Consolidation

The rate of vol. decrease with time.

$S = S_I + S_p + S_s$

Total setelment = Imediate consolidation settelment + primary + secondary

Diff b/w compaction and consolidation:

1) Consolidation is for fully saturated soils whereas in compaction soil is not fully saturated.
2) Consolidation is by the expulsion of water whereas compaction is usually by addition of water
3) Consolidation takes place under the effect of steady long term load whereas compaction proceeds under the short term loads.

Compressibility of soil.

The reduction of vol. of a soil mass could be attributed to 3 factors

1) The escape of water and air from the voids
2) Compression of solid particles
3) Compression of water and air within voids.

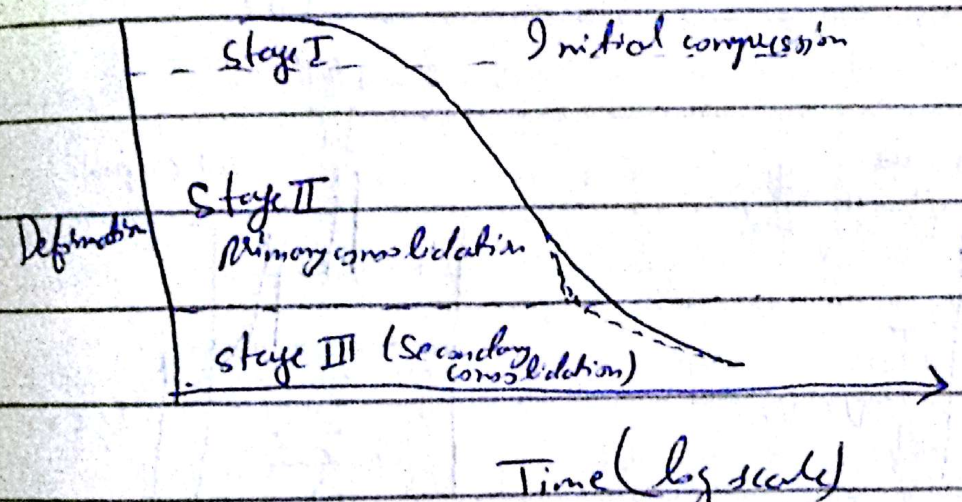
The compression produced by the decrease of the solid particles as a % of the total amount is quite negligible to is that due to compression of water. Hence instead

Primary consolidation.

It results from the expulsion of air and pore water from the voids of the soil mass.

Secondary consolidation or creep:

It is speculated to be due to the plastic deformation of the soil as a result of some complex colloid chemical processes whose roles in this regard are mostly hypothetical at this point



Of the 2 types of deformation;

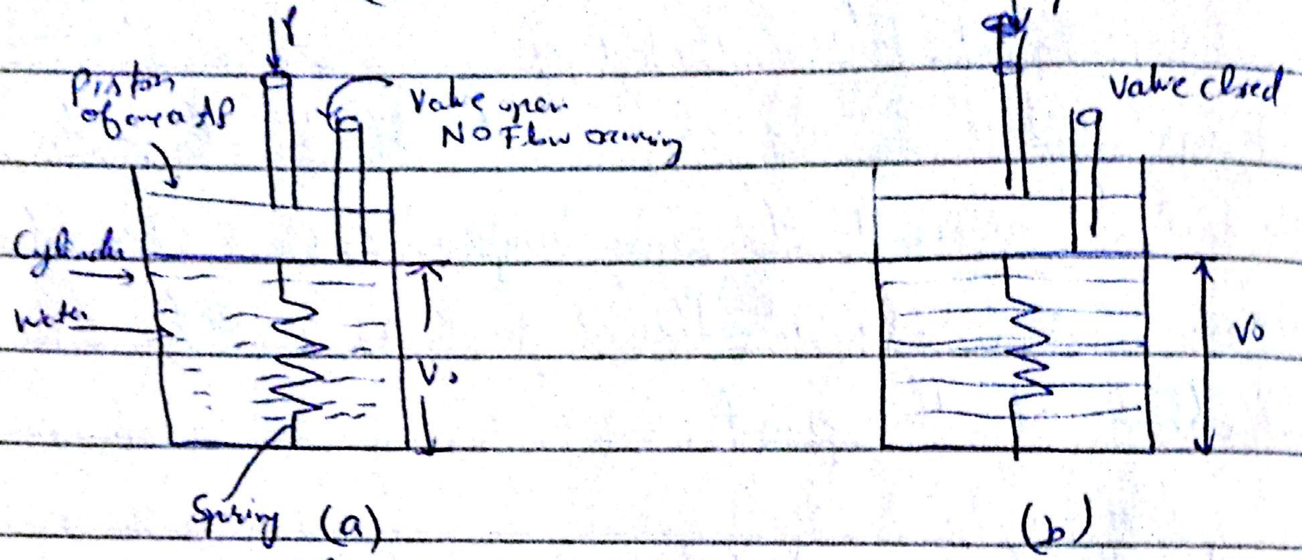
Primary is normally is much larger, easier to predict occurs at a faster rate, and is generally the more imp of the two. In many problems however, the secondary consolidation is the more imp. particularly in highly organic soils

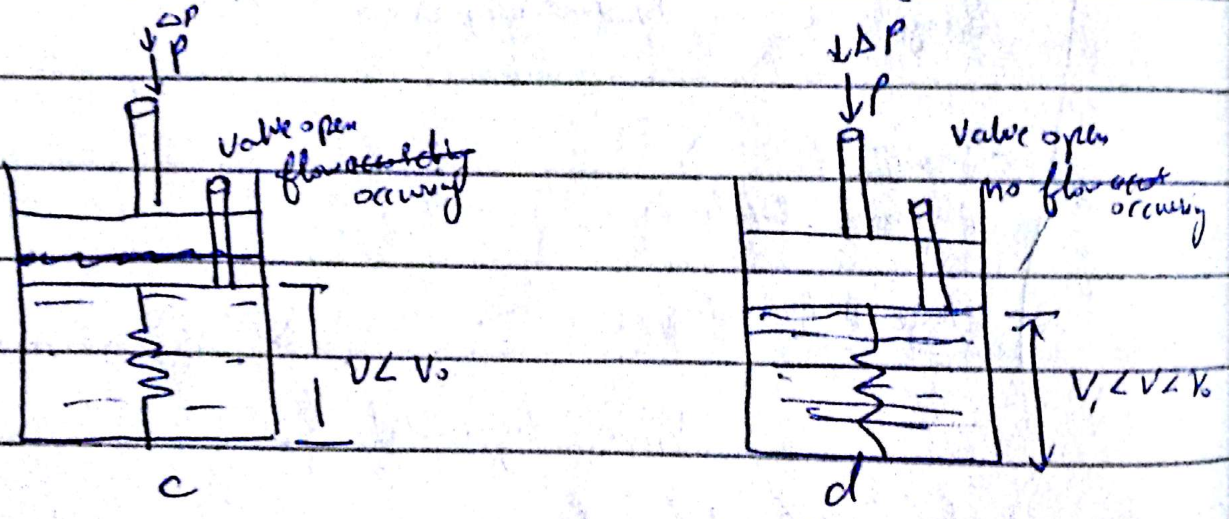
A Mechanical Model:

a) $\sigma = \sigma' + u$ (Total stress = effective stress + water stress; u = zero)

b) $\sigma = \sigma' + u(\Delta P)$

c) $\sigma = (\sigma' + \Delta P)$





a) $\sigma = \sigma' + u$ (zero)

b) $\sigma_1 = \sigma' + \Delta P / AP$

$\sigma_2 = \left(\sigma' + \frac{\Delta P}{AP}\right) + \Delta u$ (zero)

↓ effective stress

load app

$\text{stress} = \frac{F}{A} = \frac{\Delta P}{A_p}$

A_p ← area of piston

$u = \sigma$

$\sigma = \frac{\Delta P}{A} = u$

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The process of change in the soil vol. on account of water flowing out of its voids on account of dissipation of excess pore water pressure produced on an app of total stress is known as consolidation.

In (a)

Soil is said to be consolidation to an effective stress P/Ap.

In (b)

Total stress has been increased but consolidation has not begun.

In (c)

The soil is consolidating as effective stress is increasing.

In (d)

Soil has been consolidated to an effective stress of $(P+\Delta P)/A_p$

Deformation only occurs when there is change in effective stress and not only in total stress.

(One dimensional Consolidation Theory)

Terzaghi put this theory for primary consolidation of soils, with its help it is possible to make a reasonable estimate of the magnitude and rate of settlement of a structure placed on soils. This theory is referred to one dimensional consolidation theory because of the assumption that "the flow of water in soil pores take place in vertical direction only"

In the development of this theory following assumptions were made

1) Change in effective stress (P) in soil causes a corresponding change in 'e'
2) The seepage flow is restricted to one direction
3) Darcy's law applies
4) The soil mass is completely saturated.
5) The deformation is one dimensional (i.e in the direction of flow)
6) The water and solid particles are incompressible
7) Soil mass is homogeneous
8) Coefficient of permeability is constant.

In reality these assumptions are not met fully. The results from consolidation studies, however, reveal that large discrepancies between theory and nature are brought abt by the % of large V of air in the void of soil.

Constants and definitions arising from theory of consolidation

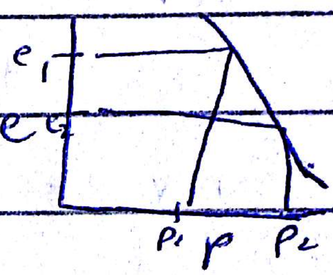
Coefficient of compressibility: (a_v)

The ratio of change in void ratio and the change in P.

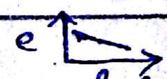
$$a_v = \frac{e_1 - e_2}{P_2 - P_1} = \frac{\Delta e}{\Delta P}$$

a_v is found from the graph drawn at natural scale b/w P and e. Units of a_v

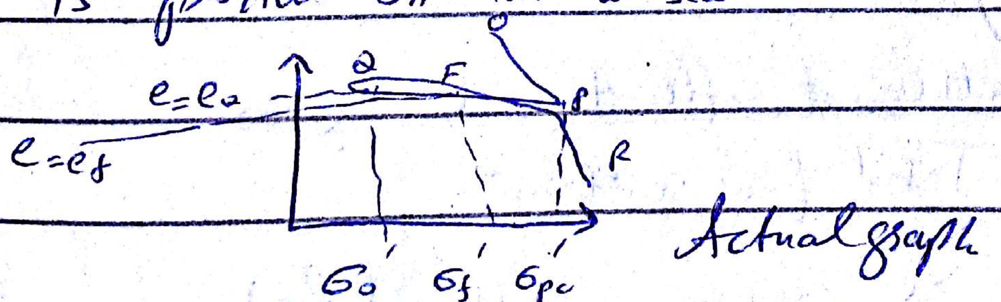
$$a_v = \frac{1}{lbs/ft^2} = \frac{ft^2}{lbs}$$



Compression index (C_c)



If we plot a graph b/w void ratio and 'P' on semi log paper, then this ratio is defined as Cc. 'e' is plotted on natural scale and P on log scale.



Actual graph

$$C_c = \frac{e_1 - e_2}{\log P_2 - \log P_1}$$

$$C_c = \frac{\Delta e}{\log P_2/P_1} \quad \text{(Unit less)}$$

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Coefficient of consolidation: Cv

Cv is derived from the theory where

$$C_v = \frac{K}{m_v \times \gamma_w}$$

K → permeability of soil = ft/s

m_v → coefficient of vol. change

$$= \frac{ft/s}{ft^2/lb \times lb/ft^3} = ft^2/s$$

coefficient of vol. change M_v

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

$$m_v = \frac{\Delta e}{\Delta P(1 + e_0)} = \frac{ft^2/lb}{1} = \frac{ft^2}{lb}$$

Degree of consolidation: (U)

The % of the total settlement that has occurred after time t:

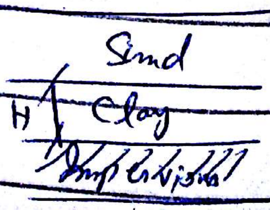
$$U = \frac{\text{Settlement after time } t}{\text{Total final settlement}} \times 100$$

$$U = \frac{S_t}{S_f} \times 100 \quad \text{(Unit less)}$$

Time factor Tv

It is a constant derived from theory

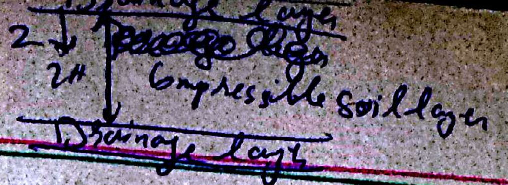
$$T_v = \frac{C_v t}{H^2} \quad \text{(Unit less)}$$



Cv = coefficient of consolidation

H = Drainage path

T = time settlement has been occurring



For $U = 0 - 60\%$ $\quad T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$ — ①

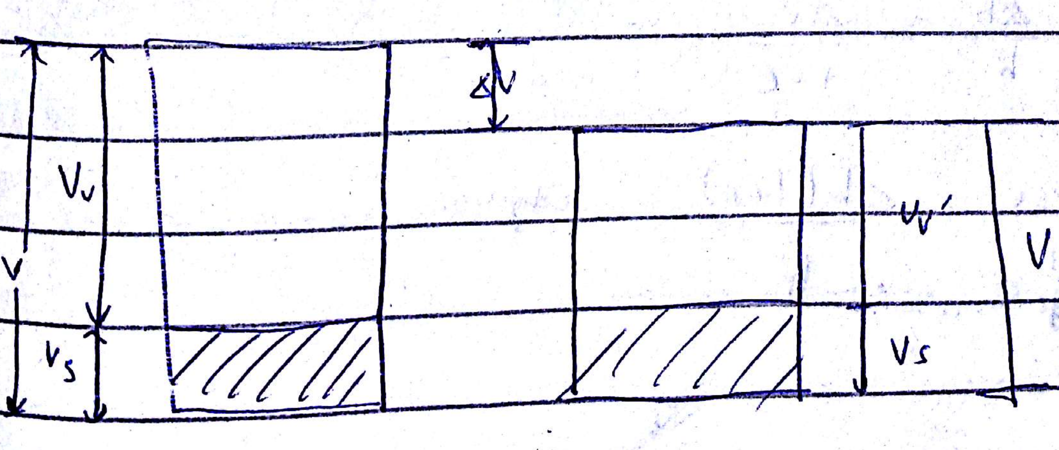
For $U > 60\%$ $\quad T_v = 1.781 - 0.933\log(100 - U\%)$ — ②

For practical purposes

	eq①						eq②		
$U =$	10	20	30	40	50	60	70	80	90
$T_v =$	0.0078	0.032	0.07	0.125	0.197	0.29	0.41	0.57	0.848

If sample is drained from top and bottom then H is always half the thickness of sample.

Change of void-ratio method:



a) Initial condition $\qquad$ b) Compression condition

In one dimensional compression the change in height Δh per unit of original height h equals the change in vol. ΔV per unit of original vol. V.

$$\frac{\Delta h}{h} = \frac{\Delta V}{V}$$

V may now be expressed in terms of 'e'

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

$$\frac{\Delta V}{V} = \frac{V - V'}{V} = \frac{V_s(1+e) - V_s(1+e')}{V}$$

$V_s e = V_v$

$V = V_s(1+e)$

$$= \frac{e - e'}{1+e} = \frac{\Delta e}{1+e}$$

$V_v' = e' V_s$

$V' = V_s(1+e')$

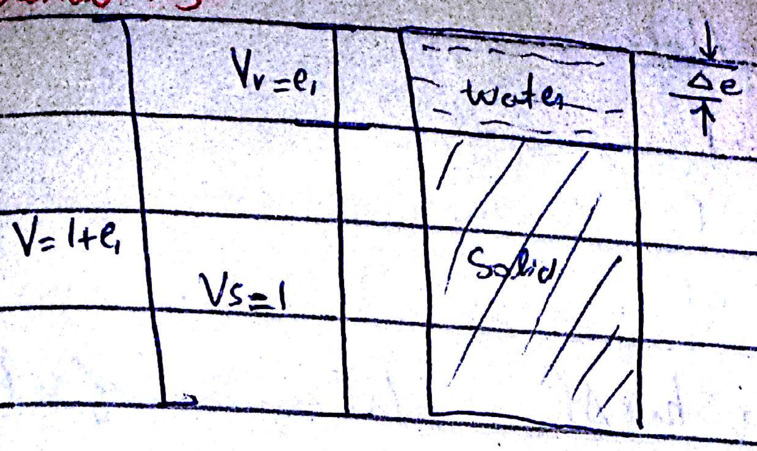
∴

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

or $\Delta e = \frac{\Delta h(1+e)}{h}$ Compressi

↓
~~Change in void ratio~~

Settlement : S



$$\frac{S}{H_1} = \frac{\Delta e}{1+e_1} = \frac{e_1 - e_2}{1+e_1}$$

$$S = \frac{(e_1 - e_2) H_1}{1+e_1}$$

$$\Rightarrow C_c = \frac{\Delta e}{\log \frac{P_2}{P_1}}$$

$$S = C_c \left(\frac{\log P_2/P_1}{1+e_1} \right) H_1$$

$$S = \frac{C_c H}{1+e_0} \log \left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'} \right)$$

Initial pressure

$$\frac{\Delta h}{h_0} = \frac{\Delta e}{1+e_0}$$

$$\Delta e = \frac{\Delta h (1+e_0)}{h_0}$$

$$m_v = \frac{a_v}{(1+e_0)} = \frac{\Delta e / \Delta p}{(1+e_0)}$$

$$m_v = \frac{\Delta e / 1+e_o}{\Delta P}$$

$$m_v = \frac{\Delta h}{h_o} \times \frac{1}{\Delta P}$$

$\Delta h = m_v \times h_o \times \Delta P$ = total compression of soil sample

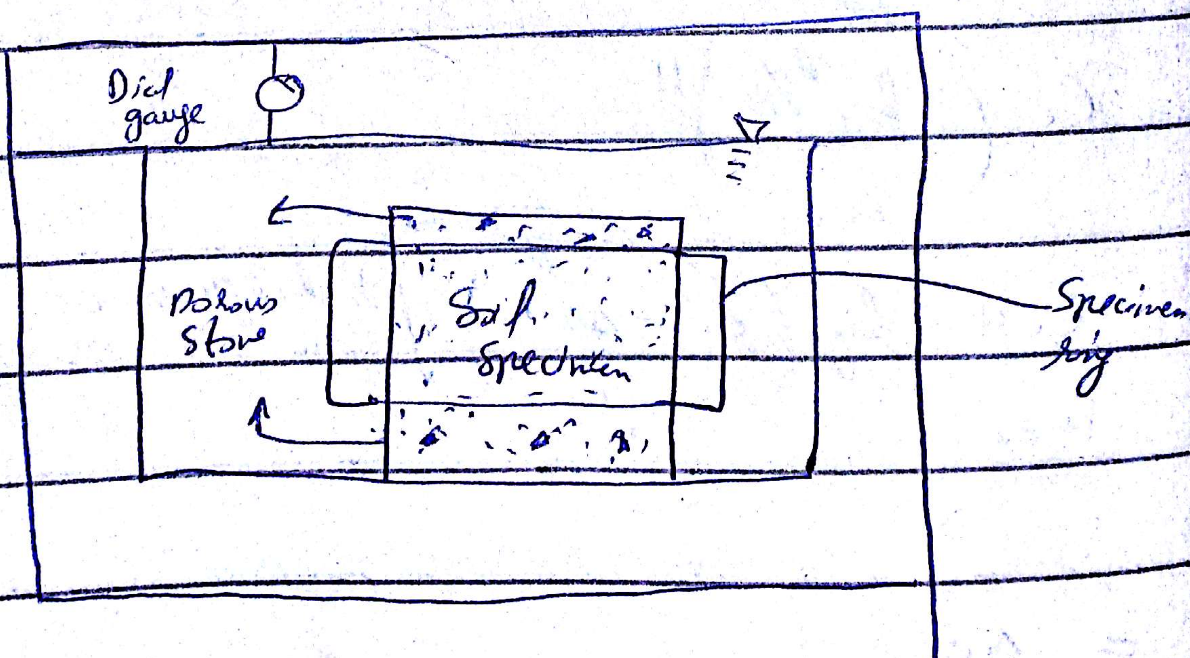
$$S = m_v \times h \times \Delta P$$

$$S = \frac{a_v h \quad \Delta P}{(1+e_o)}$$

~~Prob. 1~~

One dimensional consolidation test.

Performed by consolidometer.



Problem (1)

A 2.5 cm thick sample of clay was taken from the field for predicting time of settlement for a proposed building which exerts a pressure of 10 ton/m² over placed stratum. Sample was loaded to 10 ton/m² (2 way drainage) and 50% of total settlement occurred in 3 minutes. Find time for 50% and 90% of total settlement of building if it is to stand on 6m thick layer of clay which extends from ground surface and is under lain by sand.

For 50% settlement (lab)

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

$U = 50\%$

$T_v = 0.197$

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

$H = \frac{2.5}{2} = 1.25$

$C_v = \frac{(1.25)^2(0.197)}{3 \times 60} = 1.71 \times 10^{-3}\ cm^2/s$

$= 0.1026\ cm^2/min$

(For field)

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

~~$U = 90\%$~~
~~$T_v = 0.848$~~

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

$= \frac{(0.197)\left(\frac{6 \times 100}{2}\right)^2}{0.1026} \times \left(\frac{1}{24 \times 60}\right)$

$t = 120 days$

For 90% $t = 519.6$ day

For lab

$U = 80\%$

$T_v = 0.848$

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

$$C_v = \frac{(1.25)^2 (0.848)}{3}$$

$C_v = 0.4417\ cm^2/min$

For field

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

$$= \frac{(6 \times 100/2)^2 (0.848)}{0.4417}$$

$t = 172786.9595$ min

119.99 days

Problem 2

A recently filled up fill was 10m thick and its initial avg void ratio was 1. The fill was loaded on the surface by constructing an embankment covering a large area of the fill. Some months after the construction, measurement of the fill indicated an avg. e = 0.8. Estimate the compression of fill.

$$\Delta H = \frac{\Delta e}{1+e_0} H_0$$

$$= \left(\frac{1.0 - 0.8}{1+1}\right) \times 10 = 1\,m$$

ΔH = compression

Δe = change in e

e_0 = initial void ratio

H_0 = thickness of fill

$\gamma_w = 1 g/cc = 10^{-3} kg/cc$

Prob 3

A strata of normally consolidated clay of thickness 3m is drained on 1 side only. It has K value of 5×10^{-8} cm/s. Coefficient of vol. change $m_v = 125\times10^{-4}$ cm²/kg. Determine value of compression of strata clay by assuming a UDL of 25 tons/m². Also determine the time for 20% and 80% consolidation.

$\Delta P = UDL = 25 \text{ tons}/m^2 = \frac{25\times1000}{(100)^2} kg/cm^2 = 2.5 kg/cm^2$

$S = m_v h \Delta P$ h = thickness

$= 125\times10^{-4} \times 2.5 \times 300 = 9.375$ cm

t for 20% $U = 20\%$, $T_v = 0.032$

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

~~$K = \frac{H^2 T_v}{C_v}$~~

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

$= \frac{5\times10^{-8}}{(125\times10^{-4})(10^{-3})}$

$C_v = 0.004$

Now $t = \frac{H^2 T_v}{C_v} = \frac{(300)^2(0.032)}{0.004}$

$t = 720000$ s

$t = 720000 \left(\frac{1}{60\times60\times24}\right)$

$t = 8$ days

t for 80% $U = 80\%$, $T_v = 0.57$

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

$= \frac{5\times10^{-8}}{(125\times10^{-4})(10^{-3})}$

$C_v = 0.004$

$t = \frac{H^2 T_v}{C_v} = \frac{(300)^2(0.57)}{0.004} \times \left(\frac{1}{60\times60\times24}\right)$

$t = 148.03$ days

15/4/16

Determination of Coefficient of consolidation (Cv) from lab consolidation test.

One by Taylor and other by Casagrande

Although empirical in nature, they are rather simple and expedient, and gives results that are comparable to some developed from th. expressions.

The value of Cv for a particular P increment in the oedometer test can be determined by comparing the characteristics of the exp. and th. consolidation curves, the procedure being referred to as curve fitting. The characteristics of the curves are brought out clearly if time is plotted to a square root or log scale.

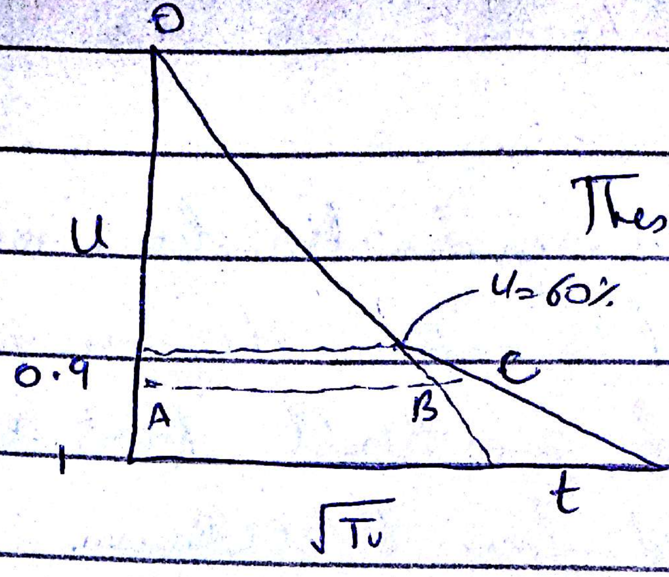
Determination of 'Cv' from lab consolidation test:

→ Taylor's Square root of the

If show the th. characteristic curve b/w ~~th~~ $\sqrt{T_v}$ and (U)

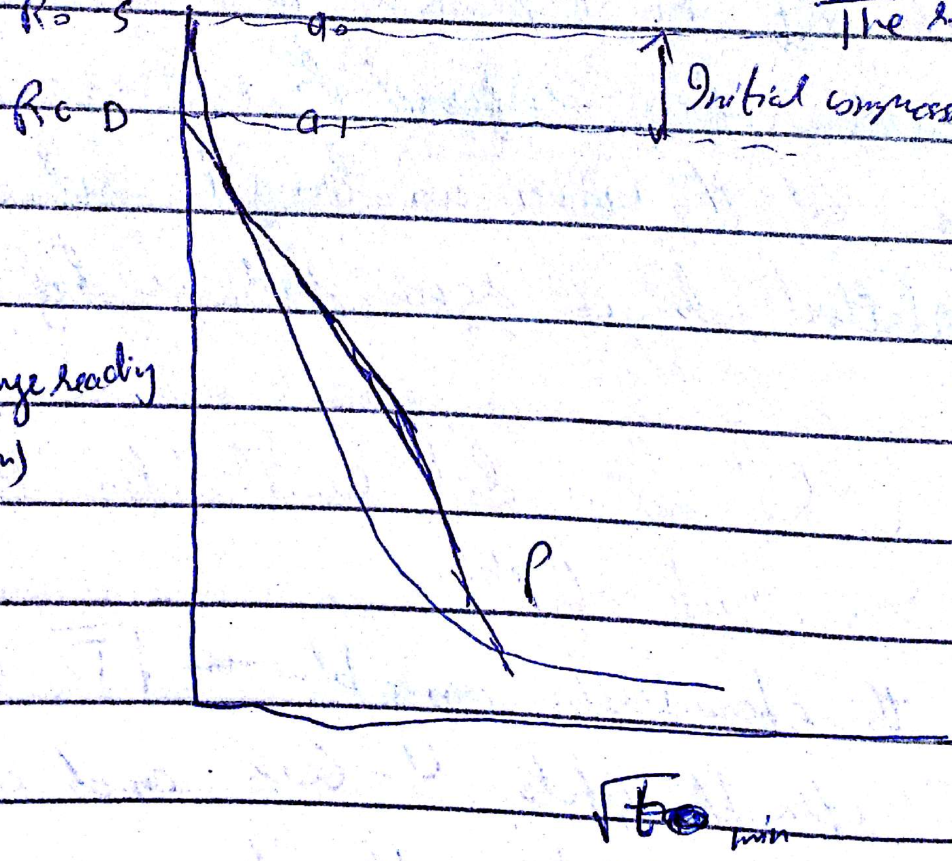
The curve is straight upto U = 60% and abscissa at U = 90% ~~is~~ = 1.15 times the abscissa at U = 60%.

The use of this characteristic of the th. curve to determine the 90% U point on a lab time consolidation curve was suggested by Taylor.



The method consists of drawing the curve b/w root of time √t as absissa and the dial reading 'R' representing the compress of specimen as ordinate, for any P increment in the consolidation test

The root time method



The initial dial Reading R_0 corresponds to the point $t=0$ and $u=0$. The straight portion (line A) is produced back to meet the ordinate at reading R_c, which is called the corrected zero reading and the consolidation b/w R_0 and R_c is called initial consolidation. From R_c, another line 'B' is so drawn that its abscissa at every point is 1.15 times that of line 'A'. The intersection of line 'B' with the consolidation curve gives a point 'P' corresponding to $u = 90\%$ whose dial gauge reading and time may be designated as R_{90} and t_{90} respectively.

If reqd. the point (R_{100}) on the exp. curve corresponding to $u = 100\%$ the limit of primary consolidation, can be obtained by proportion. The coefficient of consolidation is calculated from eq.

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

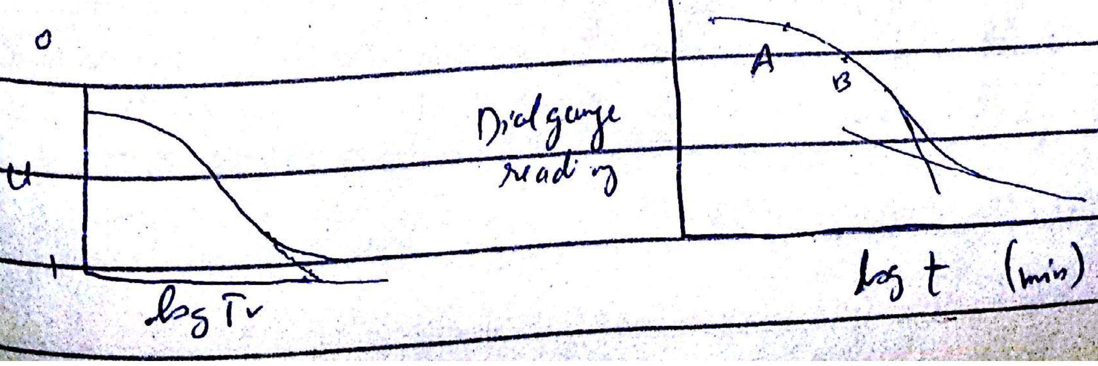
l of drainage path.

t → time for given % of consolidation

The log time Method: (due to casagrande)

Th. curve

log time curve



The exp. curve is obtained by plotting the dial gauge reading in the oedometer test against the log of time in (min)
The theoretical curve is given as the plot of the avg degree of consolidation against the log of the time factor

20/04/16

The log time method, the

th. and exp. The exp. curve is obtained by plotting the dial gauge reading in the oedometer test against the log of time in minutes. The th. curve is given as the plot of avg degree of consolidation against the log of the time pattern The th. curve consists of 3 parts and initial curve which approximates closely to parabolic relationship a part which is linear and a final curve to which the horizontal axis is an ~~isymtope~~ asymptote at U=100%. In the exp. curve the point corresponding U=0 can be determined by using the initial portion (parabolic) of the curve & and selecting two points which are in the ratio of 4:1 and vertical

Determine the vertical distance b/w these 2 points.

An equal distance set of above the 1st point fixes the point AS corresponding to U=0 As a check the procedure should be repeated using diff. pairs of points The point corresponding U=0 will not generally corresponds to point As i.e point of 0 dial gauge reading. The difference btt being due to small quantities of air in the soil The degree of saturation being marginally below 100% This compression is called initial compression.

The final part of exp. curve is linear but not horizontal and the point A_{100} corresponding to $U = 100\%$ is taken as interception of two linear part of the curve. Compression b/w A_S and A_{100} is called primary consolidation. Beyond the point of intersection, compression of the soil continues at a very slow rate for an indefinite period of time and is called secondary compression

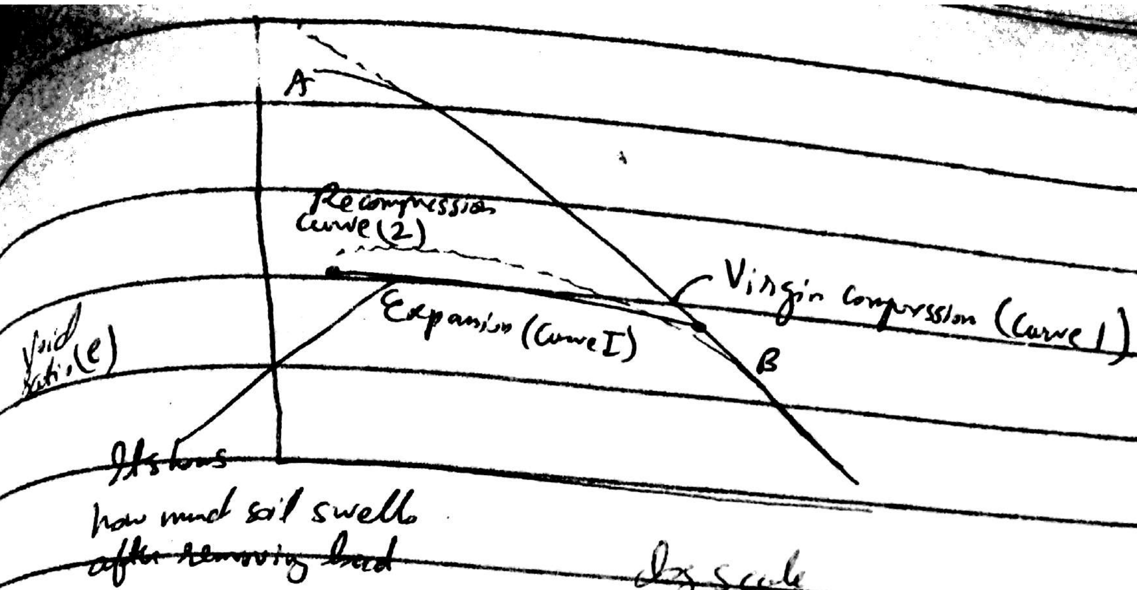
Compression index (C_c) and ~~spell~~ swell index C_s

$$C_c = 0.009(LL - 10)$$

The swell index is appreciably

$$C_s = \frac{1}{5} \text{ to } \frac{1}{10} \times C_c$$

$$= \frac{1}{5} C_c \text{ or } \frac{1}{10} C_c$$



Normally consolidated clays: (NCC)

A clay is said to be normally consolidated if the present effective stress is the max. to which the clay has ever been subjected.

Over consolidated clays: (OCC)

If the effective stress at some time in the past has been greater than the present value.

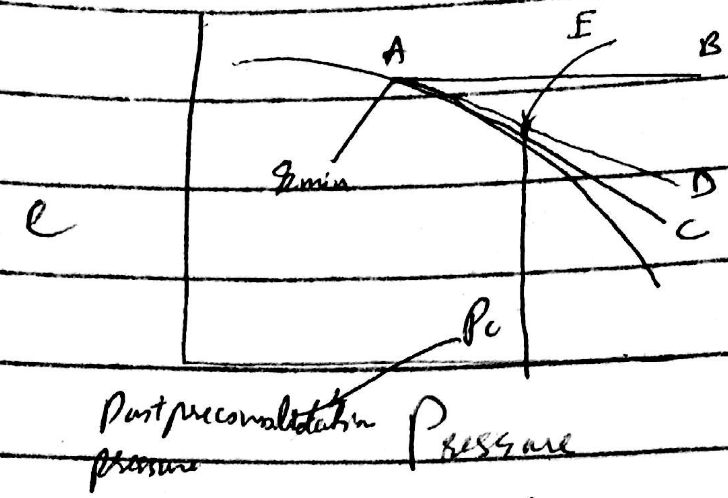
Over consolidation ratio (OCR)

The max. value of effective stress in the past (P_c) divided by present value (P_o) is defined as OCR

$OCR = P_c/P_o$

NCC has $OCR = 1$

OCC has $OCR > 1$



Determining preconsolidation P - A caa

On this curve, the point of max. curvature (min radius) is selected as say A. A horizontal line AB is drawn. A tangent AC is drawn to the curve. A line AD is then drawn bisecting the angle CAB. The straight portion of the curve is extended back to meet the bisector AD at point say E. This point E corresponds to the reqd. preconsolidation pressure pc

A knowledge of this preconsolidation P is often of interest in determining the geological history of soil. It also can be concluded that within the range of recompression, the change of e is small and hence the settlement