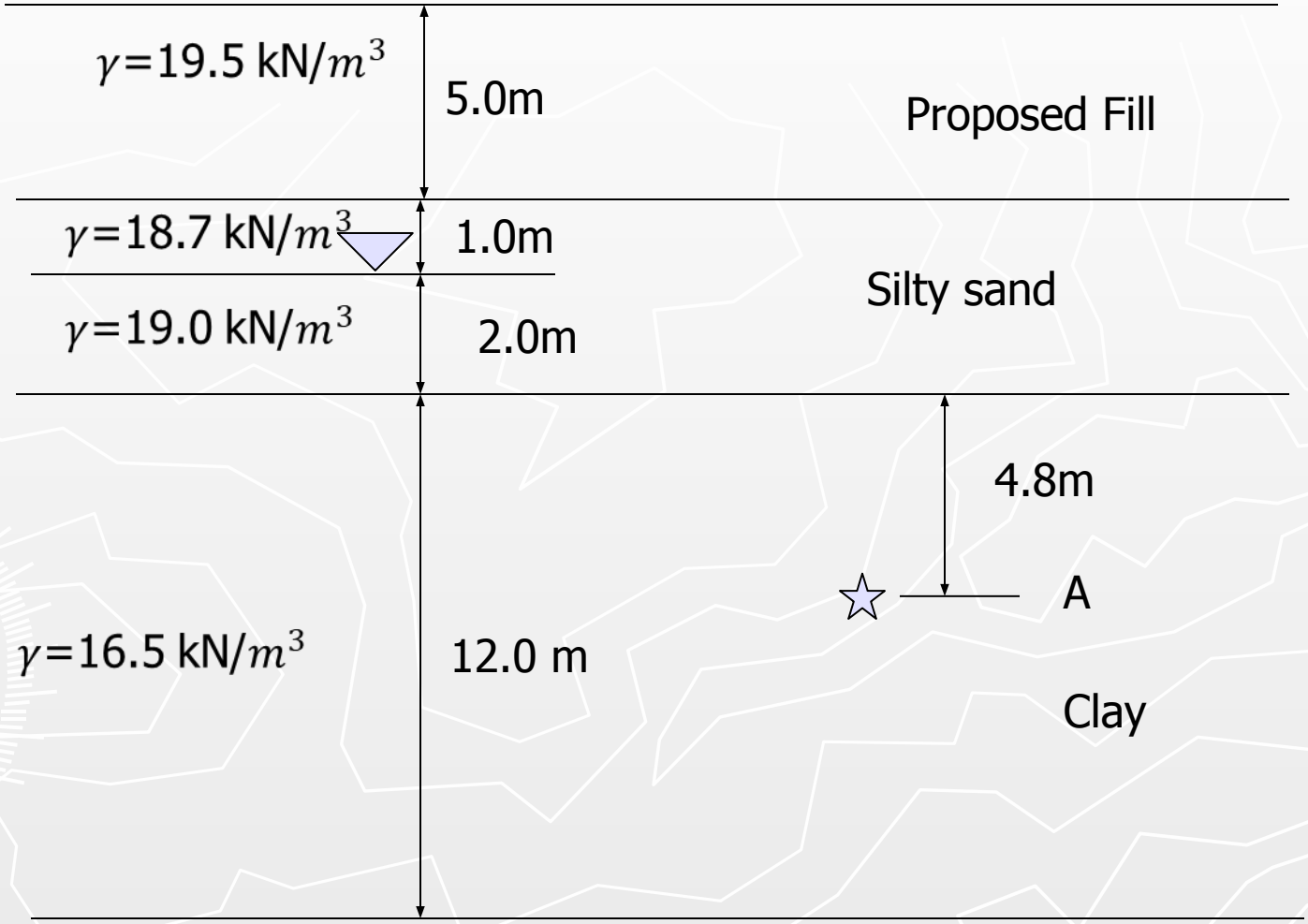


Figure 1: Soil profile

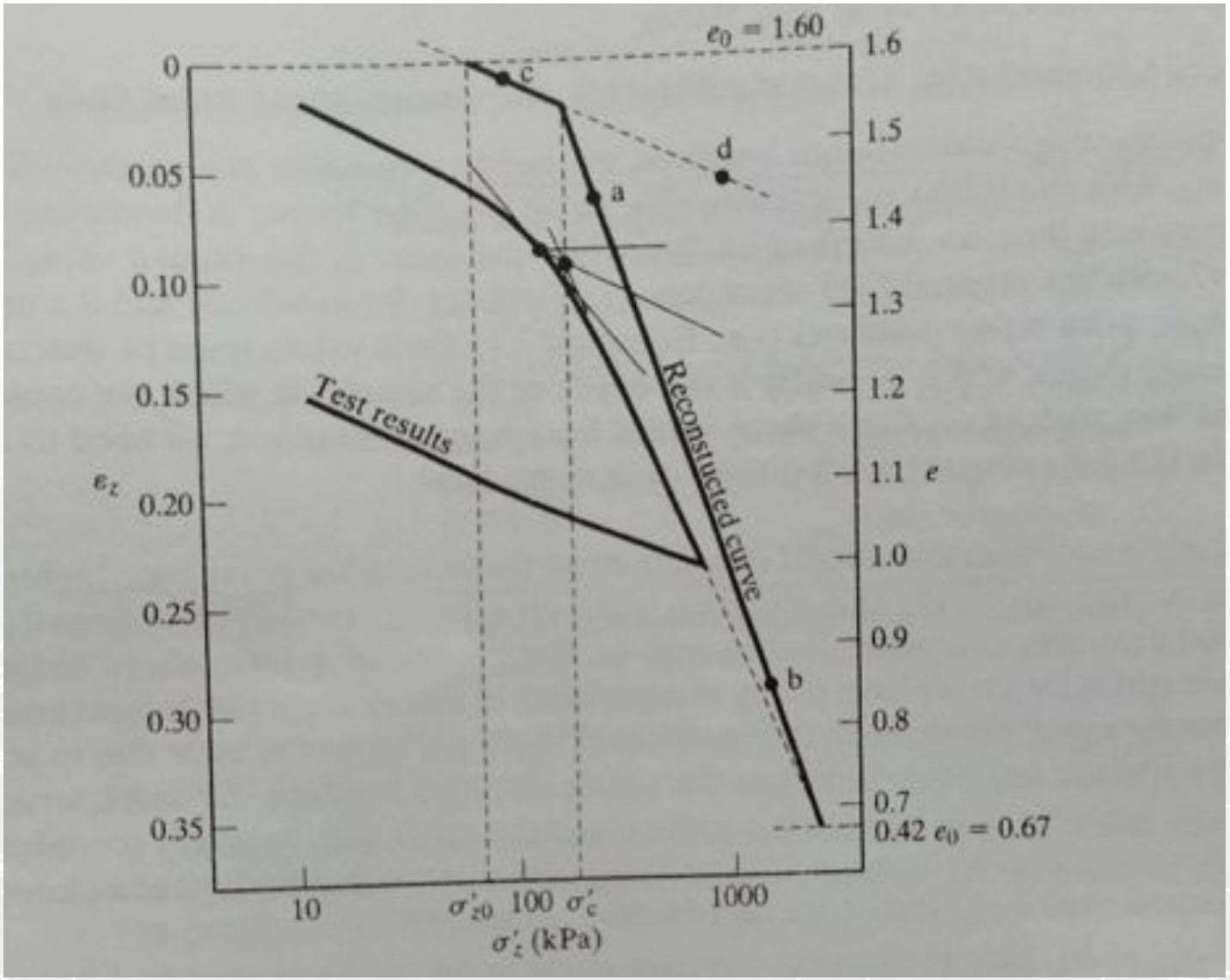


Figure 2: Adjusted consolidation data from laboratory data

- $u = \gamma_w h_w$

  $= (9.8\ \text{kN}/m^3)(6.8.0\text{m}) =$ **67 kPa**

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

$= (136 - 67)\ \text{kPa} =$ **69 kPa**

From Figure 2. Computed $\sigma'_c =$ **140 kPa**

Here, $\sigma'_{z0} < \sigma'_c$ **by more than 20% (51%),** so the soil is over – consolidated **(OC).**

Solution:

Slope of the reconstructed lines:

$$C_c = \frac{e_a - e_b}{(\log \sigma'_z)_b - (\log \sigma'_z)_a}$$

$$C_c = \frac{1.43 - 0.84}{(\log \sigma'_z)_b - (\log \sigma'_z)_a}$$

$$= \frac{1.43 - 0.84}{\log 248\ kN/m^3 - \log 40\ kN/m^3} = \mathbf{0.74}\ (0.05 \text{ to } 0.6)$$

Highly compressible clay

$$C_r = \frac{e_c - e_d}{(\log \sigma'_z)_d - (\log \sigma'_z)_c}$$

$$= \frac{1.58 - 1.46}{\log 157 \frac{kN}{m^3} - \log 16\ kN/m^3} = \frac{0.12}{1} = \mathbf{0.12}\ (0.02 \text{ to } 0.2)$$

Stiffer soil

Thank you