UNIT- 5

CONSOLIDATION

INTRODUCTION :-

The property of soil mass at which the change in volume or decrease in volume takes place under compressive forces is known as compressibity of soil.

compression of solid particles and water in the voids

(a) compression of solid particles and water in the voids

(b) Compression and expulsion of air in the voids

(c) Expulsion of water in voids.

Settlement :- plastic re adjustment of solid particle with the expulsion of air by , compaction, consolidation.

Expulsion of air + water + adsorbed water + plastic readjustment of solid particles (settlement)

Stages of Consolidation :-

consolidation of soil deposit can be divided into 3 stages

1. Intial consolidation
2. primary consolidation
3. Secondary Consolidation.

(a) **Intial consolidation :-** When load is applied to a partially saturated soils, decreases in volume occur due to expulsion of air in the voids

* The Reduction in the volume of the soil just after the application of the load is known as "intial Consolidation" (or) "intial compression".

(b) **primary consolidation :-** After intial consolidation, further reduction occurs due to expulsion of water from voids

* The Reduction in volume due to expulsion of water is known as " primary Consolidation"

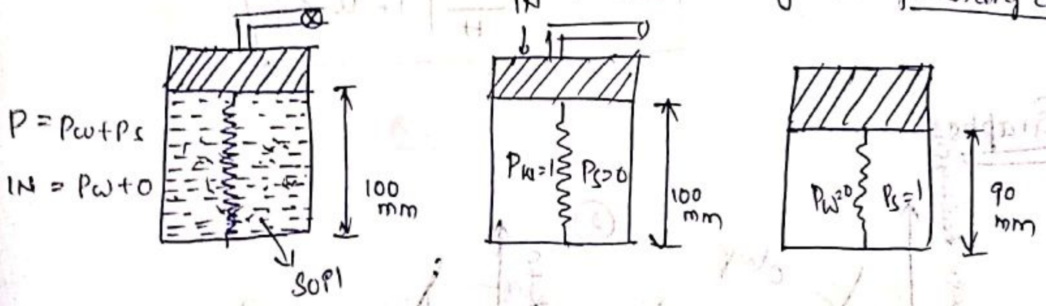
* The decrease depends upon the permeability of soil and its time dependent.
* The fine grained soils, the primary consolidation occurs over a long time.
* In coarse grained soils, the primary consolidation occurs rather than quickly due to high permeability.

ⓒ **Secondary Consolidation** :- The additional reduction in odame of soil at a slow rate is called as "Secondary consolidation"

* The decrease in the volume of soil mass due to adsorbed water and also plastic readjustment of solid particles is called as "Secondary consolidation"
* Secondary consolidation is important for certain types of soil, such as peats and soft organic clays.

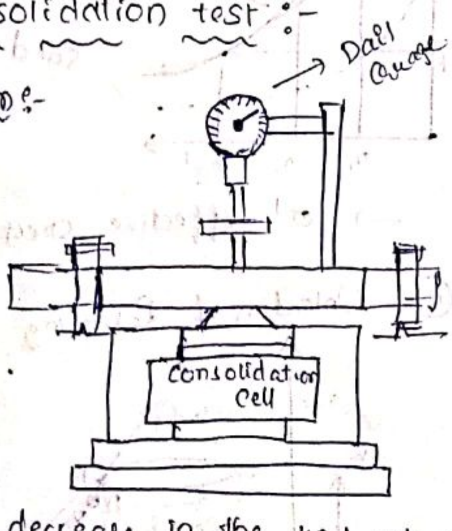
Consolidation mean primary consolidation unless otherwise stated. It is the most important component of the total consolidation.

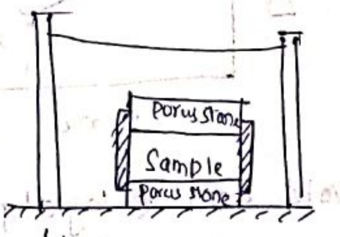
Spring Analogy :- It is used for determining the "primary consolidation"



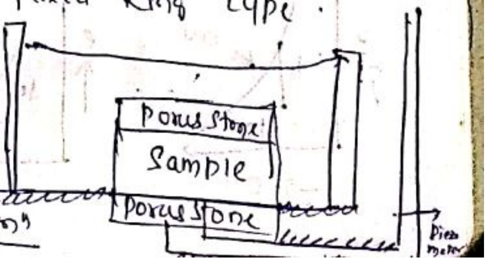
Consolidation test :-

diagram :-





ⓐ Floating Ring type.
ⓑ Fixed Ring Type.



The decrease in the vol of soil due to expulsion of water is called "Consolidation"

Applied pressure | Dail guage Readings | ΔH change in thickness (or) height

① Height of solids method. (partially saturated + fully saturated — we can use this method)

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

$$e = \frac{A \times H - A \times H_s}{A \times H_s} \Rightarrow \boxed{e = \frac{H - H_s}{H_s}}$$

$$G = \frac{\gamma_s}{\gamma_w} \Rightarrow \gamma_s = G\gamma_w \Rightarrow \frac{W_s}{V_s} = G\gamma_w$$

$$V_s = \frac{W_s}{G\gamma_w} \Rightarrow A \times H_s = \frac{W_s}{G\gamma_w}$$

$$\boxed{H_s = \frac{W_s}{G A \gamma_w}}$$

② Change in void ratio method.

$$\frac{\Delta H}{H} = \frac{\Delta e}{1+e}$$

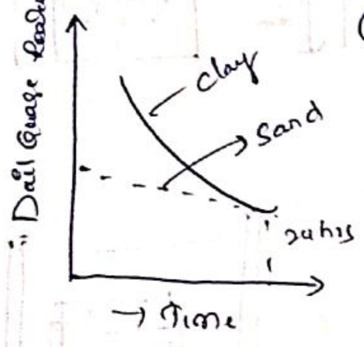
(W.K.th $es = wG$; $S = 1$ for fully saturated soils) $\boxed{e = wG}$

$$\Delta e = \frac{\Delta H}{H}[1+e]$$

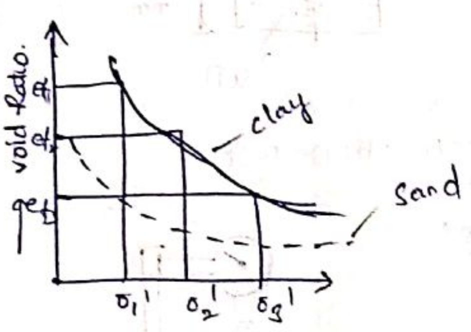
$$\boxed{\Delta e = \frac{\Delta H}{H}[1+wG]}$$

Graphs:

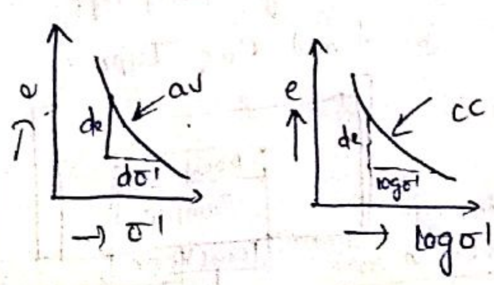
①



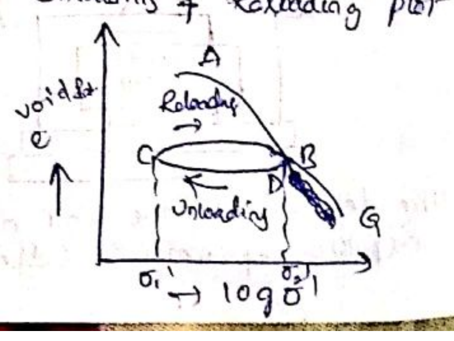
②



③ void Ratio Vs $\log \sigma'$ plot



④ Unloading & Reloading plot



Basic Definitions :-

Co-efficient of compressibility (a_v) :-

$$a_v = -\frac{de}{d\sigma'}$$

$$\therefore a_v = \frac{e_0 - e}{\sigma_1' - \sigma_0'}$$

It is defined as the decrease in void ratio per unit increasing effective stress "$d\sigma'$"

UNITS :- m^2/kN (or) mm^2/N.

Co-efficient of volume change (m_v) :- It is defined as volumetric strain to per unit increasing effective stress.

$$m_v = \frac{-\Delta V}{V_0} \times \frac{1}{\Delta\sigma'} \quad \text{(or)} \quad m_v = \frac{a_v}{1+e_0}$$

$$\Delta H = m_v H \Delta\sigma'$$

Compression Index :- (C_c) :- It is defined as "It is equal to slope of the linear portion of the void ratio Vs $\log \sigma'$ plot"

$$\therefore C_c = \frac{-\Delta e}{\log_{10}\left(\frac{\sigma_0'}{\sigma_0'}\right)} \quad \left(\text{where } \therefore \sigma' = \sigma_0' + \Delta\sigma'\right)$$

$$C_c = \frac{-\Delta e}{\log_{10}\left(\frac{\sigma_0' + \Delta\sigma'}{\sigma_0'}\right)}$$

$$C_c \times \log_{10}\left(\frac{\sigma_0' + \Delta\sigma'}{\sigma_0'}\right) = \frac{\Delta H}{H} \times (1+e_0)$$

$$\boxed{\Delta H = \frac{H \times C_c}{1+e_0} \log_{10}\left(\frac{\sigma_0' + \Delta\sigma'}{\sigma_0'}\right)}$$

Q. A soil sample of height 25 mm which has been subject to a consolidation test. has an area of 50 cm^2. dry weight of the soil is 190.2 grams, G = 2.67 then find height of the soil will change in void ratio?

Sol:-

Area (A) = 50 cm^2

H = 25 mm.

G = 2.67

W_d = 190.2 grams

H_s = ? $\quad \Delta e$ = ?

$\therefore H_s = \frac{W_d}{G A \gamma_w} = \frac{190.2}{2.67 \times 50 \times 1} = 1.42\ cm = 14.2\ mm$

(v.i.)

$\therefore \Delta e = \frac{H - H_s}{H_s} = \frac{25 - 14.2}{14.2} = 0.76\ \%$.

⊛ In a consolidation test the following results can be opted. The load ~~pass~~ changed from 50 KN/m² ~~to~~ 100 KN/m², void ratio is changed from 0.4 to 0.65 then determine co-efficient of volume change, co-efficient of compressibility? and compression index?

Sol:-

$e_0 = 0.72$, $e = 0.65$

$\sigma_1' = 100\ KN/m^2$, $\sigma_0' = 50\ KN/m^2$

co-efficient of compressibility

$a_v = \frac{e_0 - e}{\sigma_1' - \sigma_0'} = \frac{0.72 - 0.65}{100 - 50}$

$\therefore a_v = 1.4 \times 10^{-3}\ m^2/KN$

~~compression~~ ~~of~~ index (Cc) $= \frac{-\Delta e}{\log_{10}\left(\frac{\sigma_1'}{\sigma_0'}\right)}$

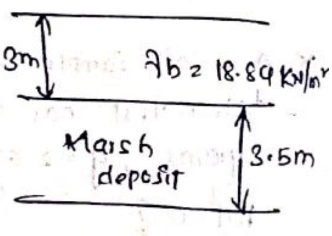
$= \frac{0.07}{\log_{10}\left(\frac{100}{50}\right)} =$

co-efficient of volume change

$V = \frac{a_v}{1+e_0} = \frac{1.4 \times 10^{-3}}{1+}$

⊛ A sample having bulk density of 18.84 KN/m3, is to be place on a compressible saturated marsh deposit, of thickness 3.5 m the height of the sample is 3m, if volume of compressibility of deposit is $7 \times 10^{-4}\ m^2/KN$.

Sol:- Given data is



bulk density (γ_b) = 18.84 KN/m3

vol of compressibility $M_v = 7 \times 10^{-4}\ m^2/KN$.

$\therefore \Delta H = m_v \times H \times \Delta\sigma$

W.K.T $\Delta\sigma = \gamma_b * H = 18.84 \times 3 = 56.52\ KN/m^2$

$\Delta H = 4 \times \Delta\sigma$

$= 7 \times 10^{-4} \times 3 \times 56.52$

$\therefore$ $\boxed{\Delta H = 0.11 m}$

⑥ A clay stratum of 5m thick, has intial void ratio of 1.5 and effective over head pressure of 120 KN/m², when sample is subjected to increase of pressure, 120 KN/m², the void ratio reduces to 1.44. determine the final settlement of the stratum.

Sol:- Given data is

$H = 5m$

$e_0 = 1.5$, $e = 1.44$

$\sigma_0' = 120 KN/m^2$

Increase of pressure $\sigma_1' = \sigma_0' + \Delta\sigma'$

$\sigma_1' = 120 + 120$

$\sigma_1' = 240 KN/m^2$

$\therefore \Delta H = m_v \times H \times \Delta\sigma$

$\therefore m_v = \frac{a_v}{1+e_0} = \frac{\Delta e}{\Delta \sigma} \times \frac{1}{1+e_0}$

$m_v = \frac{1.5 - 1.44}{120} \times \frac{1}{1+1.5} = 2 \times 10^{-4} m^2/KN$

$\therefore \Delta H = 2 \times 10^{-4} \times 5 \times 120 = 0.12 m$

* A saturated soil has compression index $C_c = 0.27$, it void ratio at a stress of 125 KN/m² is 2.04 and its permeability is 3.5×10^{-8} cm/sec. compute the change in void ratio it effective stress is increased 187.5 KN/m². The Settlement of the soil if its thickness is 5cm.

Sol:- given data is

compression index $(C_c) = 0.27$

$e_0 = 2.04$

$K = 3.5 \times 10^{-8} cm/sec$

$\sigma_0' = 125 KN/m^2$

$e = ?$

$\sigma_1' = 187.5 KN/m^2$

$\Delta H = ?$ and $H = 5 cm$

$$C_c = \frac{-\Delta e}{\log_{10}\left(\frac{\sigma_1'}{\sigma_0}\right)}$$

$$0.27 = \frac{e_0 - e}{\log_{10}\left(\frac{187.5}{125}\right)}$$

$$0.27 \times \left[\log\left(\frac{187.5}{125}\right)\right] = 2.04 - e$$

$$e = 1.93$$

W.Know that

$$\frac{\Delta H}{H} = \frac{\Delta e}{1+e_0}$$

$$\Delta H = H \times \frac{\Delta e}{1+e_0}$$

$$\Delta H = 5 \times \frac{2.04 - 1.93}{1+2.04} = \underline{0.18\ cm}$$

⊛ The Laboratary consolidation data for undisturbed clay sample are as follows. $e_1 = 1$, $\sigma_1 = 85\ KN/m^2$, $e_2 = 0.8$, $\sigma_2 = 465\ KN/m^2$, $e_3 = ?$, $\sigma_3 = 600\ KN/m^2$

Sol:- For the Same soil Sample "C_c" (Compression index C_c) is Same.

$e_1 = 1$ then $\sigma_1 = 85\ KN/m^2$

$e_2 = 0.8$ then $\sigma_2 = 465\ KN/m^2$

$e_3 = ?$ then $\sigma_3 = 600\ KN/m^2$

$$\therefore C_c = \frac{-\Delta e}{\log\left(\frac{\sigma_1'}{\sigma_0'}\right)} = \frac{e_1 - e_2}{\log_{10}\left(\frac{\sigma_2'}{\sigma_1'}\right)} = \frac{1-0.8}{\log_{10}\left(\frac{465}{85}\right)}$$

$$\therefore \boxed{C_c = 0.27}$$

Then $$C_c = \frac{\Delta e}{\log_{10}\left(\frac{\sigma_3'}{\sigma_2'}\right)} = \frac{e_2 - e_3}{\log\left(\frac{600}{85}\right)}$$

$$0.27 = \frac{0.8 - e_3}{\log\left(\frac{600}{85}\right)}$$

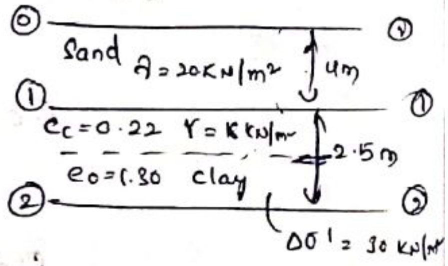
$$\therefore \boxed{e_3 = 0.77} = 77\%.$$

⊛ Calculate the final settlement of the clay layer shown in the figure due an increase in pressure of 30 KN/m² at mid height of the clay layer. also Calculate the settlement when water table rises to the ground Surface.

Sol:- Given data is

Case (i) :- No water table

effective stress = $\gamma_s \times H + \gamma_c \times H$



$$\sigma_0' = 4 \times 20 + 18 \times 1.5$$

$$= 102.5\ KN/m^2$$

$$u = 0$$

$$\sigma' = \sigma - u$$

$$\therefore \sigma' = 102.5\ KN/m^2$$

$$\Delta H = \frac{H \times C_c}{1+e_0} * \log_{10}\left(\frac{\sigma_1'}{\sigma_0'}\right) \quad (\sigma_1 = \sigma_0' + \Delta\sigma')$$

$$\Delta H = \frac{2.5 \times 0.22}{1+1.2} * \log_{10}\left(\frac{102.4+30}{102.4}\right)$$

$$\boxed{\Delta H = 0.02\ m}$$

Case III :- Water table in Ground

$$\sigma = \gamma H = 20 \times 4 + 18 \times \frac{2.5}{2} = 102.4\ kN/m^2$$

$$u = \gamma_w H = 10 \times (4 + 1.25) = 52.5\ kN/m^2$$

$$\sigma' = \sigma - u = 102.4 - 52.5 = 49.9\ kN/m^2$$

$$\Delta H = \frac{H \times C_c}{1+e_0} \times \log_{10}\left(\frac{\sigma_1'}{\sigma_0'}\right)$$

$$\Delta H = \frac{2.5 \times 0.22}{1+1.2} \times \log_{10}\left(\frac{49.9+30}{49.9}\right)$$

$$\boxed{\Delta H = 0.04\ m}$$

Terzaghi's one - Dimensional Consolidation :-

Assumptions :-

* Soil is homogenious and fully saturated
* Soil and water are incompressible
* Deformation of soil is due to decrease in vol of soil
* permeability is Constant.
* Load is applied in 1 direction → Deformation in 1 direction

$$u = \gamma_w H \rightarrow H = \frac{u}{\gamma_w}$$

$$i = \frac{u/\gamma_w}{z} \qquad i = \frac{H}{z}$$

$$i = \frac{u}{\gamma_w z} \rightarrow i = \frac{1}{\gamma_w} * \frac{\partial u}{\partial z}$$

* Darcy's Law is applicable throughout the Consolidation

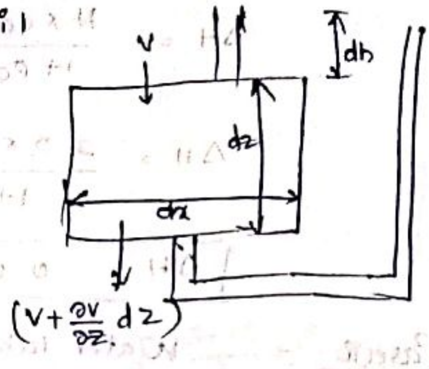
for darcy's Law $v \propto i$

$$v = ki$$

$$v = k * \frac{1}{\gamma_w} * \frac{\partial u}{\partial z}$$

$$\boxed{\frac{\partial v}{\partial z} = \frac{k}{\gamma_w} \times \frac{\partial^2 u}{\partial z^2}}$$

Quantity of water entering the soil



$\therefore Q_{in} = V * A$

$Q_{in} = v * dx * dy$

$\therefore Q_{out} = \left(v+\frac{\partial v}{\partial z}dz\right) dx dy$

Vol of water squeezes out

$$\Delta Q = Q_{out} - Q_{in}$$

$$= \left(v+\frac{\partial v}{\partial z}dz\right) dx dy - v dx dy$$

$$= v dx dy + \frac{\partial v}{\partial z} dx dy dz - v dx . dy = \frac{\partial v}{\partial z} dx dy d$$

$$m_v = -\frac{\Delta V}{V_0} * \frac{1}{\Delta\sigma'}$$

$$\Delta V = -m_v \Delta\sigma' V_0$$

V_0 = Intial volume = $dx\, dy\, dz$

$\therefore \Delta V = -m_v\, dx\, dy\, dz \cdot \Delta\sigma'$

Decrease in the vol of soil per unit time

$$\frac{\partial \Delta V}{\partial t} = -m_v\, dx dy dz \frac{\partial \Delta\sigma'}{\partial t}$$

→ Vol of water squeezed out unit time = Decrease in the vol of soil per unit time

$$\frac{\partial v}{\partial z} dx\, dy dz = -m_v\, dx\, dy\, dz \frac{\partial \Delta\sigma'}{\partial t}$$

$$\frac{k}{\gamma_w} \times \frac{\partial^2 u}{\partial z^2} = -m_v \frac{\partial \Delta\sigma'}{\partial t}$$

Total stress $(\Delta\sigma) = \Delta\sigma' + u$

differentiate on both sides with res to time

Constant $\frac{\partial \Delta\sigma}{\partial t} = \frac{\partial \Delta\sigma'}{\partial t} + \frac{\partial u}{\partial t}$

$$\frac{\partial \Delta\sigma'}{\partial t} = -\frac{\partial u}{\partial t}$$

$$\frac{k}{\gamma_w} \times \frac{\partial^2 u}{\partial z^2} = -m_v \cdot -\frac{\partial u}{\partial t}$$

$$\frac{k}{\gamma_w m_v} \times \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t}$$

$$C_v = \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t}$$

$$\boxed{C_v = \frac{k}{\gamma_w m_v}}$$

C_v co-efficient of Consolidation