Chapter 7

Consolidation

CHAPTER HIGHLIGHTS

Introduction

In this chapter, the concept on consolidation of soils is discussed. The calculations of final settlement due to consolidation, time taken for occurring final settlement of soil for different drainage conditions and Terzaghi's theory of consolidation is discussed.

Compressibility

The property of the soil due to which a decrease in volume occurs under compressive forces, is known as the compressibility of soil.

In soils, compression takes place due to:

1. Compression of solid particles and water in the voids.
2. Compression and expulsion of air in the voids.
3. Expulsion of water in the voids.
4. Compression of solid particles is negligibly small and compression of water in the voids is also extremely small and negligible.

Consolidation

The compression of soil due to expulsion of water from the voids under a steady static pressure is known as consolidation.

Compaction

Compression of soils as a result of expulsion of air due to dynamic methods, such as rolling and tamping is known as compaction.

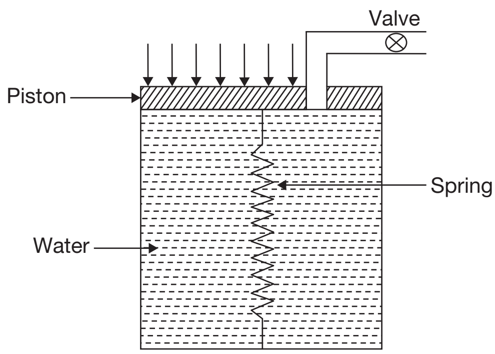
- Settlement of a structure occurs due to the compression of soils below.

Stages of Consolidation

1. **Initial consolidation:** The reduction in volume of a partially saturated soil due to expulsion and compression of air in voids just after the application of load is known as initial consolidation or initial compression.
   - In saturated soil, the initial consolidation is mainly due to compression of solid particles.
2. **Primary consolidation:** The reduction in volume of soil due to the expulsion of water from voids is known as primary consolidation or primary compression.
   - For fine-grained soils, the primary consolidation occurs over a long time, whereas for coarse gained soil, the primary consolidation occurs quickly due to the high permeability.

3. **Secondary consolidation:** The reduction in volume continues at a very slow rate even after primary consolidation due to the expulsion of absorbed water and plastic readjustment of solid particles. Hence, secondary consolidation is also known as secondary compression or creep.

Terzaghi's Spring Analogy for Primary Consolidation



Comparison (simulation)	Model
Soil grains	Spring
Voids and water	Cylinder
Permeability	Valve opening
Effective stress in soil	Load on spring
Excess pore pressure	Load on water

Basic Definitions

1. **Coefficient of compressibility (a_v):** The coefficient of compressibility (a_v) is defined as decrease in void per unit increase in effective stress.
   - It is equal to slope of the e–σ' curve.

$$\boxed{a_v = \frac{-\Delta e}{\Delta\sigma'}}$$

   - The coefficient of compressibility (a_v) has the dimensions of $\left[\frac{L^2}{F}\right]$ and the units are m^2/kN.

2. **Coefficient of volume change (mv):** The coefficient of volume change (or the coefficient of volume compressibility) is defined as the volumetric strain per unit increase in effective stress.

$$\boxed{m_v = \frac{(\Delta v / v_0)}{\Delta\sigma'}}$$

Where

m_v = Coefficient of volume change
V_0 = Initial volume
Δv = Change in volume
$\Delta\sigma'$ = Change in effective stress

- Coefficient of volume change is inverse of the bulk modulus.
- The volumetric strain (Δ_v/V_0) can be expressed in terms of either void ratio or the coefficient of the thickness.

$$\boxed{\frac{\Delta v}{V_0} = \frac{\Delta e}{1+e_0}}$$

- For laterally confined soils,

$$\boxed{\frac{\Delta v}{V_0} = \frac{\Delta H}{H_0}}$$

Where, H_0 = Initial height

$$\boxed{m_v = \frac{-\Delta e/(1+e_0)}{\Delta\sigma'}}$$

and

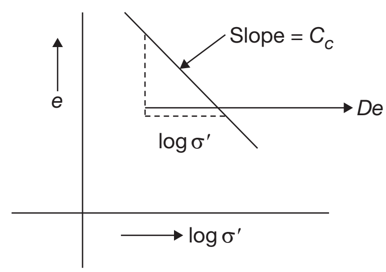
$$\boxed{m_v = \frac{\left(\frac{-\Delta H}{H_0}\right)}{\Delta\sigma'}}$$

Relation between a_v and m_v

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

- The unit of m_v is same as that of a_v.

3. **Compression index (C_c):** The compression index (C_c) is equal to the slope of the linear portion of the void ratio versus log σ' plot.



e-log σ′ plot

$$\boxed{C_c = \frac{-\Delta e}{\log_{10}\left(\frac{\sigma'_f}{\Delta\sigma'_0}\right)};\ C_c = \frac{-\Delta e}{\log_{10}\left(\frac{\sigma'_0 + \Delta\sigma'}{\sigma'_0}\right)}}$$

Where

$\Delta\sigma'$ = Initial effective stress
σ'_f = Final effective stress
Δe = Change in void ratio
$\Delta\sigma'$ = Change in effective stress

- C_c is extremely useful in the determination of settlement in the field.

Terzaghi and peck gave the empirical relation as follows:

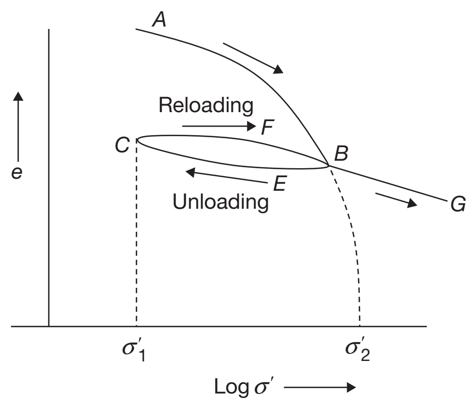
For undisturbed soils,

For remoulded soils,

$$\boxed{\begin{aligned} C_c &= 0.009(w_L - 10) \\ C_c &= 0.007(w_L - 10) \end{aligned}}$$

Where, w_L = Liquid limit in percentage

4. Expansion index:



Loading unloading and reloading plot

- The expansion index or swelling index (c_e) is the slope of e-log σ' plot obtained during unloading. (EBC in the above figure)
- Expansion index is much smaller than compression index.

$$\boxed{C_c = \frac{\Delta e}{\log\left(\dfrac{\sigma' + \Delta\sigma'}{\sigma'}\right)}}$$

5. Recompression index (C_r):

- The slope of the recompression curve obtained during reloading (CFD in the above figure) when plotted as e-log σ' is equal to recompression index (C_r).
- The recompression index is smaller than the compression index.
- It is usually in the range of $\frac{1}{10}$ to $\frac{1}{15}$ of the compression index.

Consolidation Settlement (S_f)

1. $S_f = \Delta H = m_v \cdot H_0 \cdot \Delta\sigma'$
2. $\dfrac{\Delta H}{H_0} = \dfrac{\Delta e}{1 + e_0}$
3. $S_f = \Delta H = \dfrac{C_c}{1 + e_0} H_0 \log_{10}\left(\dfrac{\sigma'_f}{\sigma'_0}\right)$
4. $S_f = \dfrac{C_c}{1 + e_0} H_0 \log_{10}\left(\dfrac{\sigma'_0 + \Delta\sigma'}{\sigma'_0}\right)$

Consolidation of Undisturbed Specimen

1. **Over-consolidated clays:** A soil is said to be over-consolidated if it had been subjected in the past to a pressure in excess of the present pressure.
2. **Normally consolidated clay:** A normally consolidated soil is one which had not been subjected to a pressure greater than the present existing pressure.
3. **Under-consolidated clays:** If the clay deposit has not reached equilibrium under the applied overburden loads, it is said to be under-consolidated. This occurs in areas of recent land fills.

NOTES

1. Normally consolidated soils and over- consolidated soils are not different types of soils, but these are conditions in which a soil exists.
2. The settlements of the structure built on an over-consolidated clay are small due to the smaller compressibility.

Over-consolidation Ratio (OCR)

The maximum pressure to which an over consolidated soil had been subjected in the past divided by the present pressure is known as over-consolidation ratio.

$$\text{OCR} = \frac{\sigma'_c}{\sigma'}$$

OCR > 1 $\Rightarrow$ Over-consolidated clay

OCR = 1 $\Rightarrow$ Normally consolidated clay

OCR < 1 $\Rightarrow$ Under-consolidated clay

Terzaghi's Theory of Consolidation

Assumptions:

1. The soil is homogeneous and isotropic.
2. The soil is fully saturated.
3. The solid particles and water in the voids are incompressible. Consolidation occurs due to expulsion of water from voids.
4. The coefficient of permeability of the soil has the same value at all points, and it remains constant during the entire period of consolidation.
5. Darcy's law is valid throughout the consolidation process.
6. Soil is laterally confined and consolidation takes place only in vertical direction.
7. Coefficient of compressibility and coefficient of volume change are constant.

Differential Equation of Consolidation

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

- The above equation gives the distribution of excess pressure $\bar{U}$ with depth z and time 't'.

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

Where

K = Coefficient of permeability (m/s)

m_v = Coefficient of volume change

- Units of C_v are m^2/s or cm^2/s. Solution of the differential equation (above) gives three non-dimensional parameters. These are as follows:
  - The first is Z/H. It is related to the location of the point of which consolidation is considered. Here, 'H' is the maximum length of drainage path.
  - The second is the consolidation ratio or degree of consolidation (U). It indicates the extent of dissipation of the hydrostatic excess pressure in relation to the initial value.

Degree of Consolidation (U)

$$\boxed{U = \frac{(\bar{U}_i / \bar{U})}{\bar{U}_i} \times 100}$$

$$U = \left(\frac{\text{Settlement at any time}}{\text{Ultimate settlement}}\right) \times 100$$

$$U = \frac{S}{S_f} \times 100$$

- The third-dimensionless parameter, relating to time is called 'time factor'.

Time factor, $\boxed{T_v = \frac{C_V t}{d^2}}$

Where

C_v = The coefficient of consolidation

d = The drainage path

$d = H$ for single drainage (half-closed layer)

$= \frac{H}{2}$ for double drainage (double layer)

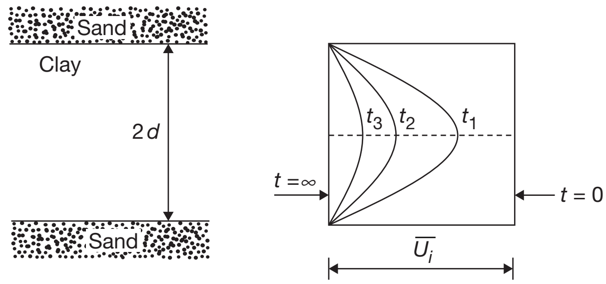
t = Time for consolidation

$$\boxed{\text{For } U \le 60\%,\ T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2}$$

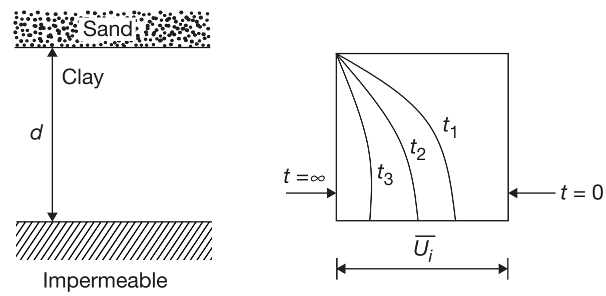
$$\boxed{\text{For } U > 60\%,\ \text{TV} = 1.781 - 0.933 \log_{10}(100 - U\%)}$$

Isochrones

- The curves indicating the distribution of excess hydrostatic pressure are known as isochrones.
- The hydraulic gradient (i) at any depth is equal to the slope of isochrone at that point.
- The following figures show the distribution of isochrones for open layer (drainage on both top and bottom) and half-closed layer (if only one boundary of clay layer is free draining).



(a) Open layer



(b) Half closed layer

Determination of Coefficient of Consolidation

The following two methods are commonly used.

1. **Square root of time fitting method:**
   - The method devised by Taylor, utilizes the theoretical relationship between and U and $\sqrt{T_v}$.
   - It is more suitable for soils exhibiting high level of secondary consolidation.
   - The value of coefficient of consolidation of soil is obtained from the value of $\sqrt{t_{90}}$ obtained from the plot.

   For $U = 90\%$, $T_v = 0.848$

$$\boxed{C_v = \frac{0.848 d^2}{\left(\sqrt{t_{90}}\right)^2}}$$

2. **Logarithm of time method:**
   - This method was given by Casagrande, the theoretical curve between U and log T_v.

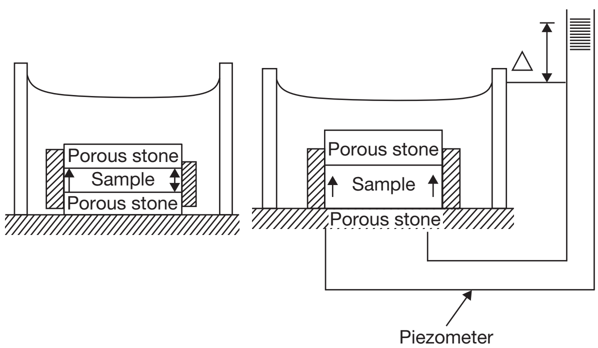
- The value of coefficient of consolidation of soil is obtained from the value of t_{50}.

  For $U = 50\%$, $T_v = 0.196$

$$\boxed{C_v = \frac{0.196d^2}{t_{50}}}$$

Consolidation Test

- The test is performed in consolidation test apparatus known as the consolidometer or an oedometer.
- Consolidometer consists of a loading device and a cylindrical container known as consolidation cell.
- Consolidation cell are of two types:
  - (a) Floating or free ring cell in which top and bottom porous stones are free to move.
  - (b) Fixed ring cell in which only the top porous stone can move while bottom the porous stone cannot move.



(a) Floating ring type (b) Fixed ring type

Determination of Void Ratio at Load Increment

1. **Height of solids method:** This method is applicable to both saturated and unsaturated soils.

$$\boxed{\begin{aligned} e_0 &= \frac{H - H_s}{H_s} \\ H_s &= \frac{W_d}{G\gamma_w \cdot A} \end{aligned}}$$

Where

H_s = Height of solids

W_d = Weight of dry soil

G = Specific gravity of solids

A = Cross-sectional area of specimen

H = Total height

e_0 = Initial void ratio

Void ratio at any stage

H_f = Final thickness of soil = $H - \Delta H$

ΔH = Change in thickness of sample

2. **Change in void ratio method:** Applicable for saturated soils only

$$\boxed{\frac{\Delta e}{1 + e_f} = \frac{\Delta H}{H_f}}$$

e_f = Final void ratio

3-D consolidation equation: The general equation for three-dimensional consolidation is:

$$\frac{\partial \overline{U}}{\partial t} = C_{vx}\frac{\partial^2 \overline{U}}{\partial x^2} + C_{vy}\frac{\partial^2 \overline{U}}{\partial y^2} + C_{vz}\frac{\partial^2 \overline{U}}{\partial z^2}$$

Immediate Settlement (S_i)

- It is also known as elastic settlements.
- It occurs in all highly-permeable soils and, also occurs in fine-grained soils.

  Immediate settlement:

$$\boxed{S_i = \frac{q_n}{E_s} B(1 - \mu^2) I}$$

Where

q_n = Net intensity of contact pressure (kN/m^2).

B = Least lateral dimension of loaded area (m).

E_s = Undrained modulus of elasticity (kN/m^2).

I = Influence factor, depends on rigidity shape of loaded area, L/B ratio.

μ = Poison's ratio of soil.

Exercises

1. The slope of the e-log p curve for a soil mass gives
   (A) coefficient of permeability, k.
   (B) coefficient of consolidation C_V.
   (C) compression index, C_C.
   (D) coefficient of volume compressibility, m_v.

2. Sand drains are used to
   (A) reduce the settlement.
   (B) accelerate the consolidation.
   (C) increase the permeability.
   (D) transfer the load.

3. Consolidation in soils
(A) is a function of the effective stress.
(B) does not depend on the present stress.
(C) is a function of the pore water pressure.
(D) is a function of the total stress.

4. A double draining clay layer; 6 m thick, settles by 30 mm in three years under the influence of a certain loads. Its final consolidation settlement has been estimated to be 120 mm. If a thin layer of sand having negligible thickness is introduced at a depth of 1.5 m below the top surface, the final consolidation settlement of clay layer will be
(A) 60 mm (B) 120 mm
(C) 240 mm (D) None of these

5. Root time method is used to determine
(A) T, time factor.
(B) C_V, coefficient of consolidation.
(C) a_v, coefficient of compressibility.
(D) m_v, coefficient of volume compressibility.

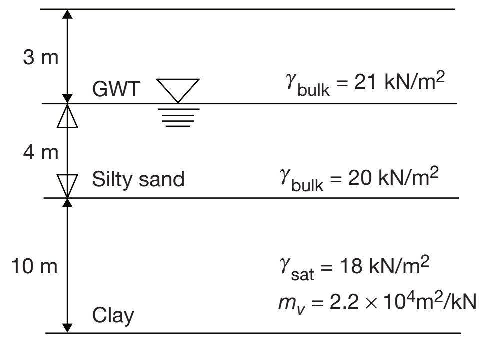
6. The time for a clay layer to achieve 90% consolidation is 15 years. The time required to achieve 90% consolidation, if the layer were twice as thick, 3 times more permeable and 4 times more compressible would be
(A) 70 years (B) 75 years
(C) 80 years (D) 85 years

7. A building is constructed on the ground surface beneath which, there is a 2 m thick saturated clay layer sandwiched between two highly previous layers. The building starts settling with time. If the average coefficient of consolidation of clay is 2.5×10^{-4} cm²/s, in how many days will the building reach half of its final settlement? ($T_{50} = 0.197$)

8. Identify the two FALSE statements from the following four statements:
I. The consolidation of soil happens due to the change in total stress.
II. When standard penetration test are performed in fine sands below the water table, the dilation correction is applied after the overburden correction is applied.
III. Over consolidated clays will have predominantly cohesive strength as compared to the frictional strength.
IV. Compaction of soils is due to expulsion of water.
(A) II and III (B) I and IV
(C) I and III (D) II and IV

9. The time for a clay layer to achieve 85% consolidation is 10 years. If the layer was half as thick, 10 times more permeable and 4 times more compressible then the time that would be required to achieve the same degree of consolidation is
(A) 1 year (B) 5 years
(C) 12 years (D) 16 years

10. At a reclamation site for which the soil strata is shown in the figure, a 3 m thick layer of a fill material is to be laid instantaneously on the top surface. If the coefficient of volume compressibility, m_v for clay is 2.2×10^{-4}/kN, the consolidation settlement of the clay layer due to placing of fill material will be



(A) 69.5 mm (B) 139 mm
(C) 228 mm (D) 278 mm

11. A 6 m thick clay undergoes 90% consolidation four times faster under two way drainage as compared to one way drainage. In an identical clay layer of 15 m thickness, two way drainage will be faster as compared to one way drainage by
(A) 8 times
(B) 4 times
(C) 2.5 times
(D) 2 times

12. The change that take place during the process of consolidation of a saturated clay would include
(A) an increase in pore water pressure and an increase in effective pressure.
(B) an increase in pore water pressure and a decrease in effective pressure.
(C) a decrease in pore water pressure and a decrease in effective pressure.
(D) a decrease in pore water pressure and an increase in effective pressure.

13. Match List I and List II and select the correct answer using the codes given below the lists (notations have their usual meaning):

	List I		List II
a.	Coefficient of compressibility	**1.**	m_v
b.	Compression index	**2.**	$C_V t/H2$
c.	Time factor	**3.**	a_v
d.	Coefficient of volume compressibility	**4.**	Soil with high organic content with high compressibility

Codes:

	a	b	c	d
(A)	3	2	4	1
(B)	1	2	4	3
(C)	1	4	2	3
(D)	3	4	2	1

14. In soil consolidation process, the following events take place after loading:

I. Decrease in excess pore pressure.
II. Increase in total stress.
III. Development of excess pore pressure.
IV. Increase in effective stress.

The correct sequence of these events is

(A) III, II, I, IV
(B) II, III, I, IV
(C) II, III, IV, I
(C) III, II, IV, I

15. Match List I (Unit/Test) with List II (Purpose) and select the correct answer using the codes given below the lists:

	List I		List II
a.	Casagrande's apparatus	**1.**	Determination of grain size distribution
b.	Hydrometer	**2.**	Consolidation characteristics
c.	Plate load test	**3.**	Determination of consistency limits
d.	Oedometer	**4.**	Determination of safe bearing capacity of soil

Codes:

	a	b	c	d		a	b	c	d
(A)	1	3	2	4	(B)	1	3	4	2
(C)	3	1	2	4	(D)	3	1	4	2

16. If the time required for 60% consolidation of a remoulded soil sample of clay with single drainage is 't', then what is the time required to consolidate the same sample of clay with the same degree of consolidation but with double drainage?

(A) $4t$
(B) $2t$
(C) $\frac{t}{2}$
(D) $\frac{t}{4}$

17. In a consolidation test the sample tested has height H; water content is w; specific gravity of solid G. After increasing the loading by an increment Δp, the height decrease is ΔH. Which one of the following expresses the corresponding change in void ratio Δe?

(A) $\Delta e = \dfrac{\Delta H}{H(1+wG)}$

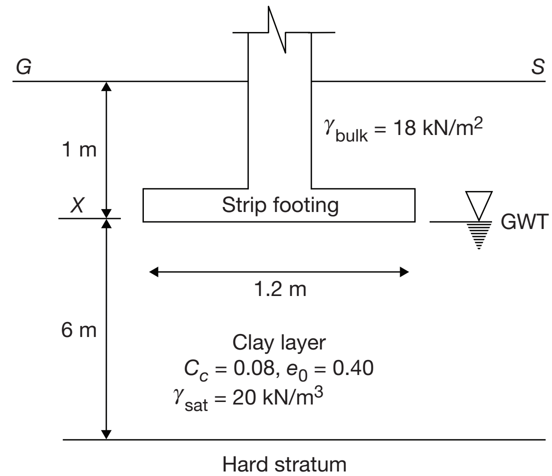
(B) $\Delta e = \dfrac{\Delta H(1+wG)}{H}$

(C) $\Delta e = \dfrac{H(1+wG)}{\Delta H}$

(D) $\Delta e = \dfrac{H}{\Delta H(1+wG)}$

Direction for questions 18 and 19:

Figure shows the geometry of a strip footing supporting the load bearing walls of a three storied building and the properties of clay layer



18. If the pressure acting on the footing is 40 kPa, the consolidation settlement of the footing will be

(A) 0.89 mm
(B) 8.9 mm
(C) 89.0 mm
(D) None of these

19. If the elastic modulus and the Poisson's ratio of the clay layer are 50×10^3 kPa and 0.4 respectively and if the influence factor for the strip footing is 1.75, the elastic settlement of the footing will be

(A) 0.41 mm
(B) 1.41 mm
(C) 14.1 mm
(D) None of these

Direction for questions 20 and 21:

The average effective overburden pressure on 10 m thick homogeneous saturated clay layer is 150 kPa. Consolidation test on an undisturbed soil sample taken from the clay layer showed that the void ratio decreased from 0.6 to 0.5 by increasing the stress intensity from 100 kPa to 300 kPa ($G = 2.65$)

20. The initial void ratio of the clay layer is

(A) 0.209
(B) 0.563
(C) 0.746
(D) 1.00

21. The total consolidation settlement of the clay layer due to the construction of a structure imposing an additional stress intensity of 200 kPa is

(A) 0.10 m
(B) 0.25 m
(C) 0.35 m
(D) 0.50 m

22. The soil which is compacted to the dry of optimum has

(A) low swelling.
(B) low shear strength.
(C) high swelling.
(D) None of these

23. During consolidation process
(A) effective pressure on soil decreases.
(B) void ratio increases.
(C) degree of saturation remains same.
(D) excess hydrostatic pressure increases.

24. The compactive effort in the modified proctor test is about ________ times than that of the standard proctor test.
(A) 4.85 (B) 4.65
(C) 4.25 (D) 4.55

25. The sensitivity of soil indicates the
(A) moisture holding capacity of soil.
(B) shear strength of the soil.
(C) consolidation of soil.
(D) weakening due to remolding of soil.

26. A cohesive soil yield a maximum dry density of 1.4 g m/cc at OMC of 16% during a standard proctar test. If the value of $G = 2.65$, then degree of saturation of the soil is
(A) 1.23 (B) 1.86
(C) 1.43 (D) 1.69

27. A saturated clay of 6 m thick takes 1.6 years for 50% primary consolidation when drained on both sides. Its coefficient of volume charge is 1.5×10^{-3} m^2/kN. The coefficient of permeability of soil will be
(A) 0.013 m/year
(B) 0.016 m/year
(C) 1.58 m/year
(D) 2.54 m/year

28. A 5 m thick clay has coefficient of consolidation 0.025 cm^2/min and final settlement 10 cm. The time required for 80% of settlement to occur is

U	T_v
80%	0.567
25%	0.078

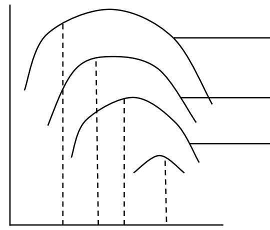
(A) 5.6×10^6 minutes (B) 6.5×10^6 minutes
(C) 7.5×10^6 minutes (D) 5.8×10^6 minutes

29. Time required for 2.5 cm settlement is
(A) 7.5×10^5 minutes (B) 7.8×10^5 minutes
(C) 7.6×10^5 minutes (D) 7.2×10^5 minutes

30. With the increase of water content incompaction the maximum dry density will
(A) increase.
(B) decrease.
(C) first increase and then decrease.
(D) first decrease and then increase.

31. Which of the following property increases with increase in compaction
(A) permeability
(B) shear strength
(C) void ratio
(D) compressibility

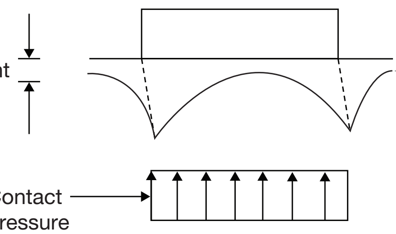
32.



The type of soil present at Q is
(A) high plastic clay. (B) high plastic silt.
(C) low plastic clay. (D) poorly graded soil.

33. When the OCR = 1 then the type of clay is known as
(A) over consolidated clay.
(B) normal consolidated clay.
(C) under consolidation clay.
(D) None of these

34. The following figure represents the contact pressure distribution underneath a



(A) rigid footing on sand.
(B) flexible footing on clay.
(C) flexible footing on sand.
(D) rigid footing on clay.

35. A footing carries a load of 1200 tonnes and is of 3.2 m square. It rests in dense sand of 8 m thickness overlaying a clay layer of 2.8 m. The clay layer overlies hard rock. The depth of foundation is 1.5 m liquid limit of clay is 48% and void is 0.95. The saturated unit weight of sand and clay are given as 1.86t/m^3 and 1.76t/m^3 respectively Take the load distribution as $2V$ to $1H$. Assume that the site is flooded and determine the ultimate settlement due to consolidation of clay layer.
(A) 150 mm (B) 170 mm
(C) 190 mm (D) 210 mm

36. If a clay test specimen of 25 mm thick, under double drainage condition attained 50% of primary consolidation in 50 minutes. How long will it take for the same clay layer of 10 m thick to reach the same degree of consolidation under the condition that 'clay is drained on the top surface only'.
(A) 15.4 years (B) 61.7 years
(C) 85.6 years (D) None of these

37. In a Newmarks influence chart for stress distribution, there are 12 concentric circles and 40 radial lines. The influence factor of the chart is ________.
(A) 0.002 (B) 0.02
(C) 0.2 (D) 0.0002

38. The time for a clay layer to achieve 60% consolidation is 8 years. If the layer was half as thick, 10 times more permeable and 3 times more compressible then the time that would be required to achieve the same degree of consolidation is _______.

(A) 0.6 year (B) 1 year
(C) 5 years (D) 1.5 years

39. Consider the following statements.

I. The optimum moisture content is expected to be more for the tests with lesser energy.
II. The maximum dry density is expected to be more for the tests with higher energy.
III. Clayey soil has more optimum moisture content than sandy soils.

Which of the following statements are correct?

(A) I, II and III are correct
(B) I and II are correct
(C) II and III are correct
(D) I and III are correct

40. The change in voids ratio due to increase in effective stress by 1.2 kg/cm^2 is 0.20. Initial void ratio is 0.4. The thickness of soil stratum is 5 m. Consolidation settlement in 'cm' is ________.

(A) 30 cm
(B) 50 cm
(C) 70 cm
(D) 10 cm

41. The time taken for a clay layer to achieve 90% consolidation is 15 years. The time required to achieve 90% consolidation, if the layer was twice as thick, 3 times more permeable and 4 times more compressible would be _______.

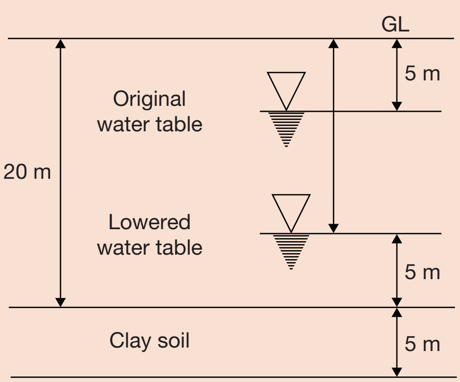
(A) 75 years (B) 120 years
(C) 80 years (D) 140 years

Previous Years' Questions

Direction for questions 1 and 2:

The ground conditions at a site are as shown in the figure. The water table at the site which was initially at a depth of 5 m below the ground level got permanently lowered to a depth of 15 m below the ground level due to pumping of water over a few years. Assume the following data

I. Unit weight of water = 10 kN/m^3
II. Unit weight of sand above water table = 18 kN/m^3
III. Unit weight of sand and clay below the water table = 20 kN/m^3.
IV. Coefficient of volume compressibility = 0.25 m^2/MN. **[GATE, 2007]**



1. What is the change in the effective stress in kN/m^2 at mid-depth of the clay layer due to the lowering of the water table?

(A) 0
(B) 20
(C) 80
(D) 100

2. What is the compression of the clay layer in mm due to the lowering of the water table?

(A) 125 (B) 100
(C) 25 (D) 0

3. A saturated clay stratum draining both at the top and bottom undergoes 50 per cent consolidation in 16 years under an applied load. If the additional drainage layer were present at the middle of the clay stratum, 50 per cent consolidation would occur in **[GATE, 2008]**

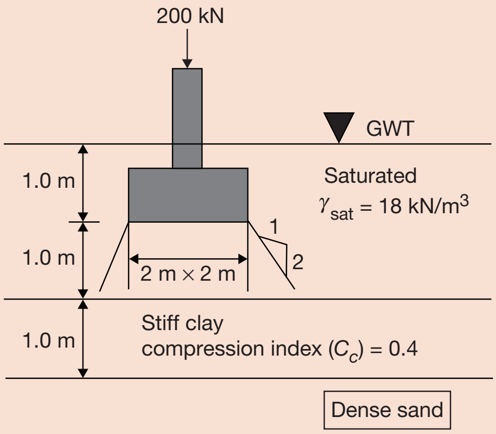
(A) 2 years
(B) 4 years
(C) 8 years
(D) 16 years

Direction for questions 4 and 5:

4. A saturated undisturbed sample from a clay strata has moisture content of 22.22% and specific gravity of 2.7. Assuming γ_w = 10 kN/m^3, the void ratio and the saturated unit weight of the clay, respectively are **[GATE, 2009]**

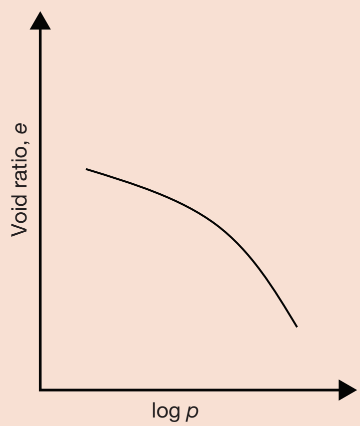
(A) 0.6 and 16.875 kN/m^3
(B) 0.3 and 20.625 kN/m^3
(C) 0.6 and 20.625 kN/m^3
(D) 0.3 and 16.975 kN/m^3

5. Using the properties of the clay layer derived form the above question, the consolidation settlement of the same clay layer under a square footing neglecting its self weight with additional data shown in the figure (assume the stress distribution as 1H : 2V from the edge of the footing and γ_w = 10 kN/m^3) is **[GATE, 2009]**



(A) 32.78 mm
(B) 61.75 mm
(C) 79.5 mm
(D) 131.13 mm

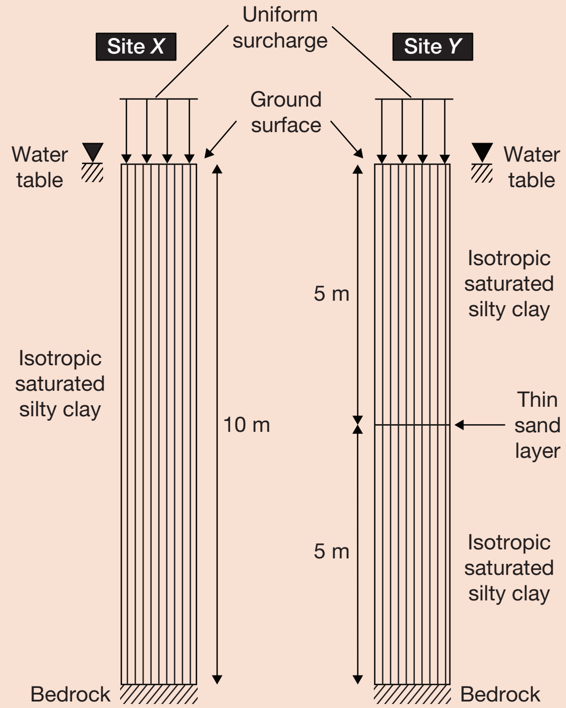
6. The *e*-log *p* curve shown in the figure is representative of **[GATE, 2010]**



(A) normally consolidated clay.
(B) over consolidated clay.
(C) under consolidated clay.
(D) normally consolidated clayey sand.

7. Identical surcharges are placed at ground surface at sites *X* and *Y*, with soil conditions shown alongside and water table at ground surface. The silty clay layers at *X* and *Y* are identical. The thin sand layer at *Y* is continuous and free draining with a very large discharge capacity. If primary consolidation at *X* is estimated to complete in 36 months, what would be the corresponding time for completion of primary consolidation at *Y*?

[GATE, 2011]



(A) 2.25 months (B) 4.5 months
(C) 9 months (D) 36 months

8. A layer of normally consolidated, saturated silty clay of 1 m thickness is subjected to one dimensional consolidation under a pressure increment of 20 kPa. The properties of the soil are: specific gravity = 2.7, natural moisture content = 45%, compression index = 0.45, and recompression index = 0.05. The initial average effective stress within the layer is 100 kPa. Assuming Terzaghi's theory to be applicable, the primary consolidation settlement (rounded off to the nearest mm) is **[GATE, 2012]**

(A) 2 (B) 9
(C) 14 (D) 16

9. The following data are given for the laboratory sample

$\sigma_0^1 = 175$ kPa; $e_0 = 1.1$;

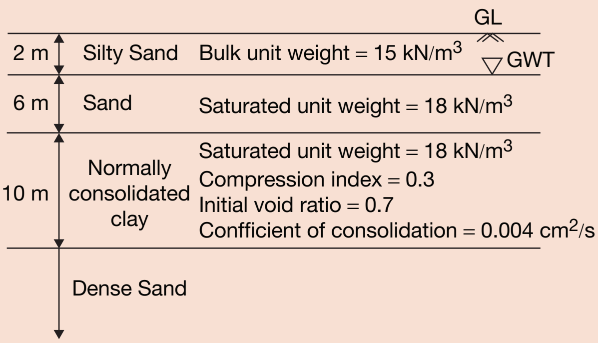
$\sigma_0^1 + \Delta\sigma_0^1 = 300$ kPa, $e = 0.9$

It thickness of the clay specimen is 25 mm, the value of coefficient of volume compressibility is ____ $\times 10^{-4}$ m^2/kN **[GATE, 2014]**

10. A circular raft foundation of 20 m diameter and 1.6 m thickness is provided for a tank that applies a bearing pressure of 110 kPa on sandy soil with Yound's modulus, E_S = 30 MPa and Poisson's ratio, μ_s = 0.3. The raft is made of concrete (E_c = 30 GPa and μ_c = 0.15) considering the raft as rigid, the elastic settlement (in mm) is **[GATE, 2014]**

(A) 50.96 (B) 53.36
(C) 63.72 (D) 66.71

11. A water tank is to be constructed on the soil deposit shown in the figure below. A circular footing of diameter 3 m and depth of embedment 1 m has been designed to support the tank. The total vertical load to be taken by the footing is 1500 kN. Assume the unit weight of water as 10 kN/m^3 and the load dispersion patter as 2V:1H. The expected settlement of the tank due to primary consolidation of the clay layer is ________ mm. **[GATE, 2015]**



12. A 20 m thick clay layer is sandwiched between a silty sand layer and a gravelly sand layer. The layer experiences 30 mm settlement in 2 years.

Given:

$$T_y = \begin{cases} \frac{\pi}{4}\left(\frac{U}{100}\right) & \text{for } U \le 60\% \\ 1.781 - 0.933\log_{10}(100-U) & \text{for } U > 60\% \end{cases}$$

where T_v is the time factor and U is the degree of consolidation in %.

If the coefficient of consolidation of the layer is 0.003 cm^2/s, the deposit will experience a total of 50 mm settlement in the next ________ years. **[GATE, 2015]**

13. A 4 m thick layer of normally consolidated clay has an average void ratio of 1.30. Its compression index is 0.6 and coefficient of consolidation is 1 m^2/year. If the increase in vertical pressure due to foundation load on the clay layer is equal to the existing effective overburden pressure, the change in the thickness of the clay layer is ________ mm. **[GATE, 2015]**

14. In the consolidated undrained triaxial test on a saturated soil sample, the pore water pressure is zero **[GATE, 2016]**

(A) during shearing stage only.
(B) at the end of consolidation stage only.
(C) both at the end of consolidation and during shearing stages.
(D) Under none of the above conditions

15. An undisturbed soil sample was taken from the middle of a clay layer (i.e., 1.5 m below GL), as shown in the figure. The water table was at the top of clay layer. Laboratory test results are as follows: **[GATE, 2016]**

Natural water content of clay	25%
Preconsolidation pressure of clay	60 kPa
Compression index of clay	0.50
Recompression index of clay	0.05
Specific gravity of clay	2.70
Bulk unit weight of sand	17 kN/m^3

A compacted fill of 2.5 m height with unit weight of 20 kN/m^3 is placed at the ground level.

Assuming unit weight of water as10 kN/m^3, the ultimate consolidation settlement (expressed in mm) of the clay layer is ____________.

16. The relationship between the specific gravity of sand (G) and the hydraulic gradient (i) to initiate quick condition in the sand layer having porosity of 30% is **[GATE, 2016]**

(A) $G = 0.7i + 1$ (B) $G = 1.43i - 1$
(C) $G = 1.43i + 1$ (D) $G = 0.7i - 1$

Answer Keys

Exercises

1. C	**2.** B	**3.** A	**4.** B	**5.** B	**6.** C	**7.** 91.2		**8.** B	**9.** A
10. B	**11.** B	**12.** D	**13.** D	**14.** B	**15.** D	**16.** D	**17.** B	**18.** C	**19.** B
20. B	**21.** D	**22.** C	**23.** C	**24.** D	**25.** D	**26.** D	**27.** B	**28.** A	**29.** B
30. B	**31.** C	**32.** B	**33.** B	**34.** C	**35.** B	**36.** B	**37.** A	**38.** A	**39.** A
40. C	**41.** C								

Previous Years' Questions

1. C	**2.** B	**3.** B	**4.** C	**5.** B	**6.** B	**7.** C	**8.** D	**9.** 7.62	**10.** B
11. 53.23	**12.** 4.43	**13.** 314	**14.** B	**15.** 36.7	**16.** C				