THE GATE COACH

Revised Study Material

For GATE – PSU

Civil Engineering

Soil Mechanics

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TABLE OF CONTENTS

Chapter 9

Compression and Consolidation Settlements

A soil mass, however, consists of a number of solid particles, with a number of voids in between them, and containing either air (or gases) or water in them. Hence, when a compressive load is applied to a soil mass, the *negligible elastic compression* **of the solid grains takes place. Along with this negligible elastic compression, much prominent** *compression deformations1* **take place due to:**

(a) Reduction in voids (pore space) *due to expulsion of air* **(or gases). This may be appreciable when pores contain air, but maybe negligible for fully saturated soils;**

(b) Reduction of pore space or voids due to: (i) *expulsion of water;* **(ii)** *plastic flow.*

Deformation due to elastic compression and that due to expulsion of air from voids, take place immediately on application of load, but the deformation due to removal of water or that due to plastic flow take place gradually. Since we are not concerned with the elastic deformation, as it causes very negligible height changes (with no volume changes), as compared to the changes caused by the other two factors, we will for our analysis here, ignore it.

Definition of Compressibility and Its Importance

We have seen above that when a compressive load is applied to a soil mass, then the volume of the soil mass tends to reduce, due to reduction in its voids. Initially, the air is expelled out of the voids, reducing its volume, as happens in *compaction,* **and later on, even water is expelled out of the voids, as happens in** *consolidation.* **The former process takes place under** *short duration loadings,* **and the latter process takes place under long duration loadings')". In both the loadings, however, the volume of the soil mass gets redured; and in other words, we can say that the soil mass gets compressed.** *This property of a soil, due to which it becomes*

'Deformation means change in shape. It may or may not be accompanied by a change in volume. Deformation without the change in volume and which is restored on release of stress is called *elastic deformation;* whereas that which is not restored is called *plastic deformation.* Elastic deformation resulting in change in height (but no change in volume) is called *elastic compression.*'Deformation means change in shape. It may or may not be accompanied by a change in volume. Deformation without the change in volume and which is restored on release of stress is called *elastic deformation;* whereas that which is not restored is called *plastic deformation.* Elastic deformation resulting in change in height (but no change in volume) is called *elastic compression.* We have seen above that when a compressive load is applied to a soil mass, then the volume of the soil mass tends to reduce, due to reduction in its voids. Initially, the air is expelled out of the voids, reducing its volume, as happens in *compaction,* and

later on, even water is expelled out of the voids, as happens in *consolidation.* **The former process takes place under** *short duration loadings,* **and the latter process takes place under long duration loadings')". In both the loadings, however, the volume of the soil mass gets redured ; and in other words, we can say that the soil mass gets compressed.** *This property of a soil, due to which it becomes susceptible to decrease in volume under pressure, is called* **compressibility. It can be indicated "By the change in the volume of the soil per unit increase in pressure.** Soft clays, for example, are highly **compressible,** Theory as Applied to Compressibility Determinations **Let p_0 represents the original stress on the soil mass** *(i.e.* σ_c '**), and** Δp **represents the additional stress. Also assume that** e_Q **is the original void ratio of the soil mass, and let** Δe **is the reduction in the void ratio that occurs after full consolidation takes place due to load** Δp then, $\frac{\Delta e}{\Delta p}$ be a_v. this is also called the coefficient of compression

$$a_\upsilon = \frac{\Delta e}{\Delta p}$$

$$\boxed{\Delta H = m_\upsilon . \Delta p . H_\circ}$$

This equation can be easily used to work out the settlement AH, that takes place with an additional load of Δp **.** m_v **corresponds to the original pressure** p_0 **.** m_v *(i.e. coefficient of volume compressibility),* **sometimes called** compressibility, **is hence** *defined as the compression of the day layer per unit of original thickness due to a unit increase of the pressure.*

The reciprocal of modulus of volume change *(m_v)* **is called the** compression modulus, **and is represented by** E_c. **It has the units of kN/m^2. It is analogous to Young's modulus.**

$$\therefore \qquad E_c = \frac{1}{m_\upsilon}$$

Values of Ec are specified for different kinds of soil. Using E_c in Eq.

$$\Delta H = \frac{1}{E_c} . \Delta p . H_c$$

Compression Index. **We have seen that beyond the range of recompression, the plot of** e **and log** p **is a straight line. The relation between the two** may, **therefore, be expressed as:**

$$\Delta e = e_0 - e = A\ cons\tan t \times \left(\log p - \log p_0\right)$$

Where e_0 and p_0 are the initial void ratio and pressure, and e is the void ratio attained at pressure *p*. **The constant is called the** compression index, **and represented** *by* C_c.

Compression index

$$C_c = \frac{\Delta e}{\Delta \log_{10} p} = \frac{e_\circ - e}{\log_{10} p_\circ} = \frac{e_0 - e}{\log_{10} \frac{p}{p_\circ}}$$

The above equation can be also be written as:

$$\Delta H = \left[\frac{C_c H_0}{(1+e_0)} \cdot \frac{p_0 + \Delta p}{p_0} \right]$$

Hence, the settlement (AH) can be easily determined by the above equation, after computing C_c **from the consolidation test data. Compression index (C_t) can also be roughly estimated more quickly and easily without a consolidation test. and on the knowledge of liquid limit, as the two are empirically related by Terzaghi as:**

(a) for undisturbed clays of normal sensitivity ≯4:

$$C_c = 0.009\left[L.L - 10\right]$$

(b) for remounted clays :

$$C_c = 0.007\left[L.L - 10\right]$$

where $L.L$ = **Liquid limit moisture-content in per cent. Thus, the knowledge of liquid limit alone may enable an approximate estimation of the settlement of a given soil layer due to a given pressure increment.** *C„* **has also been empirically related to the insitu void ratio** *e₀* **by the relation:**

$$C_c = 0.54\left(e_0 - 0.35\right)$$

CONSOLIDATION

.Consolidation Process

When a clayey soil is subjected to a loading, it first of all undergoes a very small compression due to expulsion of air from its voids, if at all it has any. This compression is called the *initial compression.* **If the loading continues, then its volume goes on compressing gradually due to removal of water from the pores. This major compression, which goes on for months and years, is the** *consolidation,* **and strictly called the** *primary consolidation (primary time effect).* **During thisprpcess, thtransfer of load from the soil pores to the soil grains takes place. Due to this gradual transfer of the excess** *hydrostatic pressure* **from the water to the soil solids, a change in the initial structure of the soil mass may occur, which may cause some compression, called the** *secondary compression.* **Secondary compression begins along with primary consolidation at some stage, and becomes more and more important in the later stages. This secondary compression is, however, quite small as compared to the primary consolidation, and hence, for all practical purposes, (where saturated clays are involved), whenever we refer to consolidation, we mean it to be primary consolidation,** *i.e.* **consolidation caused by the removal of water over a long period of time. This** degree of consolidation, U, **at any time** *t* **after the start of consolidation process, can be expressed by the simple relatio**

$$U = \frac{\Delta h}{\Delta H}$$

Where Δh = Compression at any time t

ΔH = Total ultimate compression

Alternatively, **this can be expressed in terms of void ratio, as**

$$U = \frac{e_0 - e}{e_0 - e_f}$$

where e_0 **is the initial void ratio (at the start of consolidation),** e_f **is the final void ratio (at the end of consolidation), and** e **is the void ratio at any time** t. Terzaghi's Theory of Consolidation **where is an important dimensionless factor, called the**Time factor, **and is defined by the relation**

$$T_V \frac{C_V}{d^2}.t$$

Note. In equation d **is the maximum length of the drainage path, and it is thus equal to** $\frac{1}{2}$ **of the layer thickness for a layer draining at both ends, such as in a consolidometer test. Hence if** H **is the total height of the soil sample in consolidometer test, then** $d = H/2$, **in** *Eq.* **However, for a layer draining at one end only,** d **represents the full thickness.**

$U = F(T_v)$ i.e. U is a function of T_V.

In order to determine the degree of consolidation U **at any time** t, **we can first work out** T_v

$$T_v = \frac{\pi}{4}U^2 \quad for\, U \leq 0.6\,(i.e. 60\%)$$

Determining C_v from the Consolidation Test Data. **The value of** C_v **for a particular pressure increment in the consolidometer test, can be determined by comparing the characteristics of the experimental and theoretical consolidation curves. The procedure is, therefore, referred to as** *curve fitting methods.* **Two such methods have been described here,**

Root time method. **In this method, given by Taylor, a theoretical consolidation curve (based on the solution of Terzaghi's one dimensional consolidation equation) is considered. Let it be as shown in An experimental consolidation curve, based on the consolidometer test data (for a particular pressure increment) is also plotted, as a plot between** $V(t_{min})$ **and dial gauge reading (representing compression). This is shown in** *(a)*

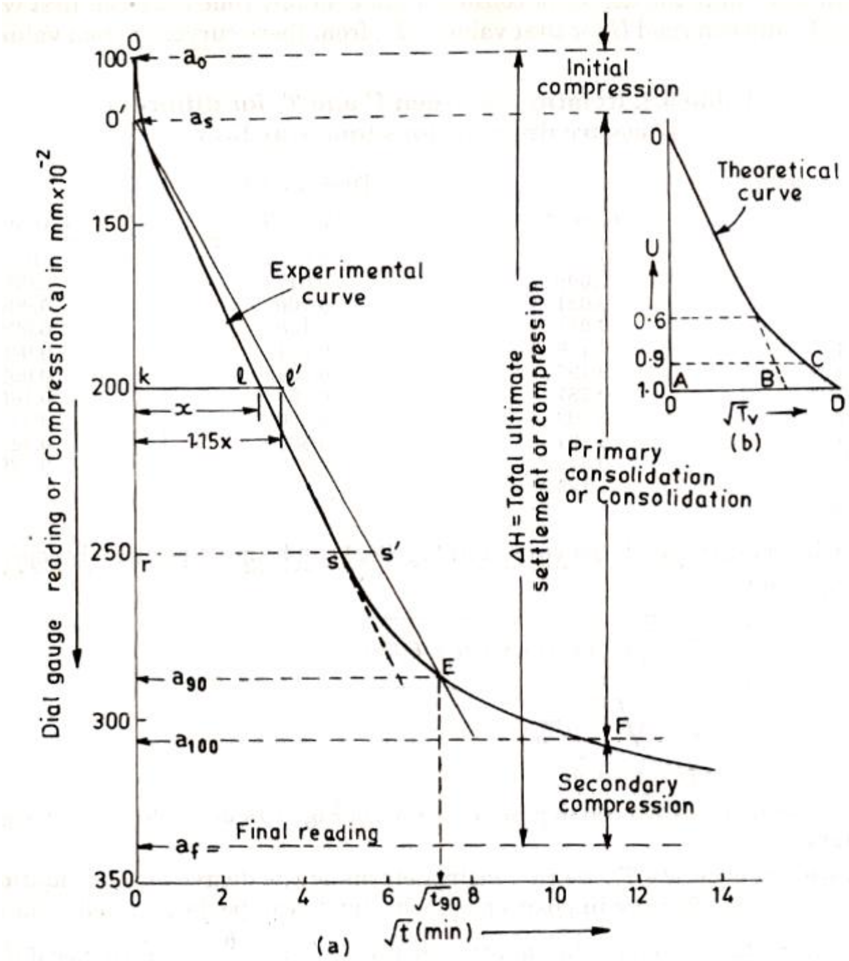
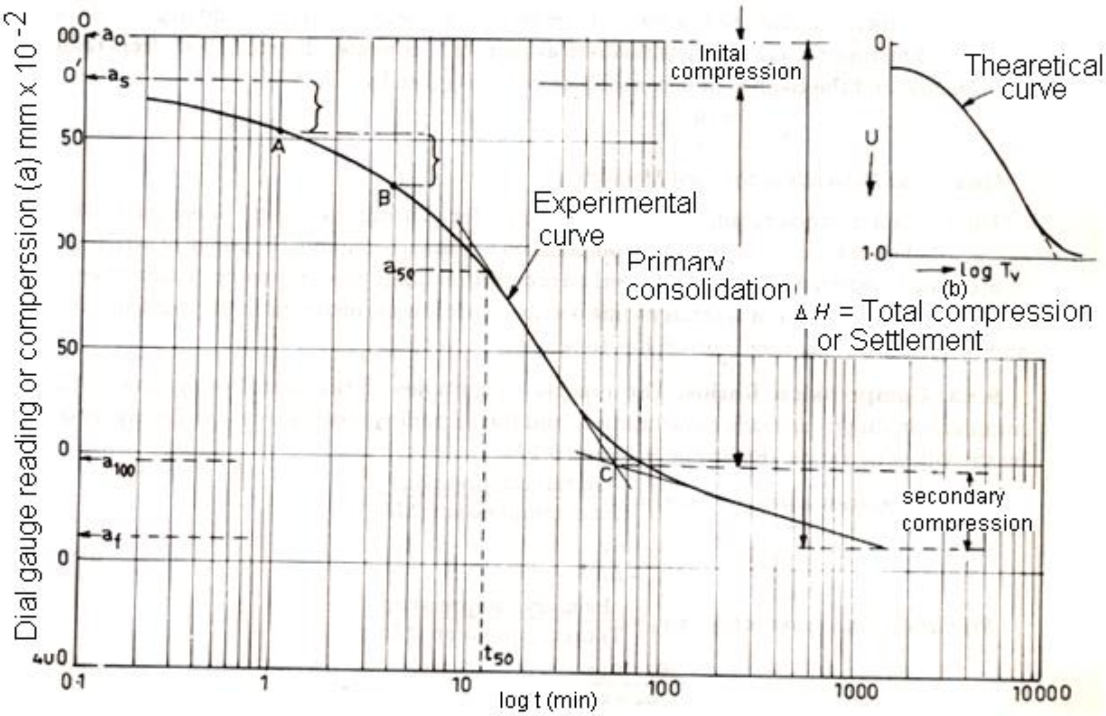


Fig. 9.16. Root time method.

It is seen that the theoretical curve is linear up to about 60% consolidation, represented by Eqand at 90% consolidation; the abscissa (AC) is about 1.15 times the abscissa (AB) of the extension of the linear part of the curve. This characteristic of the theoretical curve is used to determine the point of 90% consolidation on the experiment curve. At 90% consolidation, T_v is found theoretically to be 0.848 from Table or curve I of

$$\therefore \qquad C_v = \frac{0.848d^2}{t_{90}}$$

t_{90} can be read out as explained above from the experimental plot, and d is $H/2$, where H is the sample height in the test. Hence C_u can be determined. If required, the point F on the experimental curve corresponding to U = 100% (*i.e.*, the limit of primary consolidation) can be obtained by proportion. The curve beyond point F represents the secondary compression.



Experimental curve
Log Time Method

Secondary compression ratio = $r_s = \frac{Secondary\ compression}{Total\ compression\ (\Delta H)}$

$$= 1 - [r_0 + r_p]$$