QUIZ GT106
Soil Compressibility and Consolidation

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► PROBLEMS

PROBLEM 1

Which of the following is *not* an assumption in the derivation of Terzaghi's theory of one-dimensional consolidation?

A) The clay-water system is homogeneous.

B) The flow of water is two-dimensional.

C) Compressibility of water and soil grains is negligible.

D) The soil is fully saturated.

PROBLEM 2

When the total pressure acting at midheight of a consolidating layer is 200 kN/m^2, the corresponding void ratio of the clay is 0.98. When the total pressure acting at the same location is 500 kN/m^2, the corresponding void ratio decreases to 0.81. Find the void ratio of the clay if the total pressure acting at midheight of the consolidating layer is 1000 kN/m^2.

A) e = 0.48

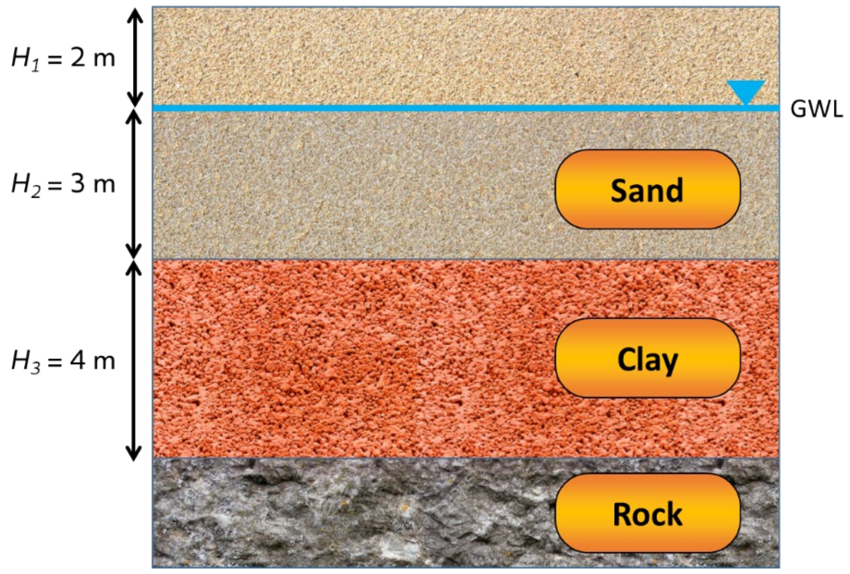
B) e = 0.58

C) e = 0.68

D) e = 0.78

PROBLEM 3A

Consider the soil profile shown in the following figure. The soil is subjected to an uniformly distributed load $\Delta\sigma$ = 31.1 kN/m^2 on the ground surface. The sand is such that γ_d = 16.5 kN/m^3 and $\gamma_{sat,sand}$ = 19.3 kN/m^3; the underlying clay has $\gamma_{sat,clay}$ = 20.5 kN/m^3, LL = 38, e_o = 0.89, and C_s = 0.25C_c. Depths H_1, H_2, and H_3 are as shown. Determine the primary consolidation displacement of the normally consolidated clay layer.



A) ρ_s = 60.2 mm
B) ρ_s = 73.8 mm
C) ρ_s = 86.2 mm
D) ρ_s = 99.8 mm

PROBLEM 3B

Determine the primary consolidation for the clay layer specified in the previous problem if it had a preconsolidation pressure σ_c' = 95 kN/m^2.

A) ρ_s = 23.4 mm
B) ρ_s = 33.3 mm
C) ρ_s = 40.2 mm
D) ρ_s = 50.1 mm

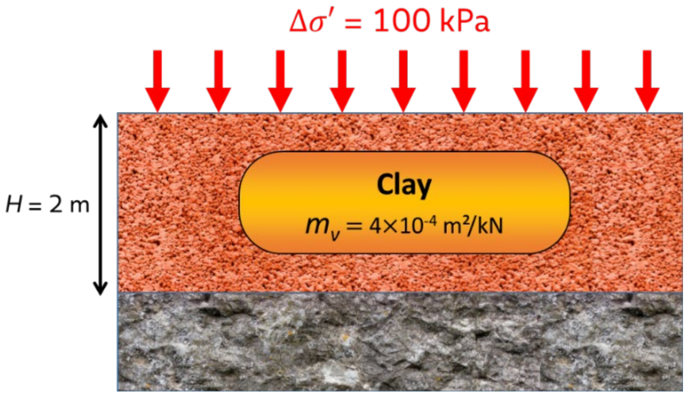
PROBLEM 3C

Refer to the soil introduced in Problem 3A. Given the coefficient of consolidation c_v = 0.24 cm^2/sec, how long will it take for 75% consolidation to be over in the field?

A) t = 221 days
B) t = 305 days
C) t = 385 days
D) t = 461 days

PROBLEM 4

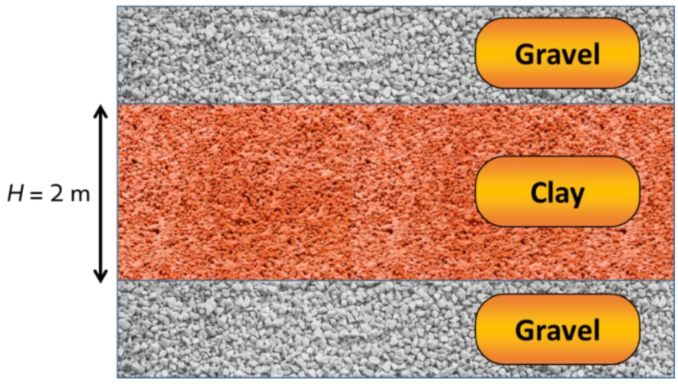
A vertical section through a building foundation at a site is shown below. The average modulus of volume compressibility of the clay is m_v = 4×10^{-5} m^2/kN. Determine the primary consolidation settlement.



A) ρ_s = 20 mm
B) ρ_s = 40 mm
C) ρ_s = 60 mm
D) ρ_s = 80 mm

PROBLEM 5

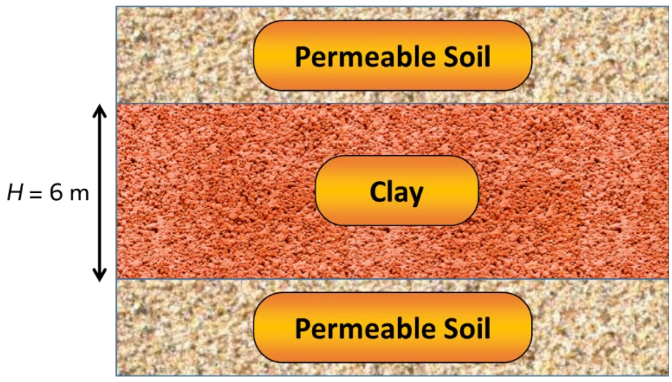
The time required for 25% consolidation of a 40-mm thick clay layer, drained on both ends, in the laboratory is 4 min. How long, in days, will it take for a 2-m-thick clay layer of the same clay in the field under the same pressure increment to reach 25% consolidation? The soil mass in the field is sandwiched between two thick layers of gravel, as shown.



A) t_{field} = 1.69 days
B) t_{field} = 2.58 days
C) t_{field} = 3.47 days
D) t_{field} = 4.36 days

PROBLEM 6A

A 6 m clay layer in the field, drained on both ends, is normally consolidated. When the pressure exerted on it is increased from 100 to 200 kN/m^2, the void ratio fell from 0.85 to 0.71. The hydraulic conductivity of the clay layer was determined as k = 5.5×10^{-7} cm/sec. Calculate the time required for the layer to reach 40% consolidation.



A) t = 13.4 days
B) t = 18.3 days
C) t = 23.6 days
D) t = 38.5 days

PROBLEM 6B

What is the settlement of the soil introduced in the previous part when it reaches 40% consolidation?

A) $(\rho_s)_{40\%}$ = 68.5 mm
B) $(\rho_s)_{40\%}$ = 120.5 mm
C) $(\rho_s)_{40\%}$ = 186.0 mm
D) $(\rho_s)_{40\%}$ = 225.0 mm

PROBLEM 7

For a laboratory consolidation test on a 20-mm-thick clay specimen, drained on one side only, the following data were obtained. If the time for 70% consolidation was 6 min, determine the hydraulic conductivity of the clay in the loading range.

Void ratio	σ' (kN/m^2)
0.85	125
0.93	240

A) k = 1.62 × 10^{-7} cm/s
B) k = 3.25 × 10^{-7} cm/s
C) k = 1.62 × 10^{-6} cm/s
D) k = 3.25 × 10^{-6} cm/s

PROBLEM 8A

A sample of saturated clay of height 25 mm and water content 33% was tested in an oedometer. Loading and unloading of the sample were carried out, beginning at 100 kN/m^2 to 400 kN/m^2 and then back to 100 again. The values of the sample's height H_z in each loading stage are tabulated below. Plot the results as void ratio versus σ_z', with the latter organized in a log scale.

σ_z' (kPa)	100	200	400	200	100
H_z (mm)	25	24.14	23.28	23.35	23.44

PROBLEM 8B

Determine the compression indexes C_c and C_r for the data introduced in the previous problem.

A) C_c = 0.035 and C_r = 0.090
B) C_c = 0.035 and C_r = 0.123
C) C_c = 0.060 and C_r = 0.090
D) C_c = 0.060 and C_r = 0.123

PROBLEM 8C

Determine the coefficient of volume compressibility between σ_z' = 200 kPa and σ_z' = 300 kPa.

A) m_v = 5.54 × 10^{-5} m^2/kN
B) m_v = 9.57 × 10^{-5} m^2/kN
C) m_v = 5.54 × 10^{-4} m^2/kN
D) m_v = 9.57 × 10^{-4} m^2/kN

PROBLEM 9A

The following results were obtained from an oedometer test on a specimen of saturated clay.

Pressure (kN/m²)	27	54	107	214	429	214	107	54
Void ratio	1.243	1.217	1.144	1.068	0.994	1.001	1.012	1.024

A layer of this clay 8 m thick lies below a 4 m depth of sand, the water table being at the surface. The saturated unit weight for both soils is 19 kN/m^2. A 4 m depth of fill of unit weight 21 kN/m^3 is placed on the sand over an extensive area. Determine the final settlement due to consolidation of the clay.

A) ρ_s = 113.4 mm
B) ρ_s = 232.5 mm
C) ρ_s = 317.9 mm
D) ρ_s = 436.8 mm

PROBLEM 9B

If the fill considered in the previous part were removed some time after the completion of consolidation, what heave would eventually take place due to swelling of the clay?

A) $\Delta\rho_s = -11$ mm

B) $\Delta\rho_s = -25$ mm

C) $\Delta\rho_s = -39$ mm

D) $\Delta\rho_s = -53$ mm

PROBLEM 9C

Assuming the fill specified in the previous parts is dumped very rapidly, what would be the value of excess porewater pressure at the center of the clay layer after a period of 3 years? The layer is open and has a coefficient of consolidation $c_v = 2.4\ m^2/year$.

A) $u_e = 35.2$ kPa

B) $u_e = 55.1$ kPa

C) $u_e = 74.3$ kPa

D) $u_e = 93.4$ kPa

PROBLEM 10

A clay layer below a foundation settles 15 mm in 200 days after the building was completed. According to the oedometer results, this settlement corresponds to an average degree of consolidation of 25%. Plot the settlement-time curve for a 10-year period, assuming double drainage.

PROBLEM 11

Data obtained from a laboratory consolidation test are shown in the next table.

Time (min)	0.25	1	2.25	4	9	16	25	36	1440
Total ΔH (mm)	0.12	0.23	0.33	0.43	0.59	0.68	0.74	0.76	0.89

Also, we have $\sigma'_o = 100$ kPa, $\sigma'_1 = 200$ kPa, and $H_o = 23.6$ mm. Find the coefficient of consolidation in mm²/min using the root time method.

A) $c_v = 2.10\ mm^2/min$

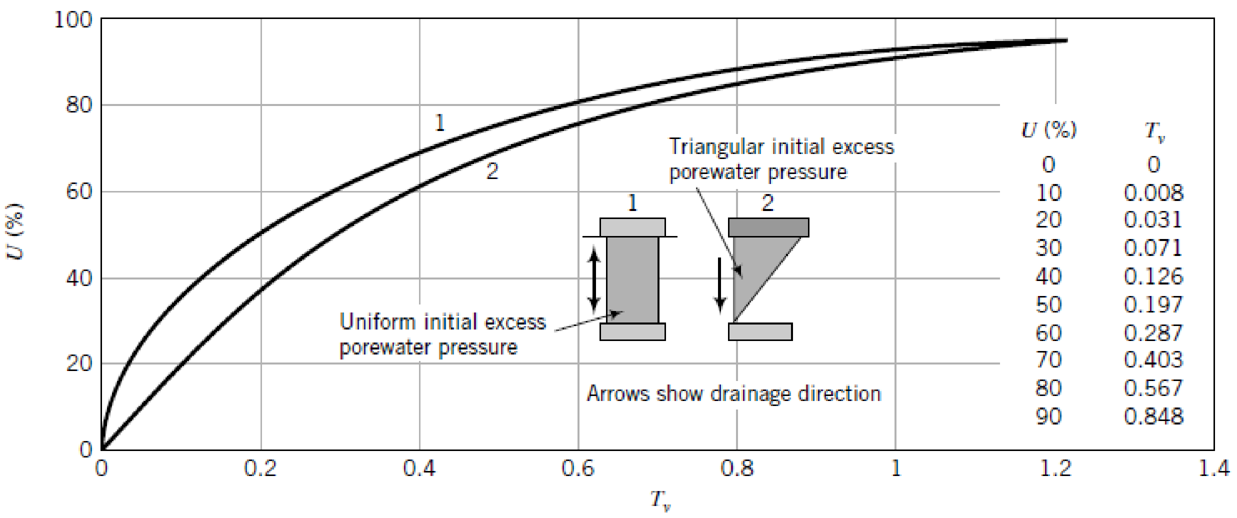
B) $c_v = 7.05\ mm^2/min$

C) $c_v = 14.05\ mm^2/min$

D) $c_v = 20.10\ mm^2/min$

▶ ADDITIONAL INFORMATION

Figure 1 Relationship between time factor and average degree of consolidation for a uniform distribution and a triangular distribution of initial excess porewater pressure.



▶ SOLUTIONS

P.1 ■ Solution

Statements A and B are correct, since Terzaghi's one-dimensional consolidation theory presupposes that the soil is homogeneous and saturated. This formulation is also based on the hypothesis that the compressibility of water and soil grains is negligible, thus confirming statement C. The false statement is B, because flow of water is assumed to occur in *one* direction only, namely, the vertical direction.

▶ The correct answer is **B**.

P.2 ■ Solution

We were given two data points, one of which says that the void ratio of the clay is 0.98 when the total pressure is 200 kN/m^2, and another according to which e_2 = 0.81 when p_2 = 500 kN/m^2. Using these data, we can determine the compression index,

$$C_c = \frac{e_1 - e_2}{\log\left(p_2/p_1\right)} = \frac{0.98 - 0.81}{\log\left(500/200\right)} = 0.427$$

We want to determine the value of C_c when the void ratio decreases to 0.81. To do so, we make use of the value of C_c we have just computed and substitute any one of the two data points we were initially given; then, we solve the ensuing equation for the new void ratio e. Mathematically,

$$C_c = \frac{e_1 - e_2}{\log\left(p_2/p_1\right)} \rightarrow 0.427 = \frac{0.98 - e}{\log\left(1000/200\right)}$$

$$\therefore 0.298 = 0.98 - e$$

$$\therefore \boxed{e = 0.68}$$

▶ The correct answer is **C**.

P.3 ■ Solution

Part A: The in-situ overburden pressure is determined as follows,

$$\sigma_o' = \gamma_{d,\text{sand}} \times H_1 + \left(\gamma_{\text{sat,sand}} - \gamma_w\right) \times H_2 + \left(\gamma_{\text{sat,clay}} - \gamma_w\right) \times \frac{H_3}{2}$$

$$\therefore \sigma_o' = 16.5 \times 2 + \left(19.3 - 9.8\right) \times 3 + \left(20.5 - 9.8\right) \times \frac{4}{2} = 82.9 \text{ kPa}$$

The compression index of the clay can be determined by means of the liquid limit relationship,

$$C_c = 0.009\left(LL - 10\right) = 0.009 \times \left(38 - 10\right) = 0.252$$

The primary consolidation settlement follows from the formula

$$\rho_s = \frac{C_c H}{1 + e_o} \log_{10}\left(\frac{\sigma_o' + \Delta\sigma}{\sigma_o'}\right)$$

where C_c is the compression index, H is the thickness of the layer undergoing consolidation, e_o is the void ratio, σ_o' is the overburden stress, and $\Delta\sigma$ is the additional above-ground load. Substituting 0.252 for C_c, 4 m for H, 0.89 for e_o, 82.9 kPa for σ_o', and 32 kPa for $\Delta\sigma$, we obtain

$$\rho_s = \frac{0.252 \times 4}{1 + 0.89} \log_{10}\left(\frac{82.9 + 31.1}{82.9}\right) = 0.0738 = \boxed{73.8 \text{ mm}}$$

The primary consolidation settlement of the clay layer is about 7 centimeters.

▶ The correct answer is **B**.

Part B: To determine which formula to use, we must verify the relationship between the overconsolidation pressure, $\Delta\sigma_c' = 95$ kN/m^2, and the sum $\sigma_o' + \Delta\sigma' = 82.9 + 31.1 = 114$ kN/m^2; since the latter is greater than the former, the primary consolidation settlement is to be determined with the expression

$$\rho_s = \frac{C_s H}{1+e_o}\log_{10}\left(\frac{\Delta\sigma_c'}{\sigma_o'}\right) + \frac{C_c H}{1+e_o}\log_{10}\left(\frac{\sigma_o' + \Delta\sigma'}{\Delta\sigma_c'}\right)$$

The swell index for the clay layer is one-fourth of the compression index, i.e.,

$$C_s = 0.25 \times 0.252 = 0.063$$

Substituting this value for C_s, $\Delta\sigma_c' = 95$ kN/m^2, and the remaining variables in the equation for ρ_s, we see that

$$\rho_s = \frac{0.063\times 4}{1+0.89}\log_{10}\left(\frac{95}{82.9}\right) + \frac{0.252\times 4}{1+0.89}\log_{10}\left(\frac{82.9+31.1}{95}\right) = 0.0501 = \boxed{50.1 \text{ mm}}$$

The overconsolidated soil will have a settlement about 30% lower than its normally consolidated counterpart.

► The correct answer is **D**.

Part C: Recall that the time factor can be computed with the following simple relationships: for U (degree of consolidation) $\in$ (0 ; 60)%, the time factor T_v is given by

$$T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$$

whereas for $U > 60\%$, the following approximation is valid,

$$T_v = 1.781 - 0.933\log(100 - U)$$

The second equation applies in this case, so that, substituting $U = 75\%$, we obtain

$$T_v = 1.781 - 0.933\log_{10}(100-75) = 0.477$$

The time factor, T_v, is computed with the relation

$$T_v = \frac{c_v t}{H_{\text{dr}}^2}$$

where c_v is the coefficient of consolidation, t is time, and H_{dr} is the longest drainage path during consolidation. For soils drained at one side only (the upper end is exposed to the adjacent sand layer, but the lower end is sealed by a rocky layer), H_{dr} is to be taken as equal to the thickness of the layer, that is, $H_{dr} = H_3 = 400$ cm. Substituting this data, along with $T_v = 0.477$ and $c_v = 0.24$ cm^2/min, we can solve for t,

$$T_v = \frac{c_v t}{H_{\text{dr}}^2} \to 0.477 = \frac{0.24\times t}{400^2}$$

$$\therefore t = \frac{0.477\times 400^2}{0.24} = 318{,}000 \text{ min}$$

or, in terms of days,

$$t = \frac{318{,}000 \text{ min}}{(60\times 24)\ \dfrac{\text{min}}{\text{day}}} = \boxed{221 \text{ days}}$$

The clay layer should take over 7 months to consolidate.

► The correct answer is **A**.

P.4 ■ Solution

The coefficient of volume compressibility allows the engineer to obtain a quick estimate of the primary consolidation settlement using the rather simple relation

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

Here, we substitute 4×10^{-4} m^2/kN for m, 2 m for the soil layer thickness H, and 100 kPa for $\Delta\sigma'$, giving

$$\rho_s = m_v H \Delta\sigma' = \left(4\times10^{-4}\right)\times2\times100 = 0.08\text{ m} = \boxed{80\text{ mm}}$$

The advantage of the equation we used is that m_v is readily determined from displacement data in consolidation tests. There is no need to compute void ratio changes, as in the case of the compression index C_c. It should be noted that, unlike settlement calculations involving C_c, computations with m_v are somewhat inaccurate because this parameter varies with stress levels. To reduce the effects of nonlinearity, the vertical effective stress difference should not exceed 100 kPa in calculating m_v.

► The correct answer is **D**.

P.5 ■ Solution

Two soils of identical characteristics, be they in the lab or in the field, should have the same time factor at the same degree of consolidation; the coefficient of consolidation should be the same as well. Accordingly, we can write

$$T_{50} = \frac{c_v t_{\text{lab}}}{H_{\text{dr,lab}}^2} = \frac{c_v t_{\text{field}}}{H_{\text{dr,field}}^2} \rightarrow \frac{t_{\text{lab}}}{H_{\text{dr,lab}}^2} = \frac{t_{\text{field}}}{H_{\text{dr,field}}^2}$$

Substituting t_{lab} = 4 min, $H_{dr,lab}$ = 0.040/2, and $H_{dr,field}$ = 2/2 = 1 m, t_{field} is determined to be

$$\frac{t_{\text{lab}}}{H_{\text{dr,lab}}^2} = \frac{t_{\text{field}}}{H_{\text{dr,field}}^2} \rightarrow \frac{4}{(0.040/2)^2} = \frac{t_{\text{field}}}{(2/2)^2}$$

$$\therefore t_{\text{field}} = \frac{(2/2)^2}{(0.040/2)^2}\times4 = 5000\text{ min}$$

$$\therefore t_{\text{field}} = 5000\text{ min}\times\frac{1\text{ day}}{1440\text{ min}} = \boxed{3.47\text{ days}}$$

or about 3 and a half days.

► The correct answer is **C.**

P.6 ■ Solution

Part A: The time factor is given by

$$T_v = \frac{c_v t}{H_{\text{dr}}^2}$$

Solving for time, we get

$$T_v = \frac{c_v t}{H_{\text{dr}}^2} \rightarrow t = \frac{T_v H_{\text{dr}}^2}{c_v} \quad \text{(I)}$$

The coefficient of consolidation, in turn, is related to other physical quantities by the expression

$$c_v = \frac{k}{m_v \gamma_w}$$

where k is the hydraulic conductivity of the soil, m_v is the coefficient of volume compressibility, and γ_w is the unit weight of water. One of the variables above that is not yet available is m_v; it is defined as

$$m_v = \frac{a_v}{1+e_{\text{avg}}}$$

where e_{avg} is the average void ratio and a_v is the coefficient of compressibility; the latter is given by the ratio of change in void ratio to change in stress,

$$a_v = \frac{|\Delta e|}{|\Delta\sigma'|} = \frac{|0.71-0.85|}{|200-100|} = 0.0014\,\frac{\text{m}^2}{\text{kN}}$$

The average void ratio e_{avg}, in turn, is

$$e_{\text{avg}} = \frac{0.71+0.85}{2} = 0.78$$

so that

$$m_v = \frac{a_v}{1+e_{\text{avg}}} = \frac{0.0014}{1+0.78} = 7.87\times10^{-4}\,\frac{\text{m}^2}{\text{kN}}$$

Substituting in the expression for c_v gives

$$c_v = \frac{k}{m_v\gamma_w} = \frac{5.5\times10^{-9}\,[\text{m/s}]}{\left(7.84\times10^{-4}\right)\left[\frac{\text{m}^2}{\text{kN}}\right]\times9.81\left[\frac{\text{kN}}{\text{m}^3}\right]} = 7.15\times10^{-7}\ \text{m}^2/\text{s} = 0.0618\ \text{m}^2/\text{day}$$

Using Figure 1, we see that the time factor that corresponds to a consolidation of 40% is T_v = 0.126. Also, for a soil stratum drained on both ends, we have H_{dr} = 6/2 = 3 m; substituting T_v, H_{dr}, and c_v in equation (I) brings to

$$t = \frac{T_v H_{\text{dr}}^2}{c_v} = \frac{0.126\times(6/2)^2}{0.0618} = \boxed{18.3\ \text{days}}$$

The soil needs over half a month to attain 40% consolidation.

► The correct answer is **B.**

Part B: To obtain the settlement at 40% consolidation, we should first determine the full primary consolidation. To do so, we compute the compression index as

$$C_c = \frac{\Delta e}{\log_{10}\left(\frac{\sigma_2'}{\sigma_1'}\right)}$$

where $\Delta e = |0.85 - 0.71| = 0.14$ and σ_2'/σ_1' = 200/100 = 2. Thus,

$$C_c = \frac{0.14}{\log_{10} 2} = 0.465$$

The primary settlement is given by

$$\rho_s = \frac{C_c H}{1+e_o}\log_{10}\left(\frac{\sigma_o' + \Delta\sigma'}{\sigma_o'}\right)$$

Substituting C_c = 0.465, H = 6 m, e_o = 0.71, σ_o' = 100 kN/m^2, and $\sigma_o' + \Delta\sigma'$ = 200 kN/m^2, it follows that

$$\rho_s = \frac{0.465\times6}{1+0.71}\log_{10}\left(\frac{200}{100}\right) = 0.491\ \text{m} = 491\ \text{mm}$$

The full consolidation of the soil will be just short of half a meter, which is quite high for a 6-m-thick layer such as the one under consideration. We assume that the 40% settlement is simply 0.4 times the full primary consolidation ρ_s; that is,

$$(\rho_s)_{40\%} = 0.4\rho_s = 0.4\times465 = \boxed{186\ \text{mm}}$$

► The correct answer is **C.**

P.7 ■ Solution

The coefficient of consolidation is given by

$$c_v = \frac{k}{m_v \gamma_w}$$

Solving for the hydraulic conductivity *k* yields

$$c_v = \frac{k}{m_v \gamma_w} \rightarrow k = c_v m_v \gamma_w \ \text{(I)}$$

The coefficient of volume compressibility, m_v, is given by

$$m_v = \frac{a_v}{1+e_{\text{avg}}}$$

where a_v is the coefficient of compressibility and e_{avg} is the average void ratio. The coefficient of compressibility, in turn, is the ratio of change in void ratio to change in overburden stress,

$$a_v = \frac{|\Delta e|}{|\Delta \sigma'|}$$

In the present case, $|\Delta e|$ = |0.85 – 0.93| = 0.08 and $|\Delta \sigma'|$ = |240 – 125| = 115 kPa, so that

$$a_v = \frac{0.08}{115} = 6.96 \times 10^{-4} \ \frac{\text{m}^2}{\text{kN}}$$

The average void ratio is e_{avg} = (0.85 + 0.93)/2 = 0.89. Substituting in the equation for m_v gives

$$m_v = \frac{\left(6.96 \times 10^{-4}\right)}{1+0.89} = 3.68 \times 10^{-4} \ \frac{\text{m}^2}{\text{kN}}$$

The time factor can be obtained from Figure 1 or computed with the approximation $T_v = 1.781 - 0.933\log(100 - U[\%])$, which is valid when U > 60%; we choose the latter option, obtaining

$$T_v = 1.781 - 0.933\log\left(100-70\right) = 0.403$$

We now have all necessary variables to determine the coefficient of consolidation, c_v,

$$T_v = \frac{c_v t}{H_{\text{dr}}^2} \rightarrow c_v = \frac{T_v H_{\text{dr}}^2}{t}$$

where H_{dr} = 50 mm for a soil drained on one end only and t = 6 min, so that

$$c_v = \frac{0.403 \times \left(20 \times 10^{-3}\right)^2}{6} = 2.69 \times 10^{-5} \ \text{m}^2/\text{min}$$

Returning to equation (I), the hydraulic conductivity is determined to be

$$k = c_v m_v \gamma_w = \left(2.69 \times 10^{-5}\right) \times \left(3.68 \times 10^{-4}\right) \times 9.81 = 9.71 \times 10^{-8} \ \text{m/min}$$

or, equivalently,

$$k = 9.71 \times 10^{-8} \ \frac{\cancel{\text{m}}}{\cancel{\text{min}}} \times \frac{1}{60} \frac{\cancel{\text{min}}}{\text{s}} \times \frac{100 \ \text{cm}}{1 \ \cancel{\text{m}}} = \boxed{1.62 \times 10^{-7} \ \text{cm/s}}$$

► The correct answer is **A**.

P.8 ■ Solution

Part A: The change in void ratio is determined as

$$|\Delta e| = \frac{|\Delta H|}{H_o(1+e_o)}$$

where e_o is the initial void ratio, ΔH is the change in height, and H_o is the thickness of the clay sample. Since the soil is saturated, the initial void ratio is simply the product of water content and specific gravity,

$$e_o = wG_s = 0.33 \times 2.67 = 0.881$$

Similarly, the change in soil thickness is such that

$$|\Delta H| = H_o - H_f = 25 - 24.14 = 0.86 \text{ mm}$$

The variation in void ratio easily follows,

$$\Delta e = \frac{\Delta H}{H_o(1+e_o)} = \frac{0.86}{25\times(1+0.881)} = 0.018$$

The void ratio e_1 after the first loading is obtained as

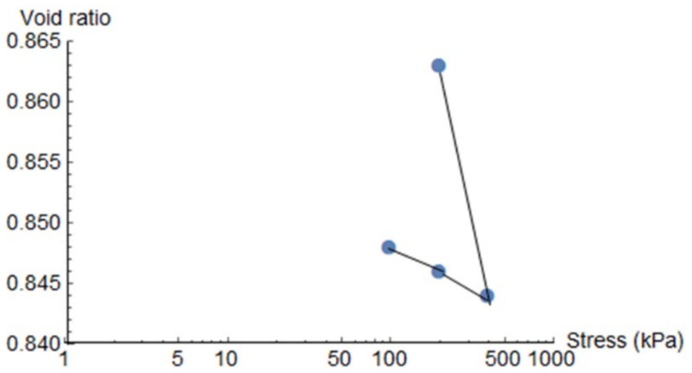
$$|\Delta e| = e_o - e_1$$

$$\therefore e_1 = e_o - |\Delta e| = 0.881 - 0.018 = 0.863$$

Applying similar calculations to the later loading stages, the following table is prepared,

σ_z' (kPa)	H_f (mm)	ΔH	Δe	e
100	25			
200	24.14	0.86	0.018	0.863
400	23.28	1.72	0.037	0.844
200	23.35	1.65	0.035	0.846
100	23.44	1.56	0.033	0.848

The plot we were asked to obtain is one of void ratio, the blue column above, versus the vertical effective stress, the red column, with the latter measured on a log scale. This can be done with Mathematica's *ListLogLinearPlot* command, as shown.



Part B: The compression index is the average slope of the normal consolidation line in a plot of void ratio versus the logarithm of stress; mathematically,

$$C_c = \frac{\Delta e}{\log_{10}\left(\dfrac{\sigma_2}{\sigma_1}\right)} = \frac{0.018}{\log_{10}\left(\dfrac{200}{100}\right)} = \boxed{0.060}$$

Similarly, the recompression index is the average slope of the unloading/reloading curve, that is,

$$C_r = \frac{\Delta e}{\log_{10}\left(\dfrac{\sigma_3}{\sigma_2}\right)} = \frac{0.037}{\log_{10}\left(\dfrac{400}{200}\right)} = \boxed{0.123}$$

► The correct answer is **D**.

Part C: The coefficient of volume compressibility can be determined with the relation

$$m_v = \frac{|\Delta e|}{|\Delta\sigma'|(1+e_o)}$$

Substituting Δe = 0.018, $\Delta\sigma'$ = 300 – 200 = 100 kPa, and e_o = 0.881 gives

$$m_v = \frac{0.018}{(300-200)\times(1+0.881)} = \boxed{9.57\times10^{-5}\ \mathrm{m^2/kN}}$$

The coefficient of volume compressibility is close to 10^{-4} $\mathrm{kPa^{-1}}$.

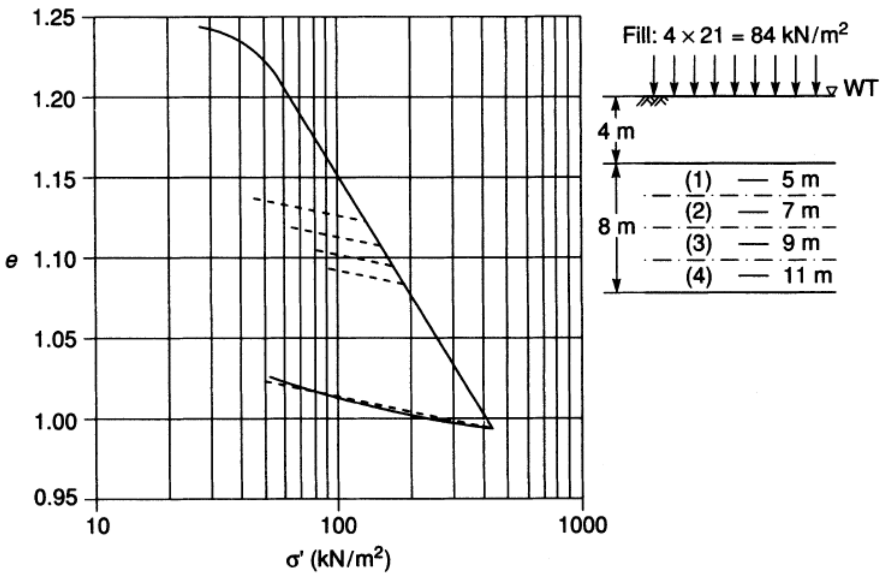
► The correct answer is **B**.

P.9 ■ Solution

Part A: For one-dimensional consolidation, we can estimate the settlement of soil with the expression

$$\rho_s = \frac{e_o - e_1}{1+e_o} H_{\mathrm{dr}}$$

Approximate values of *e* are obtained from the following graph. Since the clay layer is relatively thick, we propose dividing it into four equal strata, each with 2-m thickness, as illustrated below.



Then, the following table is prepared. In the second column the initial stress σ_o' is the product (4 + 1) × (19.0 – 9.8) = 46 kN/m², where the first factor is the depth from the surface to the middle of the first layer and the second is the submerged unit weight of either soil. The third column, in turn, is the sum of the aforementioned 46 kPa and the stress due to the overlying sand fill, 4 × 21 = 84 kPa, totaling σ_1' = 46 + 84 = 130 kPa.

Layer	σ_o' $(\mathrm{kN/m^2})$	σ_1' $(\mathrm{kN/m^2})$	e_o	e_1	$e_o - e_1$	ρ_s (mm)
1	46	130	1.236	1.123	0.113	101.1
2	64.4	148.4	1.2	1.108	0.092	83.6
3	82.8	166.8	1.172	1.095	0.077	70.9
4	101.2	185.2	1.15	1.083	0.067	62.3
					Total ρ	317.9

As highlighted in the blue column, the total settlement of the clay layer will be close to one foot.

► The correct answer is **C**.

Part B: When the clay is expanding, the stresses σ_1' and σ_o' switch places in the previous table, and the e_1 void ratio values are taken from the unloading path of the *e*-log σ' curve. Then, the following table is prepared.

Layer	σ'_o (kN/m^2)	σ'_1 (kN/m^2)	e_o	e_1	$e_o - e_1$	ρ_s (mm)
1	130	46	1.123	1.136	-0.013	-12.2
2	148.4	64.4	1.108	1.119	-0.011	-10.4
3	166.8	82.8	1.095	1.104	-0.009	-8.6
4	185.2	101.2	1.083	1.091	-0.008	-7.7
					Total ρ	-39.0

As shown in the red column, the clay will experience about 39 millimeters of heave.

► The correct answer is **C**.

Part C: If the layer is open, the drainage path is H_{dr} = 8/2 = 4 m. Substituting this value, along with c_v = 2.4 m^2/year and t = 3 yrs, we obtain a time factor

$$T_v = \frac{c_v t}{H_{\text{dr}}^2} = \frac{2.4 \times 3}{4^2} = 0.45$$

The porewater pressure corresponds to the weight of the fill, i.e., $u_i = \Delta\sigma$ = 4 × 21 = 84 kN/m^2. The expression for porewater developed in one-dimensional consolidation theory is

$$u_e = \sum_{m=0}^{m=\infty} \frac{2u_i}{M} \left[\sin\left(\frac{Mz}{H_{\text{dr}}} \right) \right] \exp\left(-M^2 T_v\right)$$

In this case, $z = H_{dr}$. and the sine term above simplifies as

$$\sin\left(\frac{Mz}{d} \right) = \sin M$$

where M is such that

$$M = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots$$

We can then prepare the following table.

M	$\sin M$	$M^2 T_v$	$\exp -M^2 T_v$
$\pi/2$	+1	1.110	0.329
$3\pi/2$	-1	9.993	4.57×10^{-5}

Notice that the term involving the second possible value of M, that is, $3\pi/2$, is associated with a term $\exp(-M^2 T_v)$ that is quite small (= 4.57×10^{-5}). Thus, considering the first value of M only is a reasonable approximation. Finally, the porewater pressure at the center of the clay after 3 years is such that

$$u_e = 2 \times 84 \times \frac{2}{\pi} \times 1 \times 0.329 = \boxed{35.2 \text{ kPa}}$$

► The correct answer is **A**.

P.10 ■ Solution

The degree of saturation, U, is the ratio of settlement at time, ρ_s, to total settlement, $\rho_{s,\text{total}}$; solving for $\rho_{s,\text{total}}$ gives

$$U = \frac{\rho_s}{\rho_{s,\text{total}}} \rightarrow \rho_{s,\text{total}} = \frac{\rho_s}{U} = \frac{15}{0.25} = 60 \text{ mm}$$

The time factor for 25% consolidation is obtained with the usual approximation (or from Figure 1),

$$T_v = \frac{\pi}{4} \left(\frac{U[\%]}{100} \right)^2 = \frac{\pi}{4} \left(\frac{25}{100} \right)^2 = 0.049$$

The time span for 25% consolidation to occur, when converted to years, is t_{25} = 200/365 = 0.55 yr. Since the drainage path and the coefficient of consolidation are the same, we can make use of the equality

$$\frac{T_{v,1}}{t_1} = \frac{T_{v,2}}{t_2} \rightarrow \frac{0.049}{0.55} = \frac{T_{v,2}}{t_2}$$

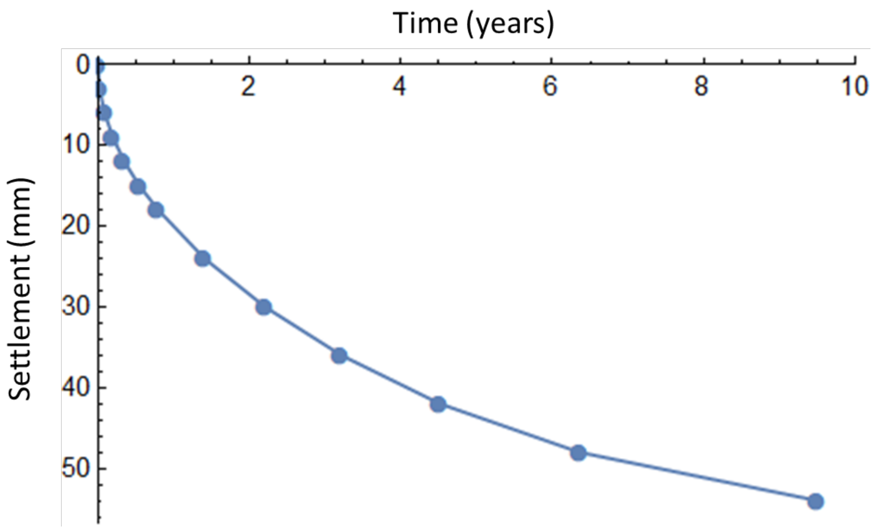
$$\therefore t_2 = \frac{0.55}{0.049} T_{v,2}$$

$$\therefore t_2 = 11.22 T_{v,2}$$

Using the relationship above and the adequate time factors, we can tabulate the necessary data.

U (%)	T_{v2}	t_2 (yrs)	ρ_s (mm)
0	0	0.00	0
5	0.002	0.02	3
10	0.008	0.09	6
15	0.018	0.20	9
20	0.031	0.35	12
25	0.049	0.55	15
30	0.071	0.80	18
40	0.126	1.41	24
50	0.197	2.21	30
60	0.287	3.22	36
70	0.403	4.52	42
80	0.567	6.36	48
90	0.848	9.51	54

The plot we are looking for is one of settlement in mm (the red column) versus time in years (the blue column).

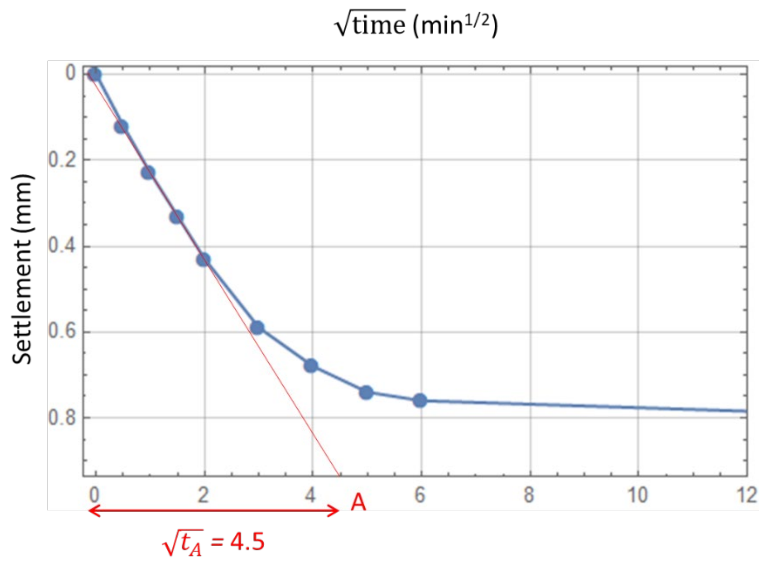


P.11 ■ Solution

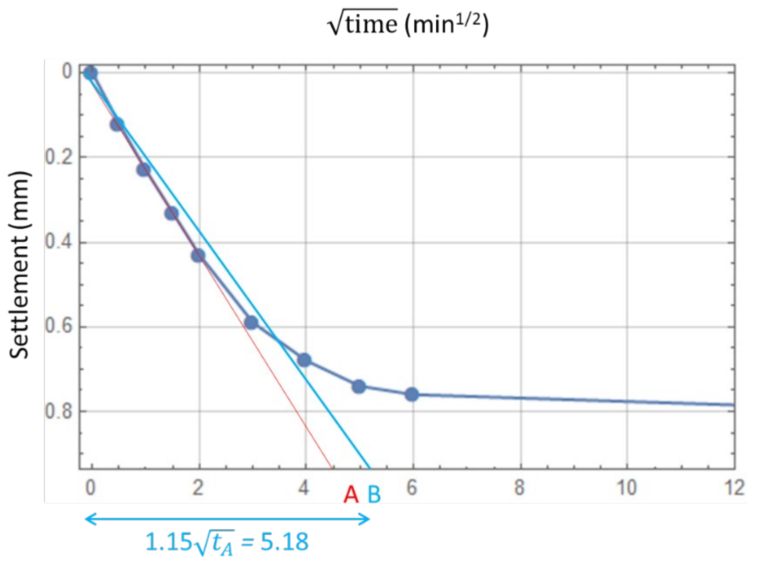
We first compute the average thickness as H_{avg} = 23.6 – 4.1/2 = 21.55 mm. The drainage path is H_{dr} = 21.55/2 = 10.78 mm. We then tabulate settlement and square-root-of-time values as shown, then plotting the former (blue row) versus the latter (red row).

Time (min)	0.25	1	4	9	16	25	36	81	1440
√Time ($min^{1/2}$)	0.5	1	2	3	4	5	6	9	37.9
Total ΔH (mm)	0.622	1.244	2.468	3.4	3.838	3.97	4	4.051	4.1

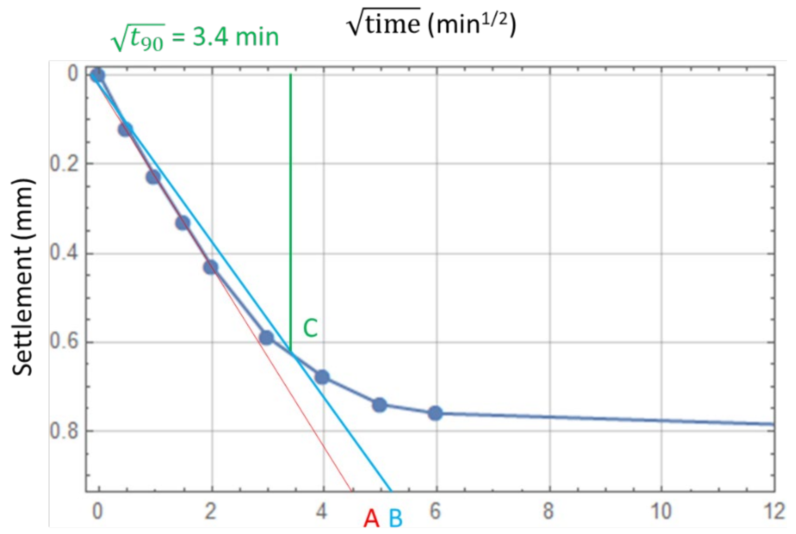
To derive the coefficient of consolidation with the root time method, we begin by delineating a tangent to the curve of settlement against time$^{1/2}$ beginning at the origin, as shown.



It is found that $\sqrt{t_A}$ = 4.5 $\text{min}^{1/2}$. The next step is to draw a second line, this time going from the origin to the abscissa corresponding to $1.15\sqrt{t_A}$ = 1.15 × 4.5 = 5.18 $\text{min}^{1/2}$; the line in question is shown in blue below.



Finally, the intercept of the blue line with the settlement-time$^{1/2}$ curve is to be taken as the time required for 90% consolidation, t_{90}. Projecting the intercept onto the abscissa yields $\sqrt{t_{90}}$.



The green line intercepts the horizontal axis at $\sqrt{t_{90}} \approx 3.4$ min., which corresponds to a time of 90% consolidation t_{90} = 11.56 min. We are then ready to substitute the available data in the expression for the time factor T_v, which can be easily solved for the coefficient of consolidation,

$$T_v = \frac{c_v t_{90}}{H_{\text{dr}}^2} \rightarrow c_v = \frac{T_v H_{\text{dr}}^2}{t_{90}}$$

At 90% consolidation, the time factor T_v = 0.848; also, given the current height 20 – 0.89 = 19.1 mm, the drainage path is such that $H_{\text{dr}} = (H_o + H_f)/4$ = (20

+ 19.1)/4 = 9.8 mm. Substituting the available data in the expression for c_v, we obtain

$$c_v = \frac{T_v H_{\mathrm{dr}}^2}{t_{90}} = \frac{0.848 \times 9.8^2}{11.56} = \boxed{7.05\ \mathrm{mm}^2/\mathrm{min}}$$

► The correct answer is **B**.

► ANSWER SUMMARY

Problem 1		B
Problem 2		C
Problem 3	**3A**	B
	3B	D
	3C	A
Problem 4		D
Problem 5		C
Problem 6	**6A**	B
	6B	C
Problem 7		A
Problem 8	**8A**	Open-ended pb.
	8B	D
	8C	B
Problem 9	**9A**	C
	9B	C
	9C	A
Problem 10		Open-ended pb.
Problem 11		B

► REFERENCES

- BUDHU, M. (2011). *Soil Mechanics and Foundations.* 3rd edition. New York: John Wiley and Sons.
- CRAIG, R. (2004). *Craig's Soil Mechanics*. 7th edition. London: Spon Press.
- DAS, B. and SOBHAN, K. (2014). *Principles of Geotechnical Engineering.* 8th edition. Stamford: Cengage Learning.
- LIU, C., and EVETT, J. (2008). *Soils and Foundations.* 7th edition. Upper Saddle River: Pearson.

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