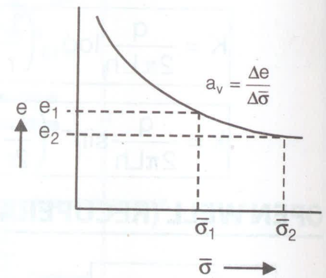
5. COMPRESSIBILITY AND CONSOLIDATION

COEFFICIENT OF COMPRESSIBILITY (a_v)

$$a_v = \frac{e_1 - e_2}{\bar{\sigma}_2 - \bar{\sigma}_1}$$

e_1 = Void ratio at effective stress $\bar{\sigma}_1$

e_2 = Void ratio at effective stress $\bar{\sigma}_2$



$$\frac{\Delta V}{V_0} = \frac{\Delta H}{H_0}$$

ΔV = Change in volume in m^3, or cm^3.

V_0 = Initial volume in m^3 or cm^3.

ΔH = Change in depth in 'm' or 'cm'.

H_0 = original depth in 'm' or 'cm'.

> **Remember:** Consolidation settlement is a function of effective stress and not the function of total stress.

COEFFICIENT OF COMPRESSION (C_c)

(a) $$C_c = \frac{e_1 - e_2}{\log_{10} \bar{\sigma}_2 - \log_{10} \bar{\sigma}_1}$$

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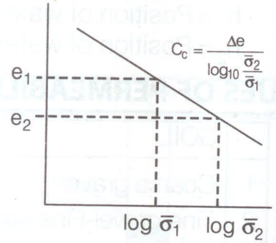
$$C_c = \frac{e_1 - e_2}{\log_{10}\left(\frac{\bar{\sigma}_2}{\bar{\sigma}_1}\right)}$$



(b) $C_c = 0.009(W_L - 10)$ For undisturbed soil of medium sensitivity.

W_L = % liquid limit.

(c) $C_c = 0.007(W_L - 7)$ For remolded soil of low sensitivity

(d) $C_c = 0.40(e_0 - 0.25)$ For undisturbed soil of medium sensitivity

e_0 = Initial void ratio

(e) For remoulded soil of low sensitivity. $C_c = 1.15(e_o - 0.35)$

(f) $C_c = 0.115\, w$ where, w = Water content

✗ For organic soil.

> **Remember:** $C_r = \frac{1}{5}$ of C_c to $\frac{1}{10}$ of C_c where, C_r = Coef. of recompression

OVER CONSOLIDATION RATIO

$$\text{O.C.R} = \frac{\text{Maximum effective stress applied in the past}}{\text{Existing effective stress}}$$

O.C.R > 1

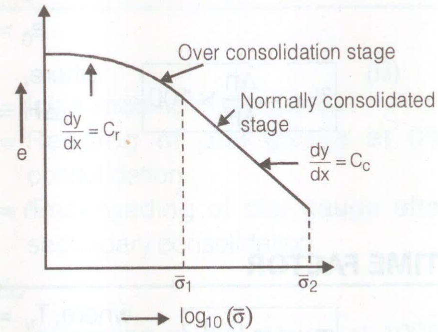
For over consolidated soil.

O.C.R = 1

For normally consolidated soil.

O.C.R < 1

For under consolidated soil.



DIFFERENTIAL EQUATION OF 1-D CONSOLIDATION

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

where, u = Excess pore pressure,

$\frac{\partial u}{\partial t}$ = Rate of change of pore pressure

C_v = Coefficient of consolidation

$\frac{\partial u}{\partial z}$ = Rate of change of pore pressure with depth.

COEFFICIENT OF VOLUME COMPRESSIBILITY

$$m_v = \frac{a_v}{1 + e_0}$$

where, e_0 = Initial void ratio

m_v = Coefficient of volume compressibility

COMPRESSION MODULUS

$$E_c = \frac{1}{m_v}$$

where, E_c = Compression modulus.

DEGREE OF CONSOLIDATION

(i) $\%U = \left(1 - \frac{U}{U_i}\right) \times 100$

where,
%U = % degree of consolidation.
U = Excess pore pressure at any stage.
$U_i = \overline{\Delta\sigma}$ = Initial excess pore pressure

at $t = 0, u = u_i \Rightarrow \%u = 0\%$
at $t = \infty, u = 0 \Rightarrow \%u = 100\%$

(ii) $\%u = \frac{e_0 - e}{e_0 - e_f} \times 100$

where,
e_f = Void ratio at 100% consolidation. i.e., of $t = \infty$
e = Void ratio at time 't'
e_0 = Initial void ratio i.e., at t = 0

(iii) $\%u = \frac{\Delta h}{\Delta H} \times 100$

where,
ΔH = Final total settlement at the end of completion of primary consolidation i.e., at $t = \infty$
Δh = Settlement occurred at any time 't'.

TIME FACTOR

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

where, T_v = Time factor
C_v = Coeff. of consolidation in cm^2/sec.
d = Length of drainage path
t = Time in 'sec'

$d = \frac{H_0}{2}$ For 2-way drainage

$d = H_0$ For one-way drainage.

where, H_0 = Depth of soil sample.

(i) $T_v = \frac{\pi}{4}(u)^2$ ... If $u \le 60\%$ $T_{50} = 0.196$

(ii) $T_v = -0.9332 \log_{10}(1-u) - 0.0851$ ... If u > 60%

METHOD TO FIND 'C_v'

(i) Square Root of Time Fitting Method

$C_V = \frac{T_{90} \cdot d^2}{t_{90}}$

where, T_{90} = Time factor at 90% consolidation
t_{90} = Time at 90% consolidation
d = Length of drainage path.

(ii) Logarithm of Time Fitting Method

$C_V = \frac{T_{50} . d^2}{t_{50}}$

where, T_{50} = Time factor at 50% consolidation
t_{50} = Time of 50% consolidation.

Remember

- Square root of time fitting method is better for soil having higher secondary consolidation.
- Square root of time fitting method is better for those soils which have high secondary consolidation such as highly plastic clays.

COMPRESSION RATIO

(i) Initial Compression Ratio

$r_i = \frac{R_i - R_0}{R_i - R_f}$

where, R_i = Initial reading of dial gauge.
R_0 = Reading of dial gauge at 0% consolidation.
R_f = Final reading of dial gauge after secondary consolidation.

(ii) Primary Consolidation Ratio

$r_p = \frac{R_0 - R_{100}}{R_i - R_f}$

where, R_{100} = Reading of dial gauge at 100% primary consolidation.

(iii) Secondary Consolidation Ratio

$r_s = \frac{R_{100} - R_f}{R_i - R_f}$ $r_i + r_p + r_s = 1$

TOTAL SETTLEMENT

$S = S_i + S_p + S_s$

where, S_i = Initial settlement
S_p = Primary settlement
S_s = Secondary settlement

(i) Initial Settlement

$S_i = \frac{H_0}{C_s} \cdot \log_{10} \frac{(\sigma_0 + \overline{\Delta\sigma})}{\sigma_0}$ For cohesionless soil.

where, $C_s = 1.5 \frac{C_r}{\sigma_0}$

where, C_r = Static one resistance in kN/m^2
H_0 = Depth of soil sample

- $$S_i = \frac{q\sqrt{A}(1-\mu^2)}{E_s}(I_t)$$ for cohesive soil.

where, I_t = Shape factor or influence factor
A = Area.

Remember

For square footing, $A = B^2$ and $I_t = 1$

$$S_i = \frac{qB(1-\mu^2)}{E_s} \times I_t$$ for strip footing

(ii) Primary Settlement

- $$S_P = \Delta H = H_0 \frac{\Delta e}{1+e_0}$$
- $$\Delta H = H_0 m_v \overline{\Delta\sigma}$$
- $$\Delta H = \frac{C_c H_0}{1+e_0} \log_{10}\left(\frac{\overline{\sigma_0} + \overline{\Delta\sigma}}{\overline{\sigma_0}}\right)$$
- $$S_P = S_{C_1} + S_{C_2}$$ $$S_{C_1} << S_{C_2} \rightarrow S_P \sim S_{C_2}$$

S_{C_1} = Settlement for over consolidated stage
S_{C_2} = Settlement for normally consolidated stage

$$S_P = \frac{C_r H_0}{1+e_0} \log_{10}\left(\frac{\overline{\sigma_1}}{\overline{\sigma_0}}\right) + \frac{C_c H_0'}{1+e_0'} \log_{10}\left(\frac{\overline{\sigma_2}}{\overline{\sigma_1}}\right)$$

(ii) Secondary Settlement

$$S_S = \frac{C_s H_0}{1+e_{100}} \log_{10}\left(\frac{t_2}{t_1}\right)$$

$\rightarrow H_{100}$

where, $H_0 \sim H_{100}$

H_{100} = Thickness of soil after 100% primary consolidation.

e_{100} = Void ratio after 100% primary consolidation.

t_2 = Average time after t_1 in which secondary consolidation is calculated.

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