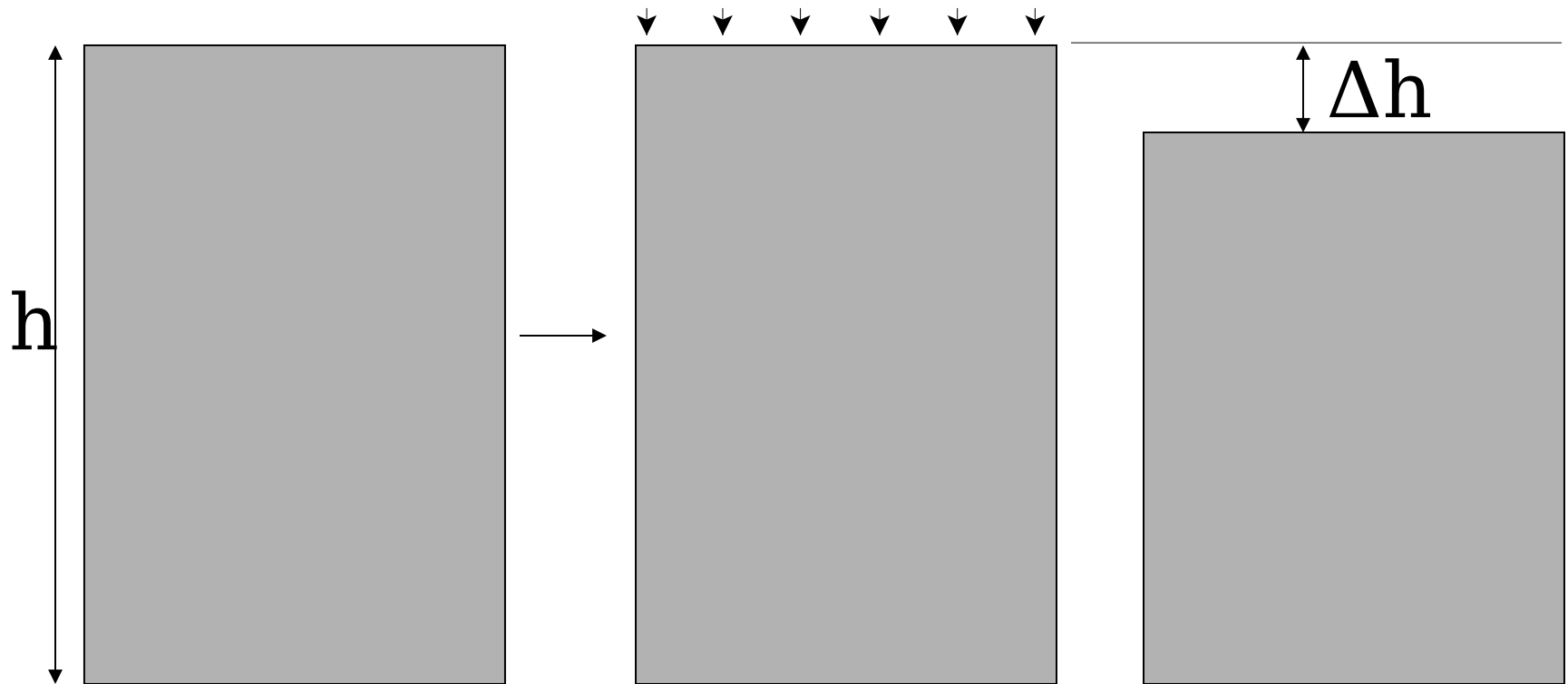


Settlement

- ***Immediate settlement*** – Caused by elastic deformation of dry and moist soil without any change in moisture content
- ***Primary Consolidation Settlement*** – Volume change caused by expulsion of water from voids in saturated cohesive soils
- ***Secondary Consolidation Settlement*** – Volume change after primary consolidation as a result of plastic adjustment of soil matrix

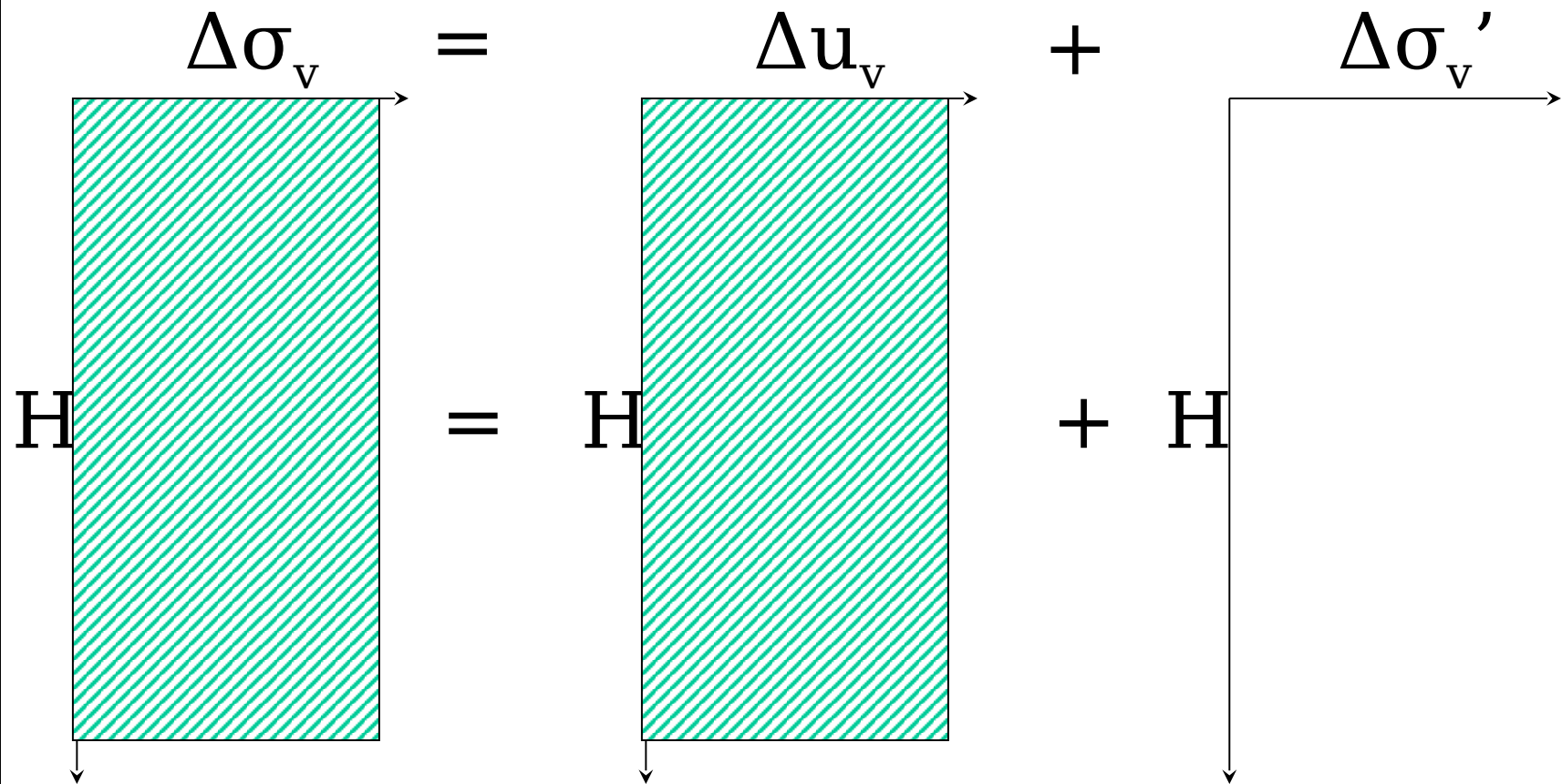
Consolidation Settlement

- We will focus on consolidation settlement



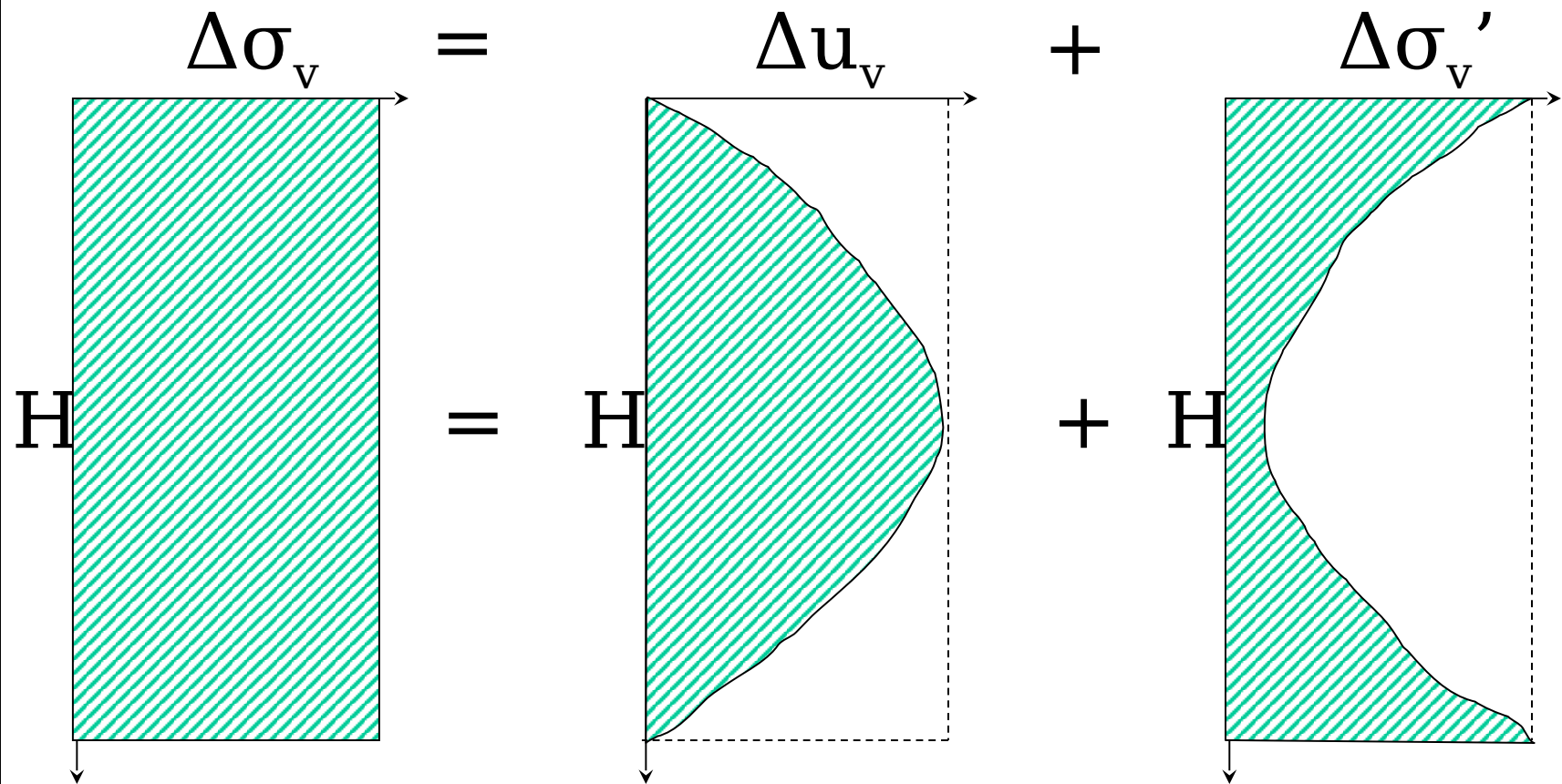
Consolidation Settlement

- Let's look at how a saturated clay reacts to an applied load, starting at time = 0 (immediately after load was applied). Assuming some clay layer of thickness H with drainage both above and



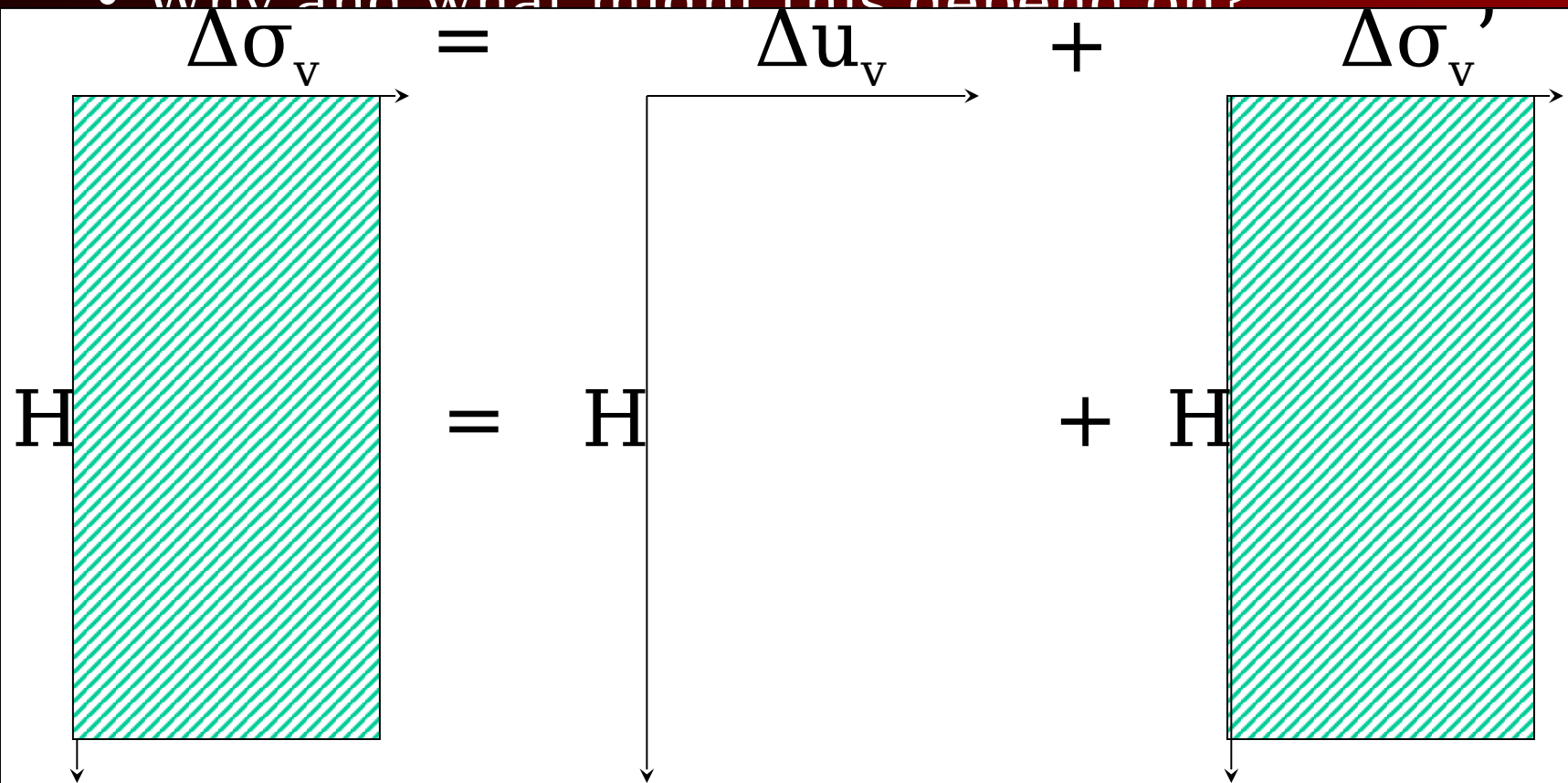
Consolidation Settlement

- Now at some time > 0
- The water slowly is squeezed out of soil and takes the path of least resistance
- Pore pressure is decreasing while the effective



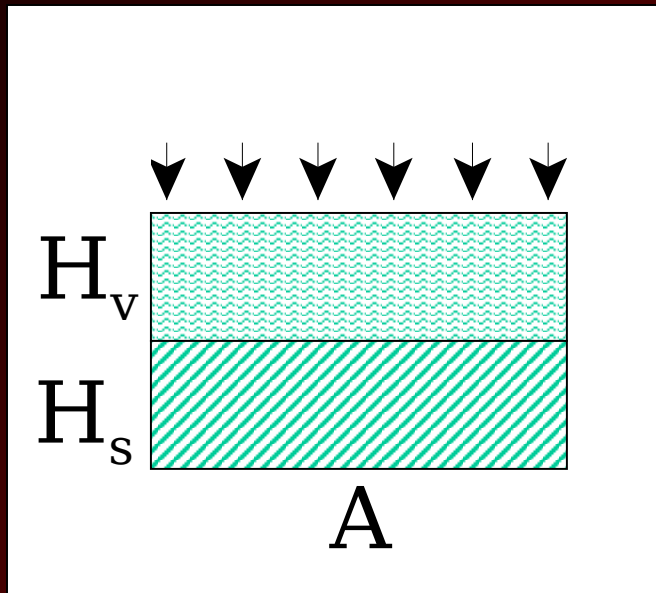
Consolidation Settlement

- Finally at time = ∞
- Pore water is in equilibrium and the soil skeleton is carrying the entire load
- This process will take time – weeks, months, even years
- Why and what might this depend on?



Laboratory Consolidation Test

- In the lab – a soil consolidation test is used to determine settlement characteristics of a soil
- All settlement will occur in voids



$$H_s A = V_s$$

$$H_s A = W_s / G_s \delta_w$$

$$H_s = W_s / A G_s \delta_w$$

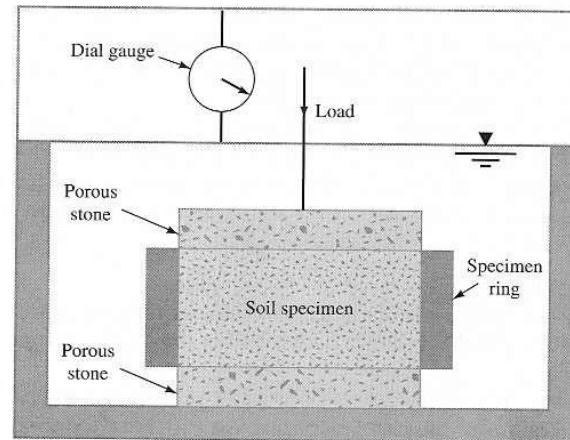
$$H_v = H - H_s$$

$$e_o = V_v / V_s = H_v A / H_s A = H_v / H_s$$

e_o = void ratio at time 0

$$\Delta e = \Delta H_1 / H_s$$

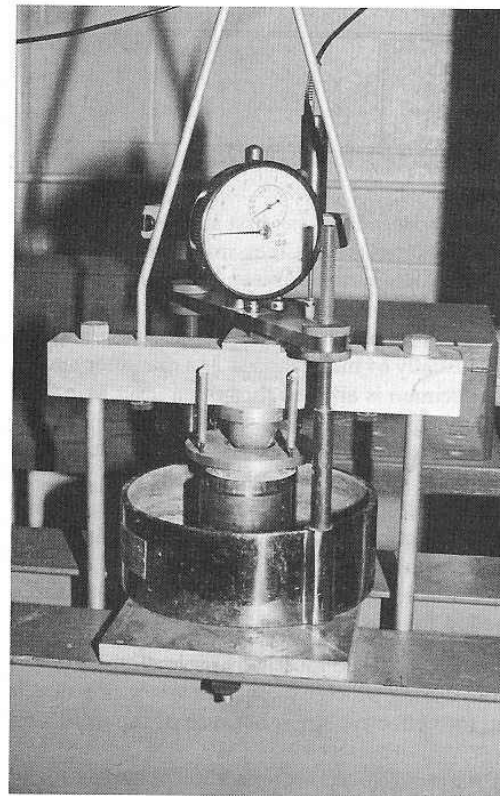
$$\Delta e = \Delta H_1 / H_s$$



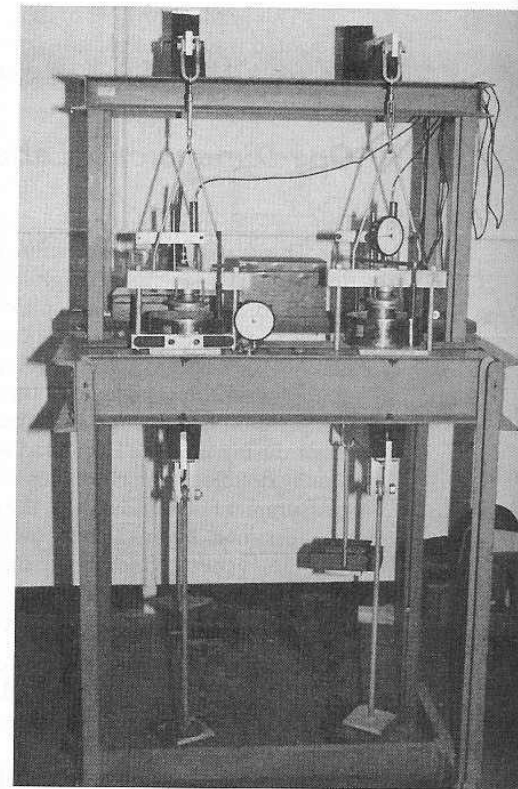
(a)

Figure 10.9

(a) Schematic diagram of a consolidometer;
 (b) photograph of a consolidometer; (c) a consolidation test in progress (right-hand side)



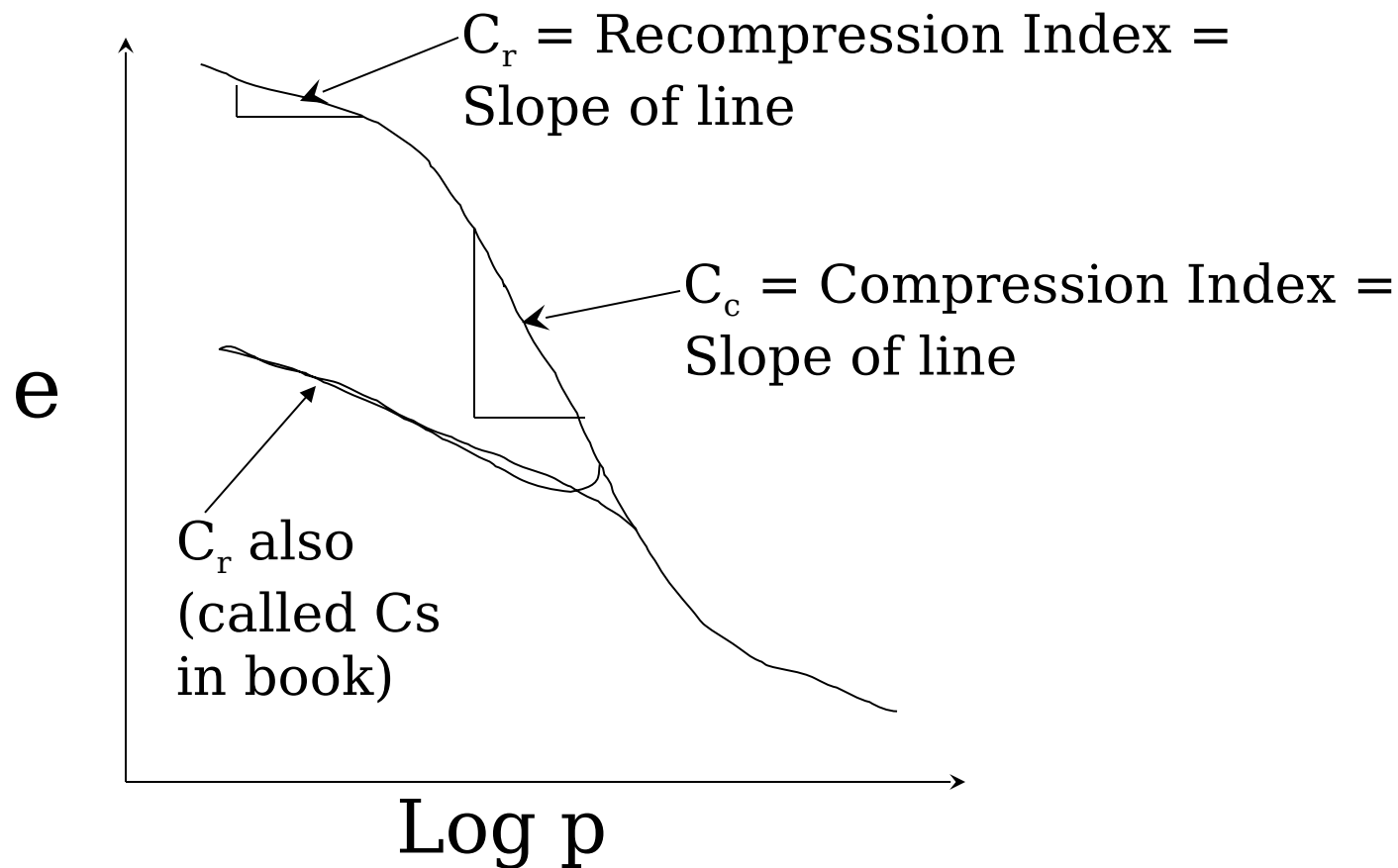
(b)



(c)

Consolidation Curve

- Plotting e vs. $\log p$ (void ratio on a linear scale vs the load on a log scale)

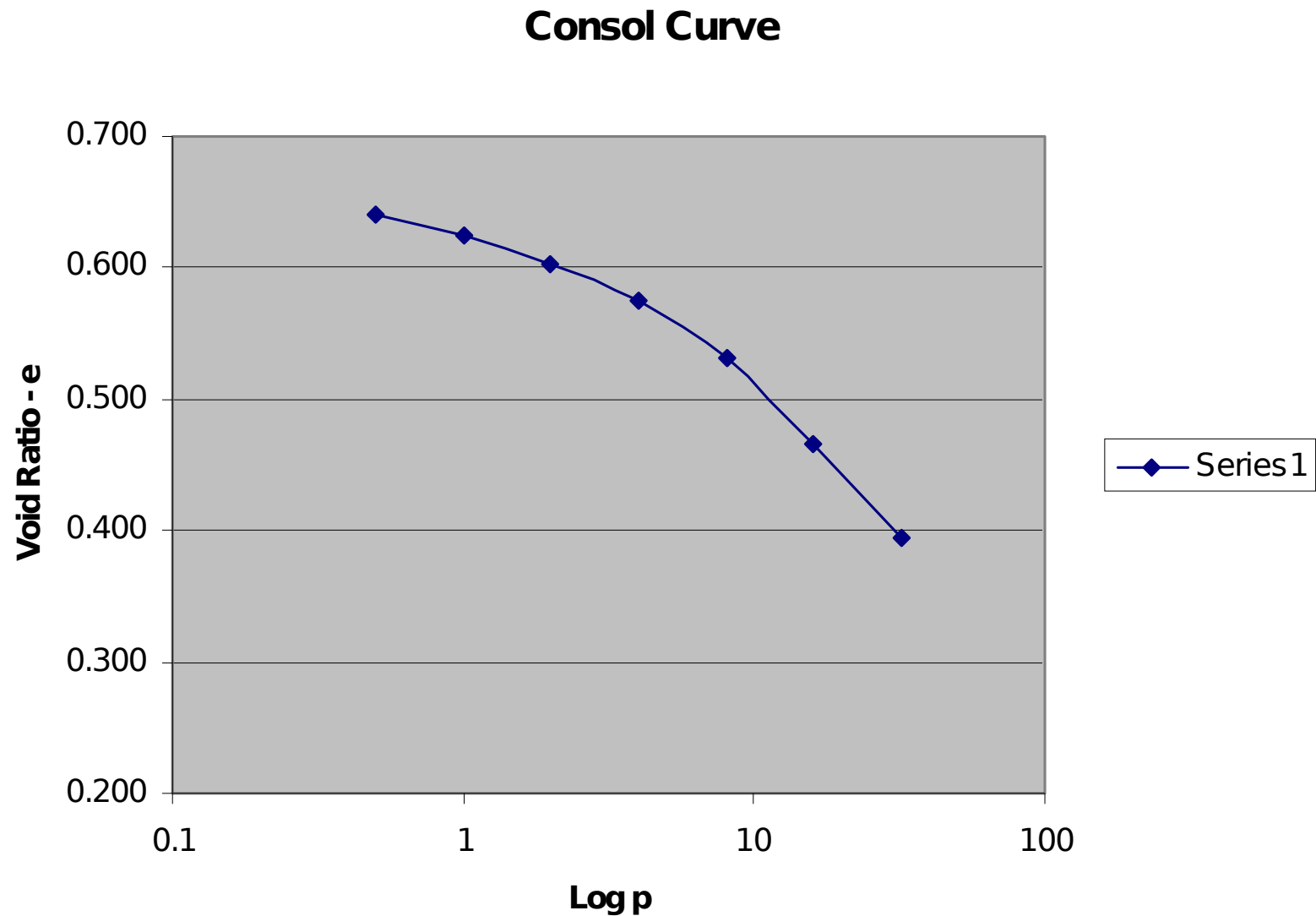


Consolidation Curve

Consolidation Test Data

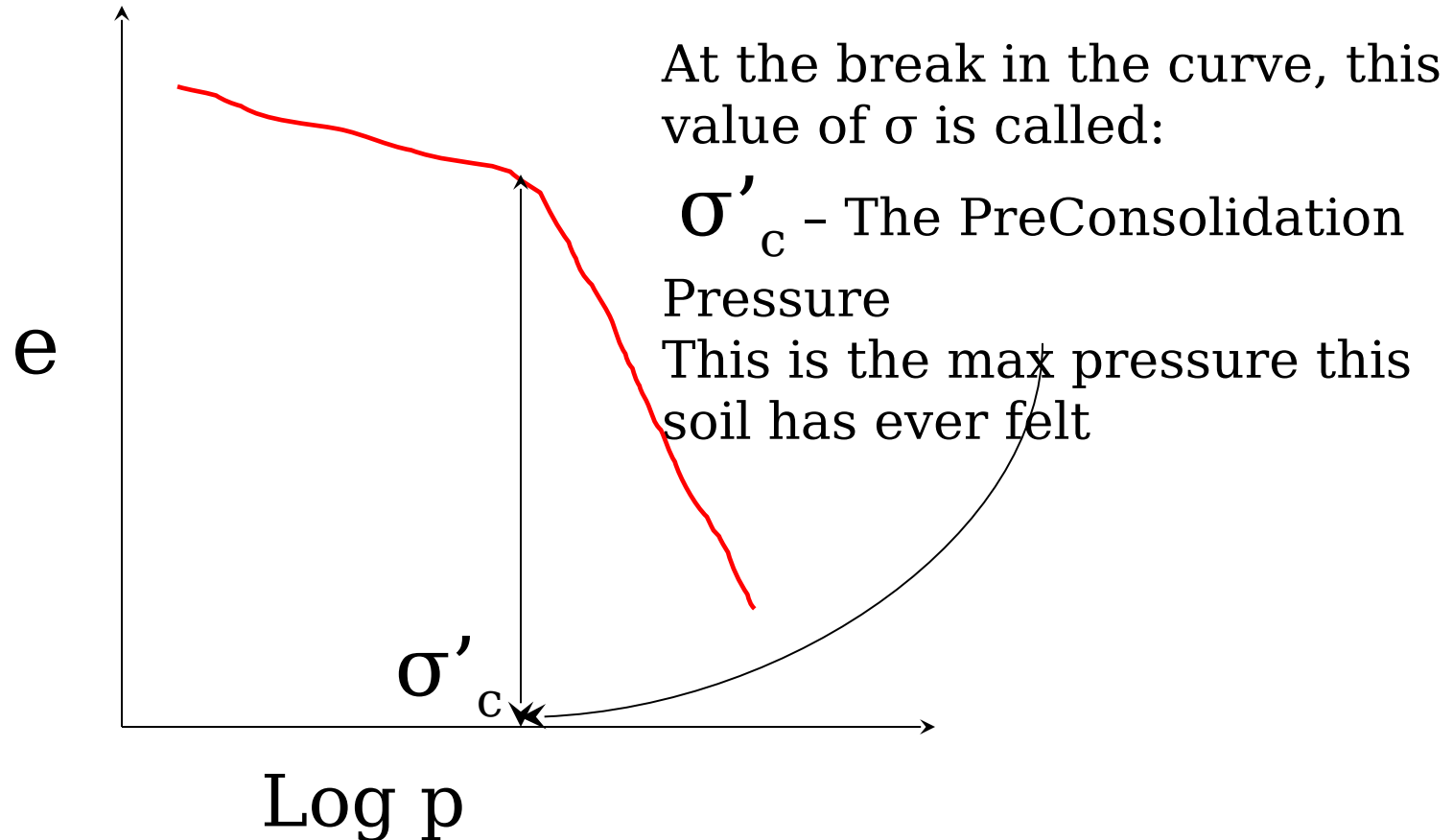
	W_s (g)	A (cm ²)	G_s	δ_w		
	128	30.68	2.75	1		
	$H_s = W_s / AG_s \delta_w$					
	$e = H_v / H_s$					
	Effective Stress	Final Height of specimen after consolidation (cm)	$H_v = H - H_s$	e		
	0	2.540	1.023	0.674		
	0.5	2.488	0.971	0.640		
	1	2.465	0.948	0.625		
	2	2.431	0.914	0.602		
	4	2.389	0.872	0.575		
	8	2.324	0.807	0.532		
	16	2.225	0.708	0.467		
	32	2.115	0.598	0.394		

Consolidation Curve



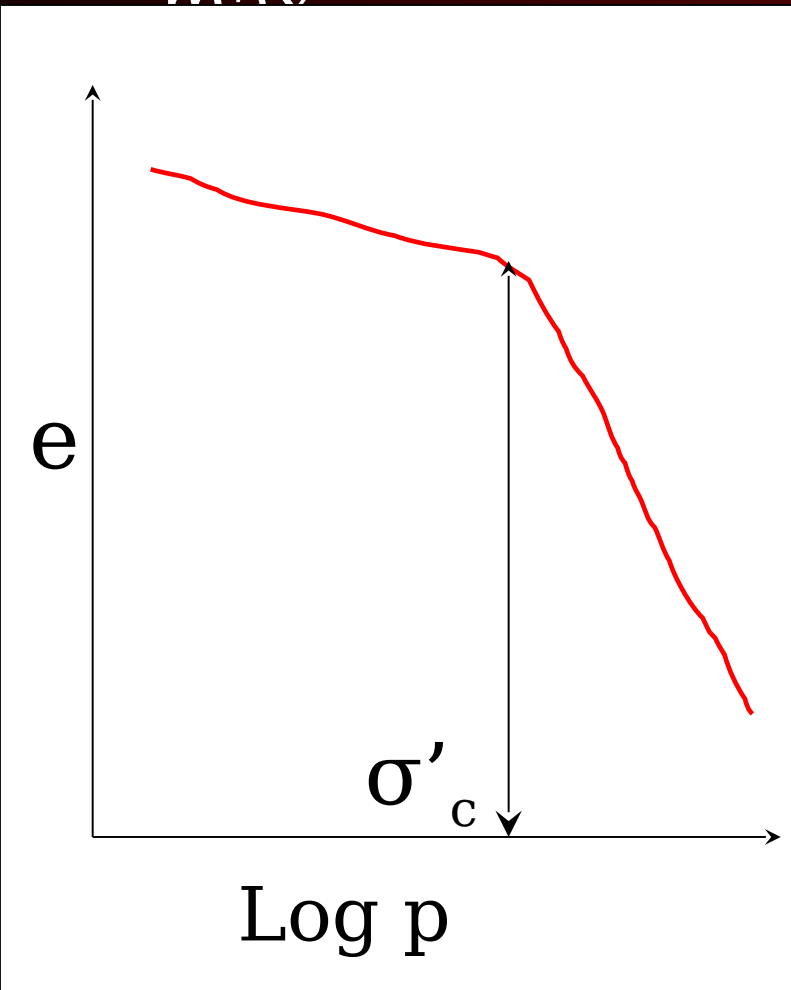
Overconsolidated – Normally Consolidated

- Overconsolidated – Some past stress was greater than current stress
- Normally Consolidated – Current stress is max



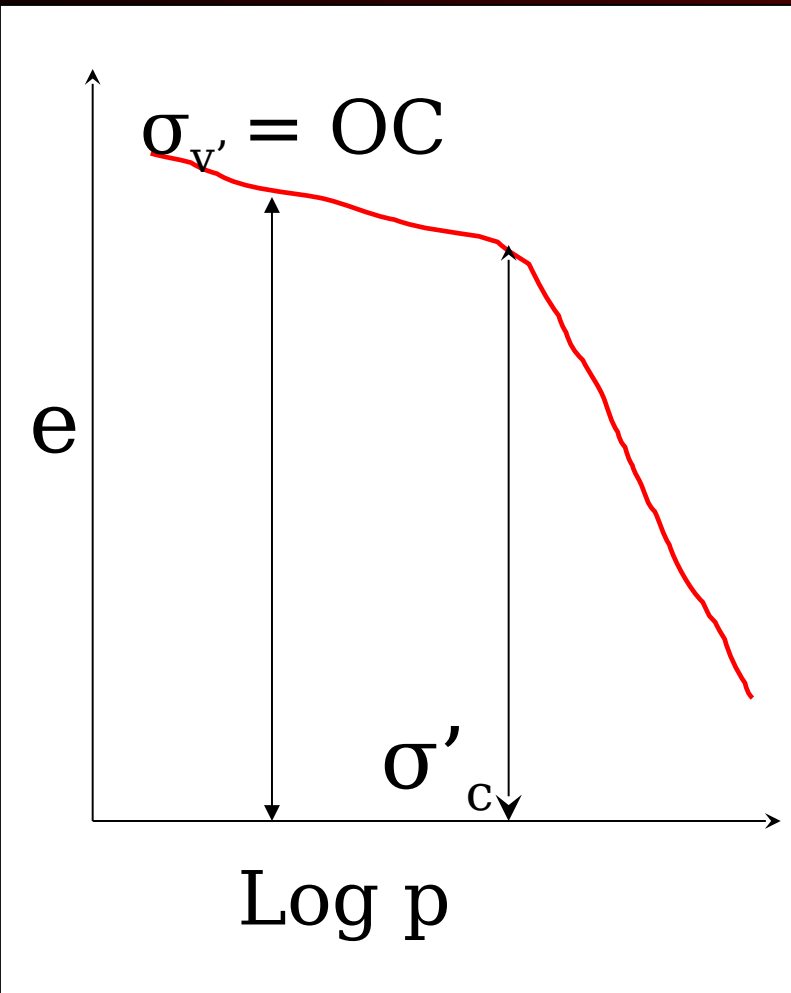
Overconsolidated – Normally Consolidated

- Overconsolidated – Some past stress was greater than current stress
- Normally Consolidated – Current stress is max



- Once σ'_c is found from the curve
- It is compared to the actual σ' in the field ($\gamma'z$)
- If $\sigma'_c = \sigma'_v$ Normally Consolidated
- If $\sigma'_c > \sigma'_v$ Overconsolidated
- ie – Sample depth 10', no water table, $\gamma = 120$ pcf, the actual

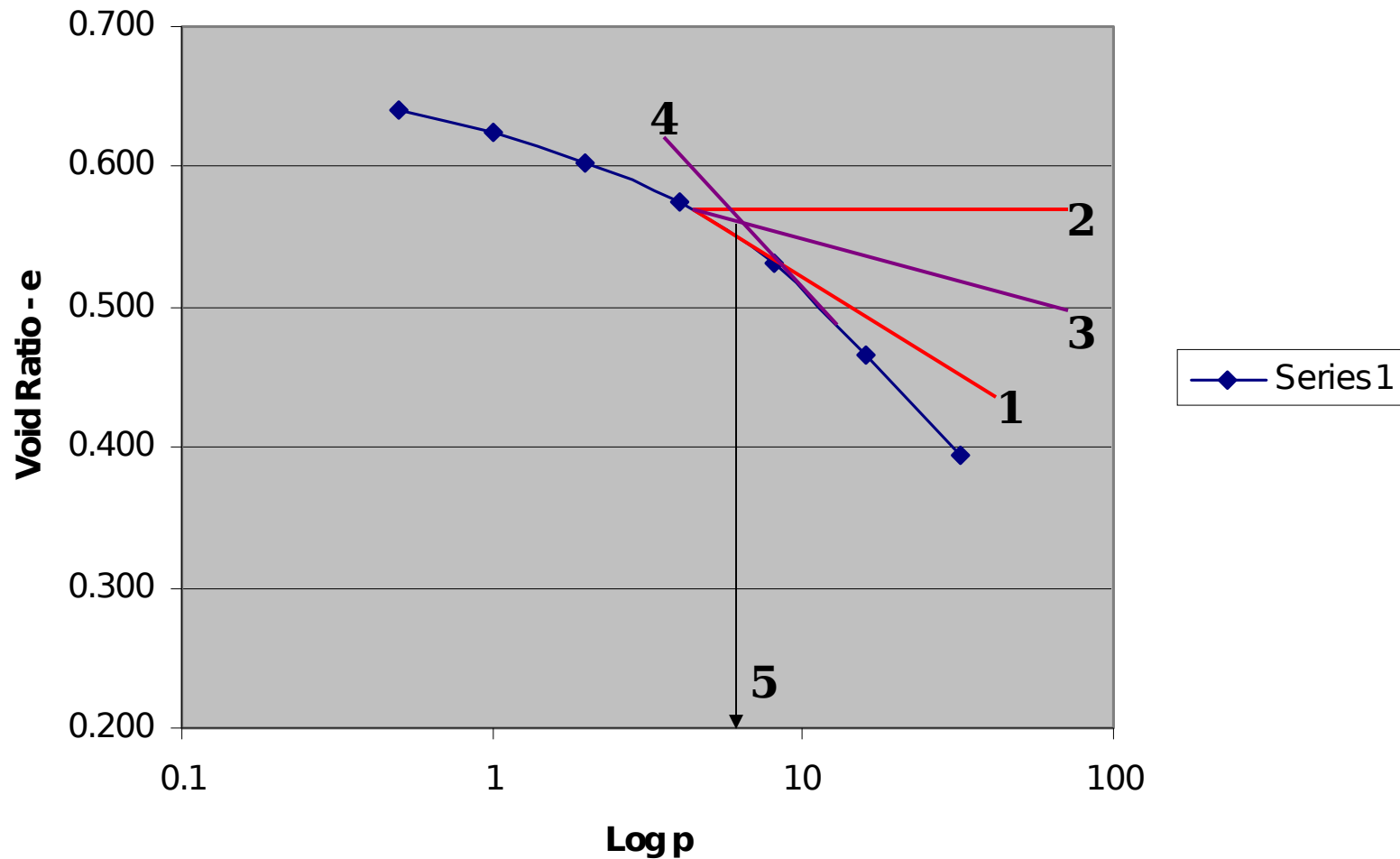
Overconsolidation Ratio



- The OCR is the ratio of past effective stress to present effective stress
- $\text{OCR} = \sigma'_c / \sigma_v'$
- $\text{OCR} = 1$ means what?

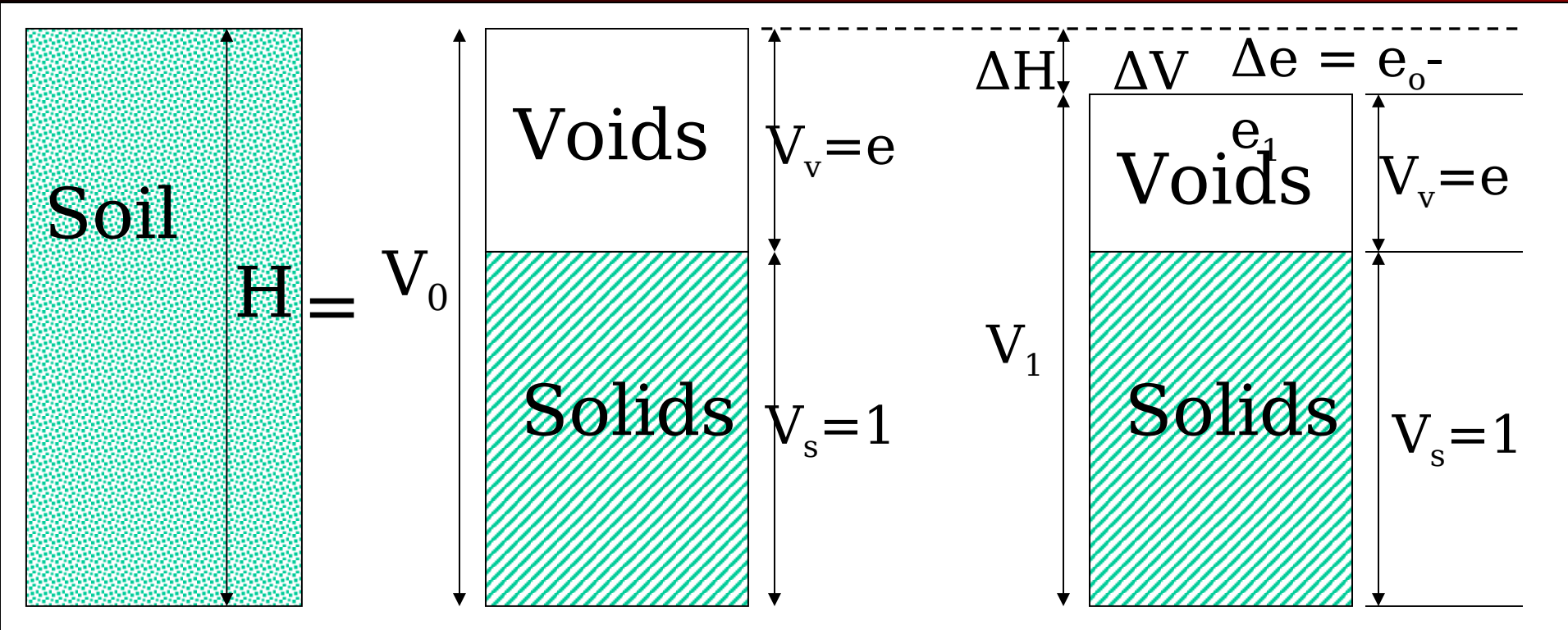
Finding P_c – Casagrandes Method

Consol Curve



Calculation of Settlement

- Consider a layer of clay under an external load



$$\Delta V = V_0 - V_1 = HA - (H - \Delta H)A = \Delta HA$$

know $e = V_v / V_s$ Also $\Delta e = \Delta V_v / V_s$ as V_s does not change

$$\Delta \sigma'_v$$

Calculation of Settlement

$$\Delta V = V_0 - V_1 = HA - (H - \Delta H)A = \Delta HA$$

We know $e = V_v / V_s$ Also $\Delta e = \Delta V_v / V_s$ as V_s does not change

$$\text{Solve for } \Delta V_v = \Delta e V_s$$

$$\text{Therefore } \Delta V = \Delta V_v = \Delta HA$$

now

$$\Delta HA = \Delta e V_s \quad \text{Equation 1}$$

$$V_s = V_0 / (1 + e_0) = AH / (1 + e_0) \quad \text{Equation 2}$$

Solve Both Equations for V_s

Calculation of Settlement

$$\Delta H \propto \Delta e = H \Delta e / (1 + e_0)$$

We get

$$\Delta H = H \Delta e / (1 + e_0)$$

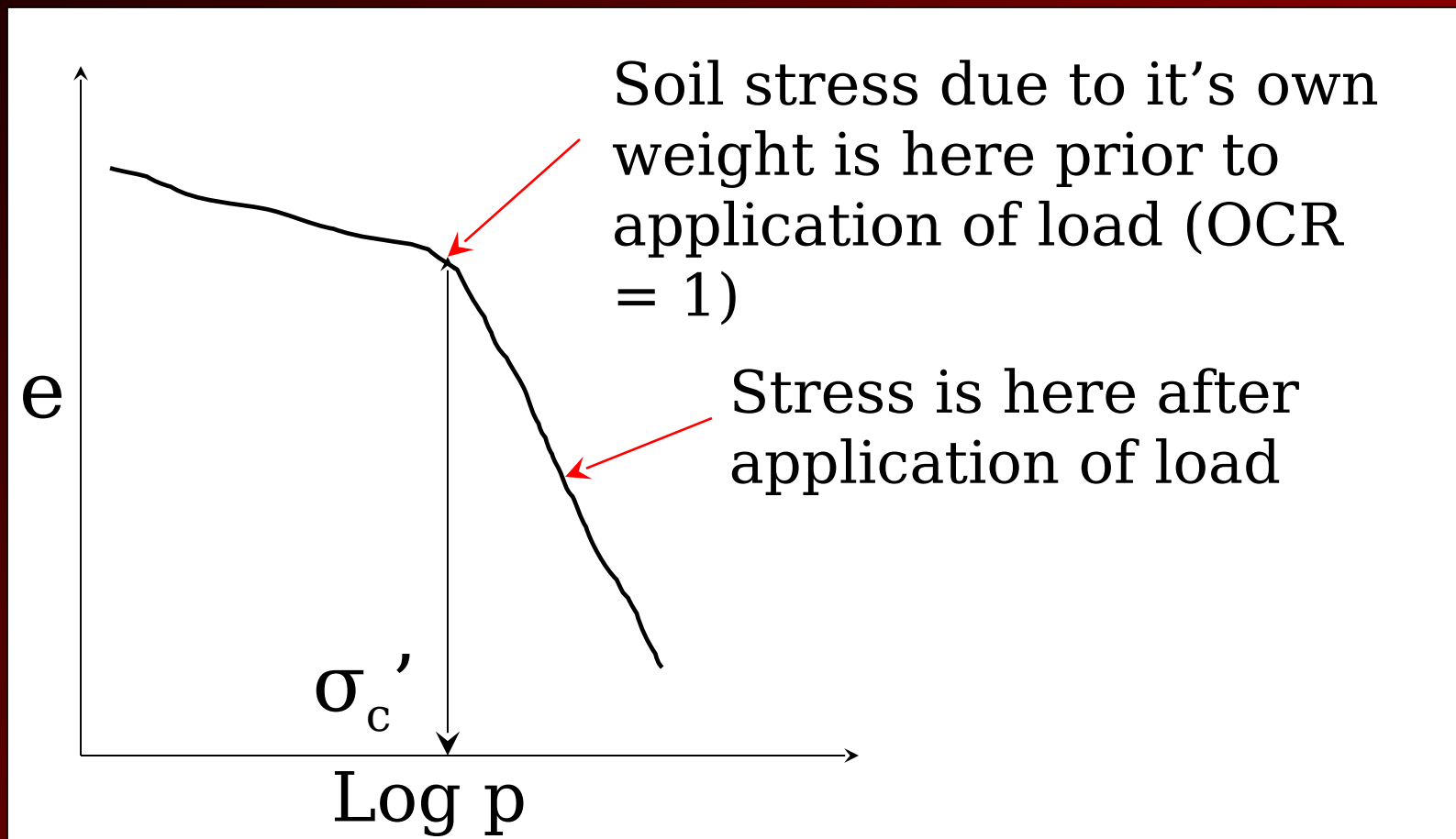
The General Settlement Equation

We will show how this is the slope of the consol curve – rise / run

Calculation of Settlement

Normally Consolidated Soil $\sigma_v' = \sigma_c'$

$$\Delta H = C_c H / (1 + e_0) \log [(\sigma_v' + \Delta \sigma_v) / \sigma_v']$$



Calculation of Settlement

Normally Consolidated Soil

$$\Delta H = C_c H / (1 + e_0) \log [(\sigma_v' + \Delta \sigma_v) / \sigma_v']$$

Review this equation – It is simply rise / run

$H / (1 + e_0)$ is from the general
settlement eq. derived

earlier
 $C_c \log [(\sigma_v' + \Delta \sigma_v) / \sigma_v']$ is the slope * Δe

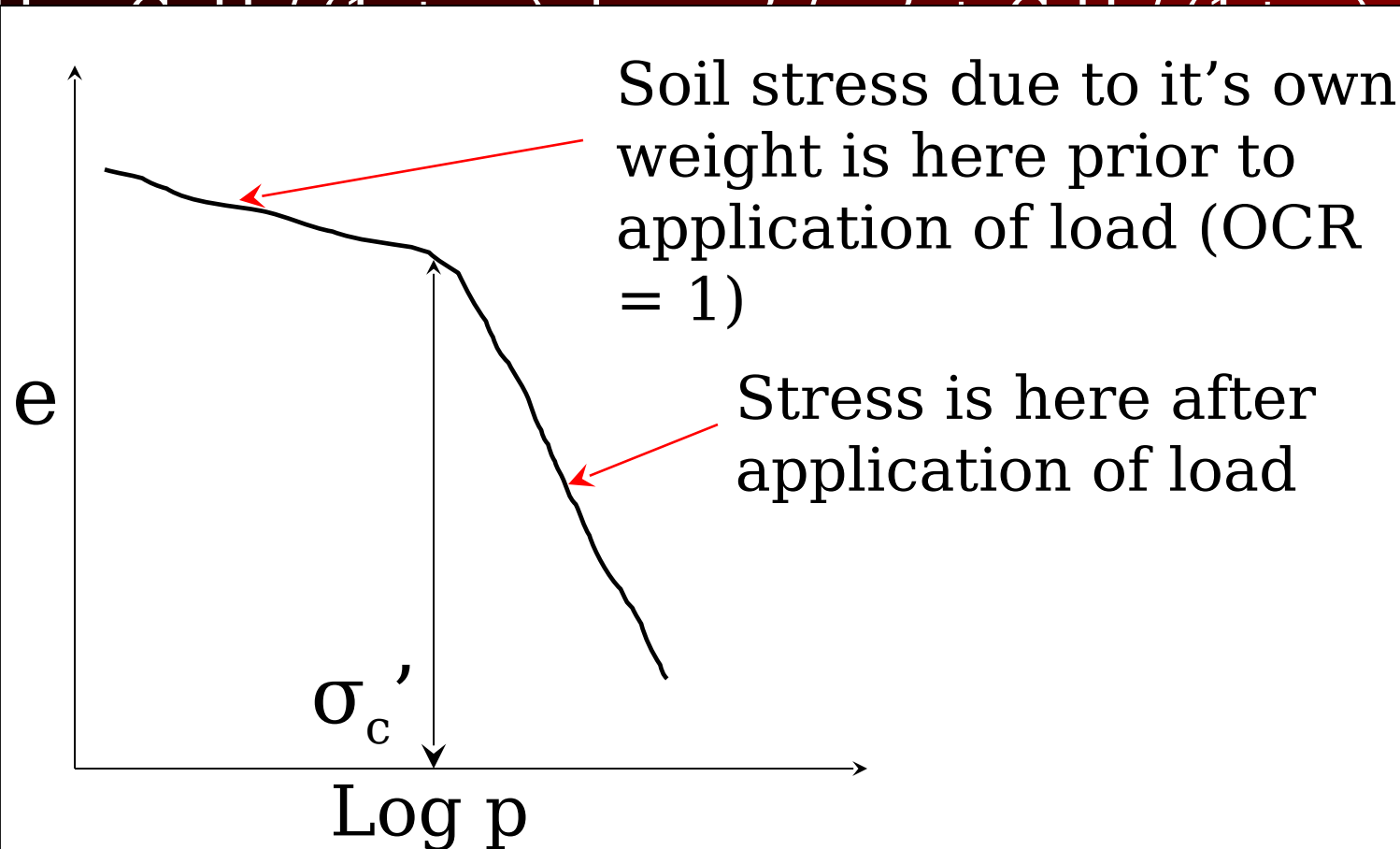
Why?

Calculation of Settlement

Over Consolidated Soil – If $(\sigma_v' + \Delta\sigma_v) > \sigma_c'$

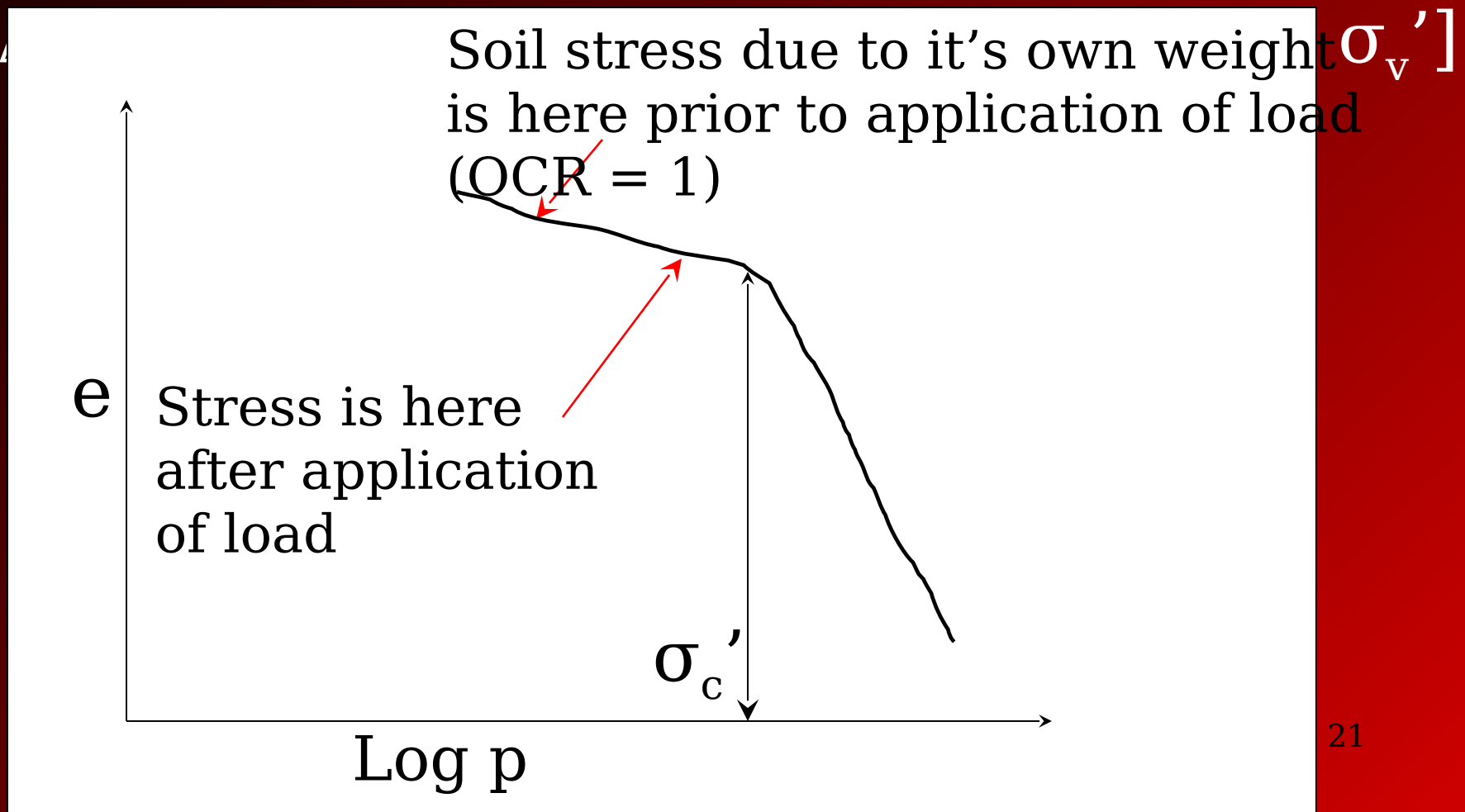
$\Delta H = C_H H / (1 + e) = \frac{C_H H}{1 + e} \left(\frac{\sigma_v' + \Delta\sigma_v}{\sigma_c'} - 1 \right)$

$[(\sigma_v' + \Delta\sigma_v) > \sigma_c']$



Calculation of Settlement

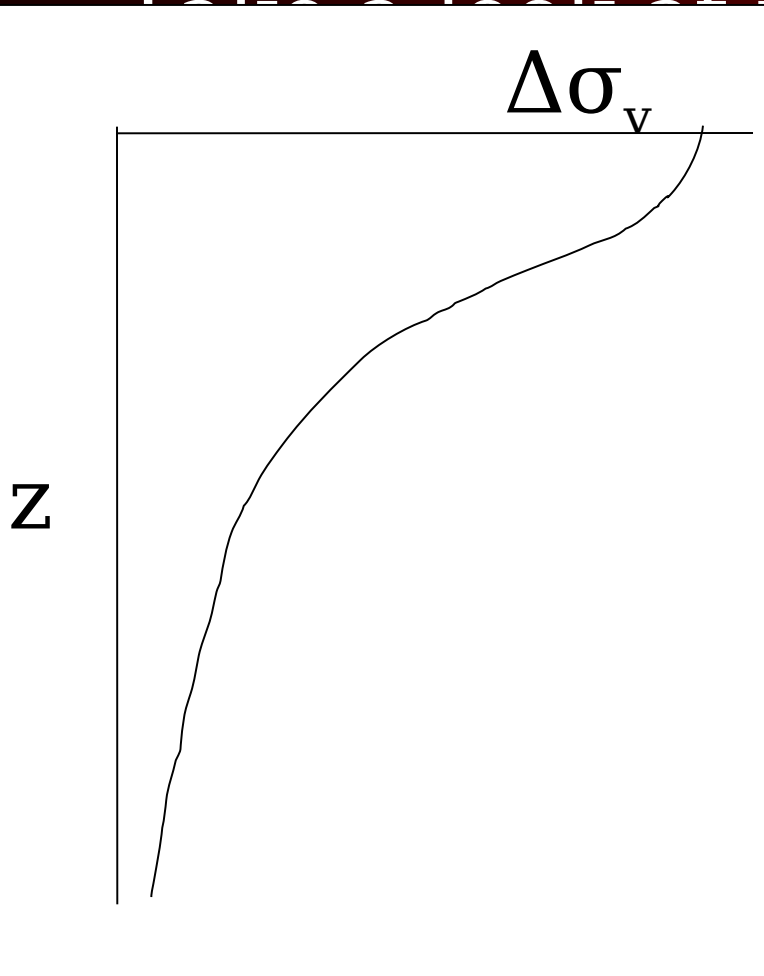
Over Consolidated Soil – If $(\sigma_v' + \Delta\sigma_v) < \sigma_c'$



Calculation of Settlement

The text covers several methods for determining the values of C_r and C_c .

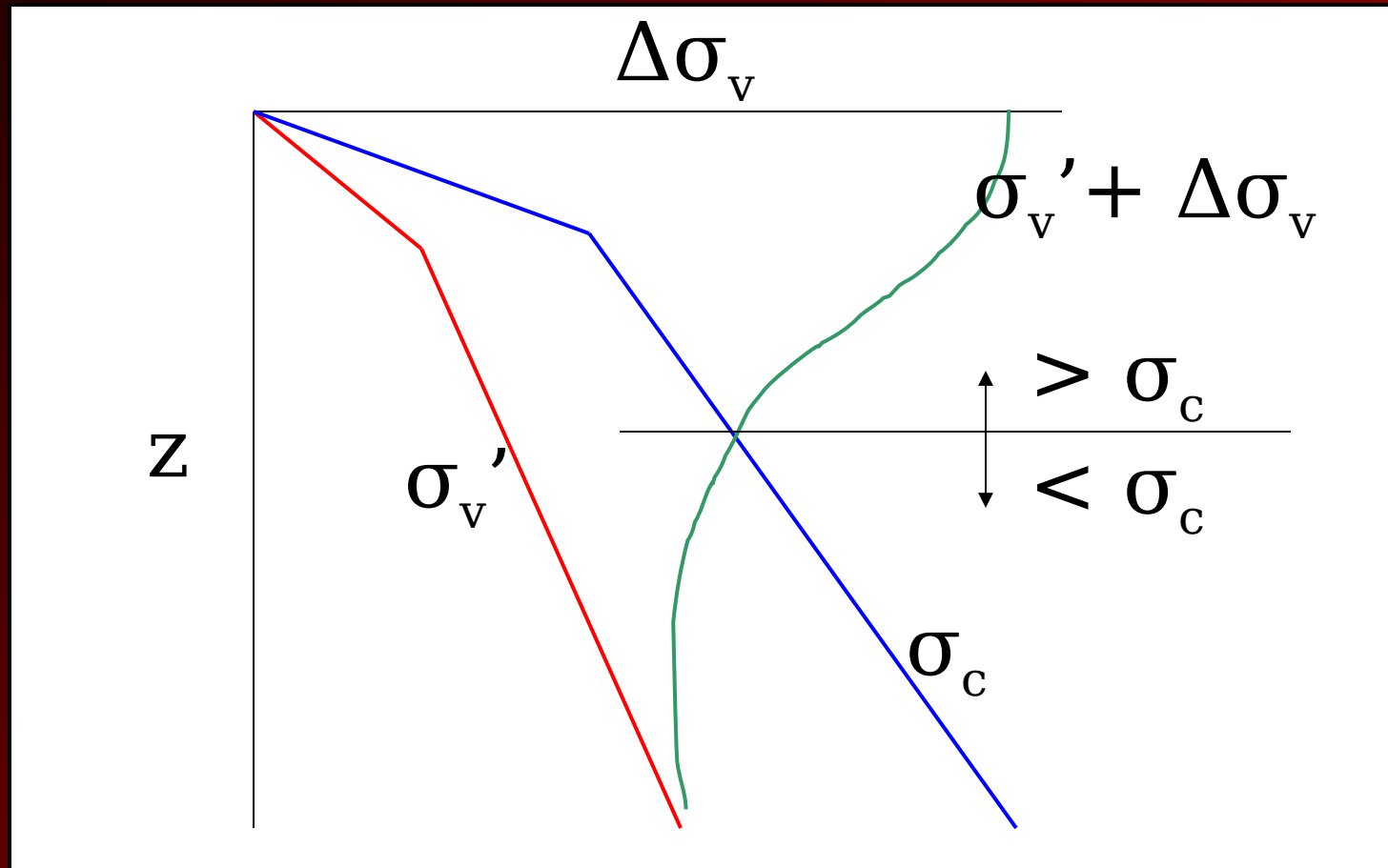
Take a look at those



- Recall the plot at left
- Now consider a layer of clay to be analyzed for settlement
- Now look at the settlement equations
- Given an H – How do you determine the values of the stresses in that layer?

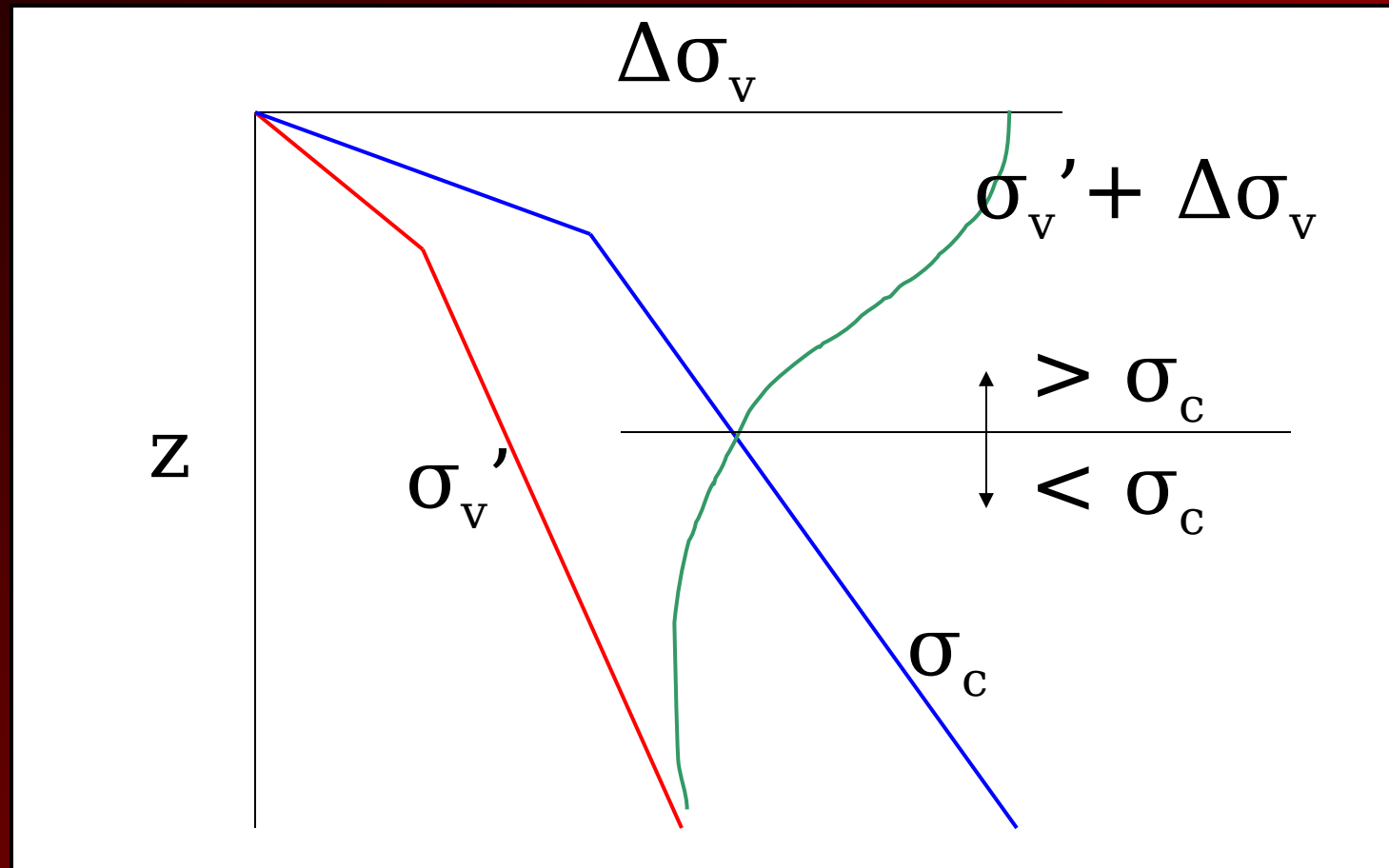
Settlement

Let's plot all the stresses



Settlement

To solve any settlement problem with an overconsolidated soil – you **MUST** do this plot (or at least calc the data points) to solve



Suggested Problems

10.3

10.5

10.8

10.13