QUIZ GT104
Flow of Water through Soil

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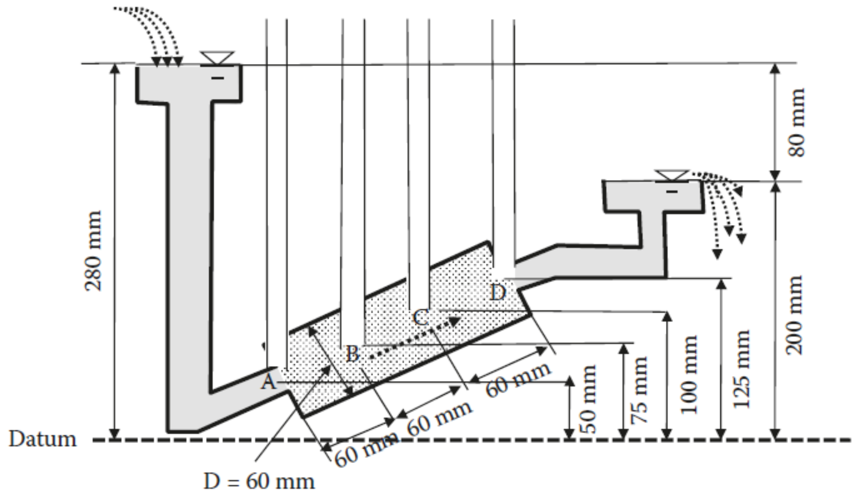
▶ PROBLEMS

PROBLEM 1A (Hazarika & Ishibashi, 2010)

The next figure shows water flow through soil in an inclined cylindrical specimen. The specimen's k value is 3.4×10^{-4} cm/s. Which of the following statements is false? Consider the velocity head to be negligible.



A) The pressure head at point *A* equals 230 mm.

B) The total head at point B equals 235.5 mm.

C) The total head at point C equals 226.6 mm.

D) The pressure head at point D equals 75 mm.

PROBLEM 1B

Compute the amount of water flow q through the specimen introduced in the previous problem.

A) $q = 1.33 \times 10^{-3}$ cm³/s

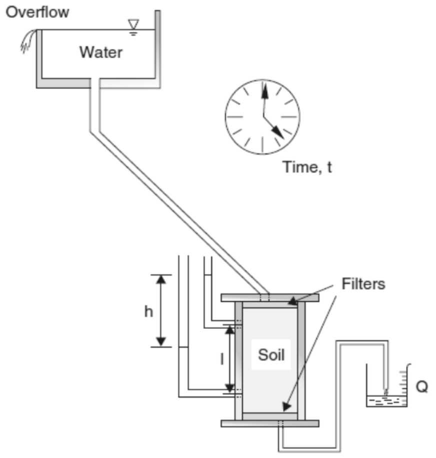
B) $q = 4.23 \times 10^{-3}$ cm³/s

C) $q = 7.21 \times 10^{-3}$ cm³/s

D) $q = 10.2 \times 10^{-3}$ cm³/s

PROBLEM 2

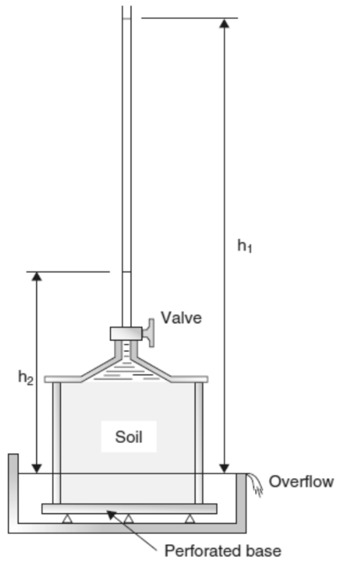
In a laboratory constant head permeability test, a cylindrical sample 100 mm in diameter and 150 mm high is subjected to an upward flow of 540 mL/min. The head loss over the length of the sample is measured to be 360 mm. Calculate the coefficient of permeability.



A) $k = 1.6 \times 10^{-4}$ cm/s
B) $k = 2.5 \times 10^{-4}$ cm/s
C) $k = 3.2 \times 10^{-4}$ cm/s
D) $k = 4.8 \times 10^{-4}$ cm/s

PROBLEM 3A

In a laboratory falling head test, the recorded data are: diameter of the tube = 20 mm, diameter of the cell = 100 mm, length of the sample = 1000 mm. The head measured from the top level of the sample dropped from 800 mm to 600 mm. Calculate the coefficient of permeability of the soil.



A) $k = 1.6 \times 10^{-4}$ cm/s
B) $k = 2.5 \times 10^{-4}$ cm/s
C) $k = 3.2 \times 10^{-4}$ cm/s
D) $k = 4.8 \times 10^{-4}$ cm/s

PROBLEM 3B

Suppose the experiment carried out in the previous problem was for a soil at a temperature of 30°C. Calculate the coefficient of permeability for the same soil at a temperature of 20°C. The viscosity of water is $1.005 \times 10^{-3}\ \mathrm{N \cdot s/m^2}$ at 20°C and $0.801 \times 10^{-3}\ \mathrm{N \cdot s/m^2}$ at 30°C.

A) $k = 1.6 \times 10^{-4}$ cm/s
B) $k = 2.5 \times 10^{-4}$ cm/s
C) $k = 3.2 \times 10^{-4}$ cm/s
D) $k = 4.8 \times 10^{-4}$ cm/s

PROBLEM 4 (Venkatramaiah, 2006)

In a falling head permeability test, head causing flow was initially 50 cm and it drops 2 cm in 5 minutes. How much time is required for the head to fall to 25 cm?

A) t = 23 min
B) t = 54 min
C) t = 85 min
D) t = 110 min

PROBLEM 5 (Murthy, 2002)

A sample in a variable head permeameter is 8 cm in diameter and 10 cm high. The permeability of the sample is estimated to be 10×10^{-4} cm/s. If it is desired that the head in the stand pipe should fall from 24 cm to 12 cm in 3 minutes, determine the diameter of the standpipe that should be used.

A) d = 7 mm
B) d = 13 mm
C) d = 21 mm
D) d = 29 mm

PROBLEM 6A (Powrie, 2004, w/ permission)

In an attempt to investigate the overall vertical permeability of a layered deposit, an engineer carries out a falling head permeability test on an artificial sample comprising 100 mm of silt overlying 100 mm of sand. The results from this test are given in the next table. The cross-sectional area of the sample is A_1= 8000 mm^3, the cross-sectional area of the top tube is A_2 = 10 mm^2, and the overall sample length is L = 200 mm.

Time t since start of test (s)	0	40	100	190	330	600
Height of water in top tube h (m)	1.00	0.85	0.70	0.55	0.40	0.25

Plot a graph of $ln(h_1/h)$ against t, with h_1 being the initial height of water in the top tube, and explain its shape in terms of what happens to the overall vertical permeability of the sample during the test. What, physically, might be the explanation for this?

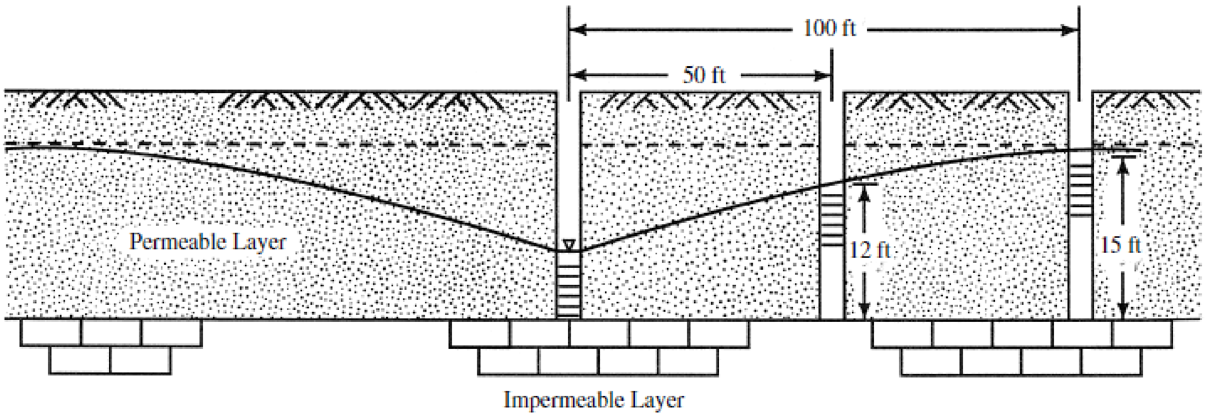
PROBLEM 6B

Estimate the overall permeability at the start and at the end of the test.

A) $k_i = 1.1 \times 10^{-6}$ m/s and $k_f = 3.0 \times 10^{-7}$ m/s
B) $k_i = 1.1 \times 10^{-6}$ m/s and $k_f = 6.0 \times 10^{-7}$ m/s
C) $k_i = 2.2 \times 10^{-6}$ m/s and $k_f = 3.0 \times 10^{-7}$ m/s
D) $k_i = 2.2 \times 10^{-6}$ m/s and $k_f = 6.0 \times 10^{-7}$ m/s

PROBLEM 7 (Evett & Liu, 2008, w/ permission)

A pump test was conducted on a test well in an unconfined aquifer, with the results shown in the next figure. If the water was pumped at a steady flow of 185 gal/min, determine the coefficient of permeability of the permeable soil.



A) $k = 1.12 \times 10^{-5}$ ft/s

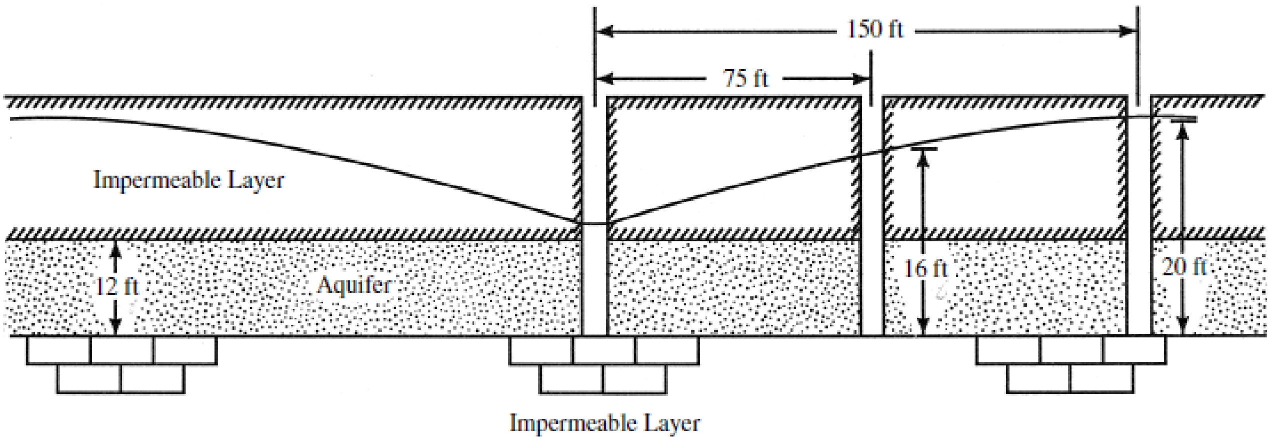
B) $k = 3.33 \times 10^{-5}$ ft/s

C) $k = 5.67 \times 10^{-5}$ ft/s

D) $k = 7.70 \times 10^{-5}$ ft/s

PROBLEM 8 **(Evett & Liu, 2008, w/ permission)**

A pump test was conducted on a test well drilled into a confined aquifer, with the results shown in the next figure. If water was pumped at a steady flow of 205 gal/min, determine the coefficient of permeability of the permeable soil in the aquifer.



A) $k = 8.62 \times 10^{-4}$ ft/s

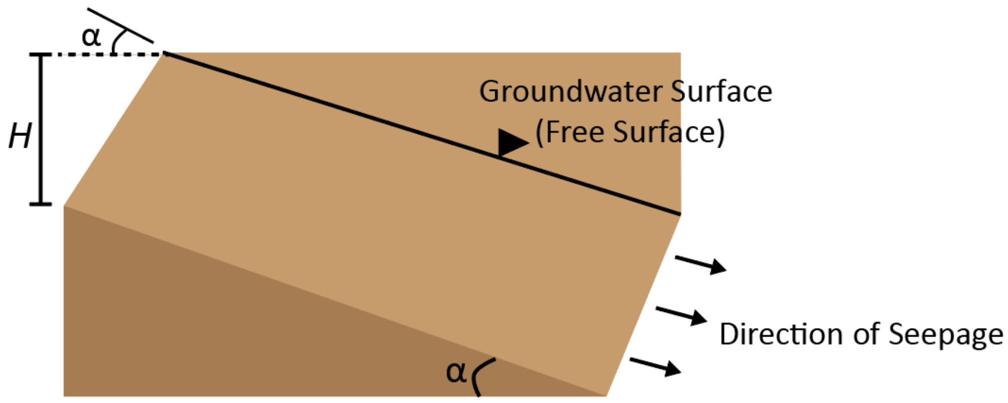
B) $k = 1.05 \times 10^{-3}$ ft/s

C) $k = 4.53 \times 10^{-3}$ ft/s

D) $k = 7.81 \times 10^{-3}$ ft/s

PROBLEM 9

A permeable soil layer is underlain by an impervious layer, as shown in the figure below. With $k = 4.5 \times 10^{-5}$ m/s for the permeable layer, calculate the rate of seepage through it in m^3/hr/m width if H = 3 m and α = 10°.



A) q = 0.025 m^3/hr/m

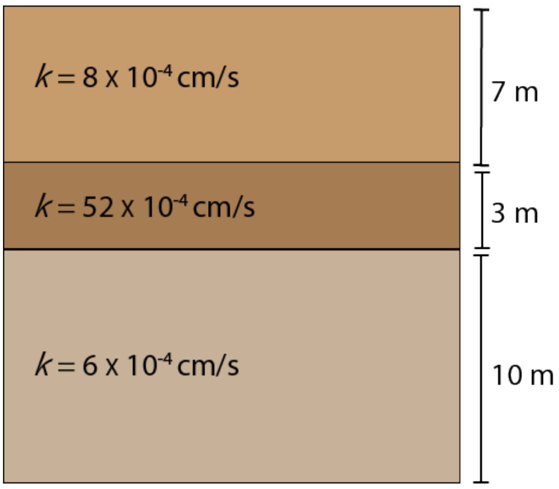
B) q = 0.047 m^3/hr/m

C) q = 0.064 m^3/hr/m

D) q = 0.083 m^3/hr/m

PROBLEM 10

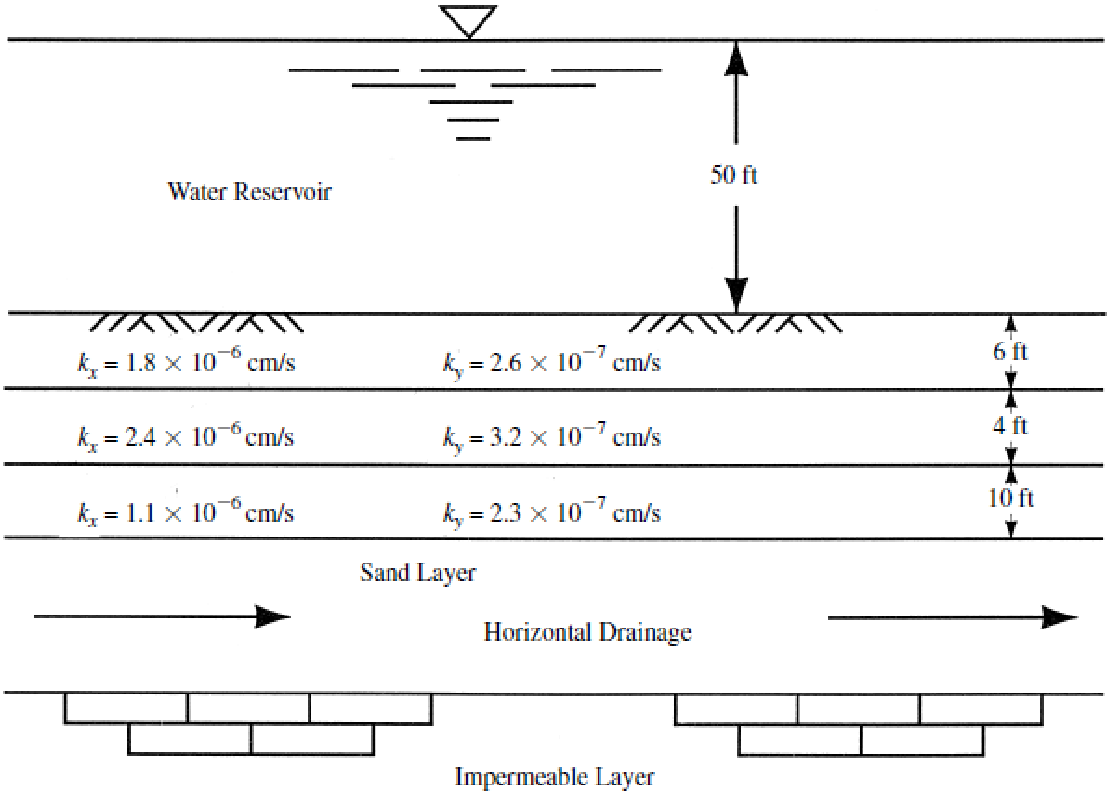
A horizontally stratified soil deposit consists of three layers each uniform in itself. The permeabilities of these layers are 8×10^{-4} cm/s, 52×10^{-4} cm/s, and 6×10^{-4} cm/s, and their thicknesses are 7, 3, and 10 m, as shown. What are the effective average permeabilities of the deposit in the horizontal (k_x) and vertical (k_z) directions?



A) $k_x = 13.6 \times 10^{-4}$ cm/s and $k_z = 3.6 \times 10^{-4}$ cm/s
B) $k_x = 13.6 \times 10^{-4}$ cm/s and $k_z = 7.7 \times 10^{-4}$ cm/s
C) $k_x = 18.8 \times 10^{-4}$ cm/s and $k_z = 3.6 \times 10^{-4}$ cm/s
D) $k_x = 18.8 \times 10^{-4}$ cm/s and $k_z = 7.7 \times 10^{-4}$ cm/s

PROBLEM 11 (Evett & Liu, 2008, w/ permission)

A reservoir with a 35,000 ft^2 area is underlain by layers of stratified soils as depicted in the next figure. Compute the water loss from the reservoir in 1 year. Assume that the pore pressure at the bottom sand layer is zero.



A) V = 105 m^3
B) V = 352 m^3
C) V = 647 m^3
D) V = 920 m^3

PROBLEM 12 (Das & Sobhan, 2014)

The hydraulic conductivity of a sand at a void ratio of 0.48 is 0.03 cm/s. Estimate its hydraulic conductivity at a void ratio of 0.64.

A) k_2 = 0.064 cm/s
B) k_2 = 0.092 cm/s
C) k_2 = 0.114 cm/s
D) k_2 = 0.136 cm/s

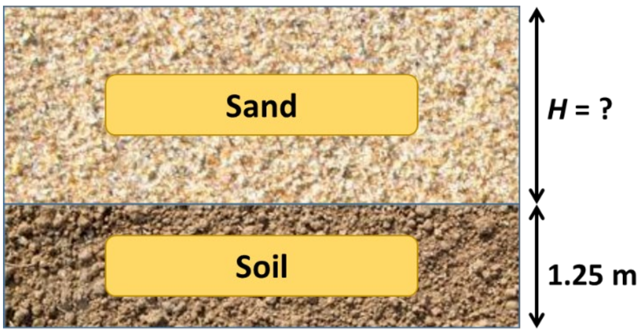
PROBLEM 13A (Venkatramaiah, 2006)

What is the critical hydraulic gradient of a sand deposit of specific gravity G_s = 2.65 and void ratio e = 0.5?

A) i_c = 0.6
B) i_c = 1.1
C) i_c = 1.6
D) i_c = 2.1

PROBLEM 13B

A 1.25 m layer of soil (specific gravity G_s = 2.65 and porosity n = 35%) is subjected to an upward seepage head of 1.85 m. What depth of coarse sand would be required above the soil to provide a factor of safety of 2.0 against piping? Assume that the coarse sand has the same porosity and specific gravity as the soil and that there is negligible head loss in the sand.



A) H = 1.05 m
B) H = 1.63 m
C) H = 2.21 m
D) H = 2.83 m

PROBLEM 14

An earth dam is built on an impervious foundation with a horizontal filter at the base near the toe. The permeability of the soil in the horizontal and vertical directions are 3×10^{-2} mm/s and 1×10^{-2} mm/s, respectively. The full reservoir level is 30 m above the filter. A flow net is constructed for the transformed section of the dam and consists of 4 flow channels and 16 head drops. Estimate the seepage loss per meter length of the dam.

A) q = 130 mL/s
B) q = 260 mL/s
C) q = 390 mL/s
D) q = 520 mL/s

▶ SOLUTIONS

P.1 ■ Solution

Part A: According to Bernoulli's equation, the total head h_t is given by the sum of elevation head h_z, pressure head h_p, and velocity head h_v.

$$h_t = h_z + h_p + h_v$$

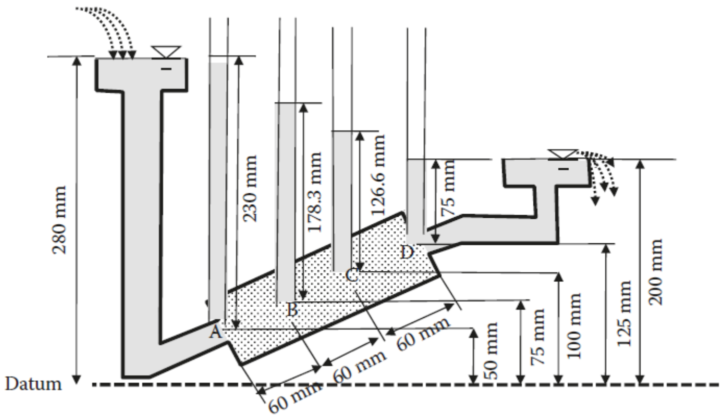
However, the velocity head term is often neglected in soil mechanics problems because its value is substantially smaller than the other two contributions to total head. Accordingly, we can write

$$h_t = h_z + h_p = z + \frac{u}{\gamma_w}$$

where *z* is elevation, *u* is the porewater pressure, and γ_w is the unit weight of water. Then, the following table is prepared. The total heads are highlighted in the blue column, while the pressure heads appear in the red column.

Point	h_z (mm)	h_t (mm)	$h_p = h_t - h_z$ (mm)
A	50	280	230
B	75	280 - 80/3 = 253.3	178.3
C	100	253.3 - 80/3 = 226.6	126.6
D	125	226.6 - 80/3 = 200	75

Since the points are evenly spaced, it makes sense that the head loss from A to B is one-third of the total head loss (= 80 mm). The same loss occurs from points B to C and from C to D. The heights of water in standpipes are illustrated below.



Clearly, the total head at point B is $h_{t,B}$ = 253.3 ≠ 235.5 mm, which implies that statement B is incorrect.

▶ The false statement is **B**.

Part B: The flow rate in the specimen can be determined with Darcy's law,

$$q = kiA$$

where the hydraulic conductivity $k = 3.4 \times 10^{-4}$ cm/s, the hydraulic gradient $i = \Delta h/L$ = 8/18 = 0.44, and the cross-sectional area $A = \pi \times 6^2/4$ = 28.3 cm². Thus,

$$q = (3.4 \times 10^{-4}) \times 0.44 \times 28.3 = \boxed{4.23 \times 10^{-4}\ \text{cm}^3/s}$$

▶ The correct answer is **B**.

P.2 ■ Solution

The hydraulic gradient within the length *L* is a dimensionless parameter defined as the rate of change in total head (or head loss), Δh, over the length, *L*,

$$i = \frac{\Delta h}{L}$$

Assuming that the flow obeys Darcy's law, we have $v = ki$, where *v* is the flow velocity and *k* is the coefficient of permeability of the material. The quantity of water that flows in a unit time through an area *A* is

$$q = \frac{Q}{t} = Av = Aki = Ak\frac{\Delta h}{L}$$

This equation can be easily solved for the hydraulic conductivity,

$$k = \frac{QL}{\Delta h \times At} = \frac{(540 \times 10^{-6}) \times (150 \times 10^{-3})}{(360 \times 10^{-3}) \times \left[\left(100^2 \times {}^{\pi}/_{4}\right) \times 10^{-6}\right] \times (1 \times 60)}$$

$$\therefore k = \boxed{4.8 \times 10^{-4}\ \text{m/s}}$$

► The correct answer is **D**.

P.3 ■ Solution

Part A: The head in the vertical capillary tube is equal to h_1. The valve on the tube is opened and the time *t* required for the head to fall to h_2 is recorded. The coefficient of permeability is then obtained from the relation

$$k = 2.303\frac{aL}{At}\log\frac{h_1}{h_2}$$

where *a* is the internal sectional area of the capillary tube, *A* is the cross-sectional area of the soil, and *L* is the length of the sample. Substituting the pertaining variables gives

$$k = 2.303\frac{\left(\frac{20.0^2\pi}{4}\right) \times 1000.0 \times 10^{-3}}{\left(\frac{100.0^2\pi}{4}\right) \times 60 \times 60}\log\left(\frac{800}{600}\right) = 3.2 \times 10^{-6}\ \text{m/s}$$

$$\therefore \boxed{k = 3.2 \times 10^{-4}\ \text{cm/s}}$$

► The correct answer is **C**.

Part B: To include the effect of temperature, the following equation may be used,

$$k_{20} = k_\theta\frac{\eta_\theta}{\eta_{20}}$$

where θ is an arbitrary temperature; in this case, θ = 30°C. Thus,

$$k_{20} = k_{30}\frac{\eta_{30}}{\eta_{20}} = 3.19 \times 10^{-4}\left(\frac{0.801 \times 10^{-3}}{1.005 \times 10^{-3}}\right) = \boxed{2.5 \times 10^{-4}\ \text{cm/s}}$$

► The correct answer is **B**.

P.4 ■ Solution

The hydraulic conductivity as obtained from the falling-head permeability test is

$$k = 2.303\frac{aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

Let us designate $2.303(aL/A)$ as a constant *C*,

$$k = \frac{C}{t}\log_{10}\left(\frac{h_1}{h_2}\right)$$

Substituting h_1 = 50 cm, h_2 = 48 cm, and *t* = 5×60 = 300 s gives

$$\frac{k}{C} = \frac{1}{300}\log_{10}\left(\frac{50}{48}\right)$$

When h_1 = 50 cm, we have h_2 = 25 cm. Thus,

$$\frac{k}{C} = \frac{1}{300}\log_{10}\left(\frac{50}{48}\right) = \frac{1}{t}\log_{10}\left(\frac{50}{25}\right)$$

$$\therefore t = 300 \times \frac{\log_{10}(50/25)}{\log_{10}(50/48)} = 5094\ \text{s} = \boxed{85\ \text{min}}$$

► The correct answer is **C**.

P.5 ■ Solution

We have k = 10 × 10^{-4} = 10^{-3} cm/s, h_1 = 24 cm, h_2 = 12 cm, t = 180 s. Substituting these and other given data into the relation for the variable head test gives

$$k = 2.303\frac{aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

$$\therefore 10^{-3} = 2.303\,\frac{a\times 10}{(\pi\times 4^2)\times 180}\log_{10}\left(\frac{24}{12}\right)$$

$$\therefore a = \frac{10^{-3}\times(\pi\times 4^2)\times 180}{2.303\times 10\times\log_{10}(24/12)} = 1.305\ \text{cm}^2$$

The diameter of the standpipe is d cm; that is,

$$1.305 = \frac{\pi d^2}{4} \rightarrow d = \left(\frac{4\times 1.305}{\pi}\right)^{\frac{1}{2}} = \boxed{13\ \text{mm}}$$

The standpipe should have a diameter of 13 mm so as to have the head of the standpipe fall the specified amount in the specified time.

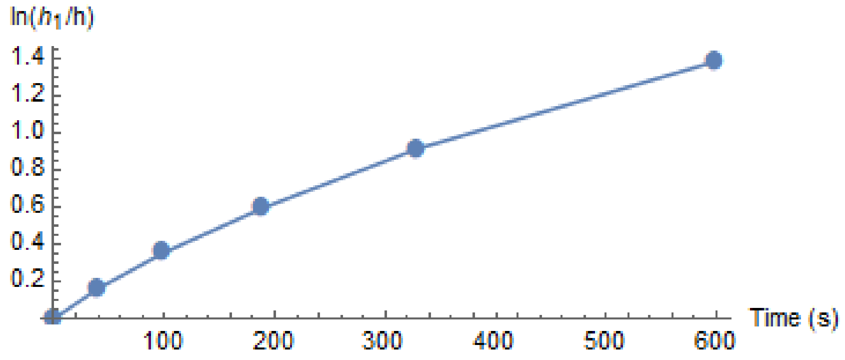
► The correct answer is **B.**

P.6 ■ Solution

Part A: The processed data are shown in the table below.

Time t since start of test (s)	0	40	100	190	330	600
h_1/h	1.000	1.176	1.429	1.818	2.500	4.000
$\ln(h_1/h)$	0	0.163	0.357	0.598	0.916	1.386

The plot we are looking for is one of *ln(h_1/h)*, the blue row in the table above, where h_1 = 1 m is the initial height of the sample, versus time t, the red row. Such a plot is shown in continuation.



The graph is curved, indicating a reduction in overall vertical permeability as the test progresses. Physically, this might be due to the migration of silt particles in the sand.

Part B: Recall that the following relation applies to the falling head permeability test,

$$\ln\left(\frac{h_1}{h}\right) = \frac{kA_1}{A_2L}t$$

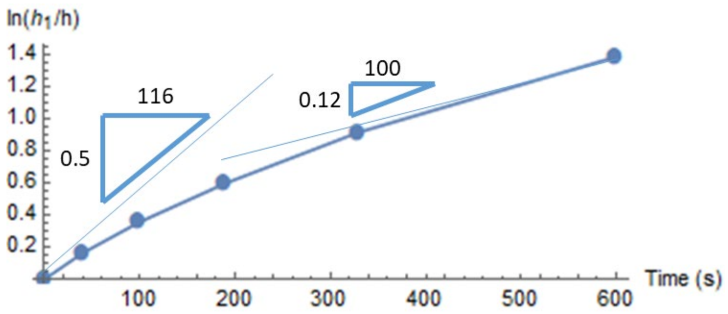
This implies that the graph of *ln(h_1/h)* versus time has slope

$$S = \frac{d(\ln h_1/h)}{dt} = \frac{kA_1}{A_2L}$$

which can be rearranged to give

$$k = \frac{A_2L}{A_1}S$$

From the graph, the initial slope is S = 0.5/116 = 4.31 × 10^{-3} s^{-1}, as shown.



Substituting A_1 = 8000 mm^2, A_2 = 10 mm^2, and L = 200 mm, we compute the factor

$$\frac{A_2 L}{A_1} = \frac{10 \times 200}{8000} = 0.25 \text{ mm} = 0.25 \times 10^{-3} \text{ m}$$

Thus, the initial hydraulic conductivity is

$$k_i = \frac{A_2 L}{A_1} S = (0.25 \times 10^{-3}) \times (4.31 \times 10^{-3}) = \boxed{1.1 \times 10^{-6} \text{ m/s}}$$

In a similar manner, the final slope is $S = 0.12/100 = 1.2 \times 10^{-3}$ s^{-1}, so that

$$k_f = (0.25 \times 10^{-3}) \times (1.2 \times 10^{-3}) = \boxed{3.0 \times 10^{-7} \text{ m/s}}$$

► The correct answer is **A**.

P.7 ■ Solution

The coefficient of permeability *k* in an unconfined aquifer such as the present one is given by

$$k = \frac{q \ln(r_2/r_1)}{\pi(h_2^2 - h_1^2)}$$

Here, q is the flow rate, r_1 and r_2 are distances from the pumped well, and h_1 and h_2 are the depths of the boreholes. Converting the flow rate q and substituting the remaining variables, we obtain

$$k = \frac{\left(\frac{1.85 \frac{\text{gal}}{\text{min}}}{7.48 \text{ ft} \times 60 \text{ sec}}\right) \text{ft/sec} \times \ln\left(\frac{100}{50}\right)}{\pi(15^2 - 12^2)} = \boxed{1.12 \times 10^{-5} \text{ ft/s}}$$

► The correct answer is **A**.

P.8 ■ Solution

The hydraulic conductivity *k* in an unconfined aquifer such as the present one is given by

$$k = \frac{q \ln(r_2/r_1)}{\pi H(h_2 - h_1)}$$

where, in addition to the variables indicated in the previous problem, we also have the thickness of the aquifer H = 12 ft. Substituting the pertaining quantities brings to

$$k = \frac{\left(\frac{205 \text{ gal/min}}{7.48 \text{ ft} \times 60 \text{ sec}}\right) \text{ft/sec} \times \ln\left(\frac{150}{75}\right)}{2\pi \times 12 \times (20 - 16)} = \boxed{1.05 \times 10^{-3} \text{ ft/s}}$$

► The correct answer is **B**.

P.9 ■ Solution

From the geometry of the terrain, we see that the hydraulic gradient, *i*, is such that

$$i = \frac{\text{Head loss}}{\text{Length}} = \frac{S \tan \alpha}{\left(\frac{S}{\cos \alpha}\right)} = \sin \alpha$$

The flow rate, in turn, is given by

$$q = kiA = k(\sin\alpha)\,(3\cos\alpha \times 1)$$

$$\therefore q = 3k\sin\alpha\cos\alpha = 3 \times 4.5 \times 10^{-5} \times \sin 10^{o} \times \cos 10^{o} = 2.31 \times 10^{-5}\ \mathrm{m^3/s}$$

To change this amount to m^3/hr, we multiply it by 3600, giving

$$q = 2.308 \times 10^{-5} \times 3600 = \boxed{0.083\ \mathrm{m^3/h/m}}$$

► The correct answer is **D**.

P.10 ■ Solution

The data we were given are summarized below.

$k_1 = 8 \times 10^{-4}\ \mathrm{cm/s}$	$h_1 = 7\ \mathrm{m}$
$k_2 = 52 \times 10^{-4}\ \mathrm{cm/s}$	$h_2 = 3\ \mathrm{m}$
$k_3 = 6 \times 10^{-4}\ \mathrm{cm/s}$	$h_3 = 10\ \mathrm{m}$

The total thickness of the soil layer is H = 20 m. The effective permeability in the horizontal direction, k_x, is given by the general expression

$$k_x = \frac{k_1h_1 + k_2h_2 + k_3h_3}{h_1 + h_2 + h_3} = \frac{(8 \times 10^{-4} \times 7) + (52 \times 10^{-4} \times 3) + (6 \times 10^{-4} \times 10)}{7 + 3 + 10}$$
$$= 0.00136 = \boxed{13.6 \times 10^{-4}\ \mathrm{cm/s}}$$

The effective permeability in the vertical direction, k_z, in turn, can be determined with the general relation

$$k_z = \frac{H}{\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3}} = \frac{20}{\frac{7}{8 \times 10^{-4}} + \frac{3}{52 \times 10^{-4}} + \frac{10}{6 \times 10^{-4}}} = \boxed{7.7 \times 10^{-4}\ \mathrm{cm/s}}$$

► The correct answer is **B**.

P.11 ■ Solution

We begin by determining the equivalent coefficient of permeability in the vertical direction, which is such that

$$k_y = \frac{k_1H_1 + k_2H_2 + k_3H_3}{H_1 + H_2 + H_3}$$

$$\therefore k_y = \frac{2.6 \times 10^{-7} \times (6 \times 30.48) + 3.2 \times 10^{-7} \times (4 \times 30.48) + 2.3 \times 10^{-7} \times (10 \times 30.48)}{(6 \times 30.48) + (4 \times 30.48) + (10 \times 30.48)}$$

$$\therefore k_y = 2.57 \times 10^{-7}\ \mathrm{cm/s}$$

or, equivalently,

$$k_y = 2.57 \times 10^{-9}\ \mathrm{m/s}$$

The water loss from the reservoir in one year follows from Darcy's law,

$$q = k_y iA$$

where i is the hydraulic gradient and A is the area of the reservoir. The former is given by

$$i = \frac{\Delta h}{H_1 + H_2 + H_3}$$

in which Δh = 70 × 0.305 = 21.35 m is the difference in elevation head. Substituting the appropriate variables in the equation for flow rate, we obtain

$$q = (2.57 \times 10^{-9}) \times \left(\frac{21.35}{6 \times 0.305 + 4 \times 0.305 + 10 \times 0.305}\right) \times (35{,}000 \times 0.0929)$$

$$\therefore q = 2.92 \times 10^{-5}\ \mathrm{m^3/s}$$

Since 1 year = 3.15×10^7 s, the water loss V of the reservoir in one year is determined to be

$$V = (2.92 \times 10^{-5}) \times (3.15 \times 10^7) = \boxed{920\ \mathrm{m^3}}$$

► The correct answer is **D**.

P.12 ■ Solution

The hydraulic conductivity of sandy soils can be determined with fair accuracy with the Kozeny-Carman equation,

$$k = \frac{1}{C_s S_s^2 T^2} \times \frac{\gamma_w}{\eta} \times \frac{e^3}{1+e}$$

which implies that the permeability follows the proportion $k \propto e^3/(1+e)$. Therefore, if a soil changes its void ratio from e_1 to e_2, the corresponding ratio of hydraulic conductivities, k_1/k_2, will be

$$\frac{k_1}{k_2} = \frac{\frac{e_1^3}{1+e_1}}{\frac{e_2^3}{1+e_2}}$$

Substituting k_1 = 0.03 cm/s, e_1 = 0.48, and e_2 = 0.64, we can determine the new hydraulic conductivity k_2,

$$\frac{0.03}{k_2} = \frac{\frac{0.48^3}{1+0.48}}{\frac{0.64^3}{1+0.64}} \rightarrow \boxed{k_2 = 0.064 \text{ cm/s}}$$

One can intuitively see that larger void ratios have higher void volumes, and hence a larger permeability. As expected, increasing the void ratio will cause the hydraulic conductivity to increase accordingly.

► The correct answer is **A**.

P.13 ■ Solution

Part A: To determine the critical hydraulic gradient, all we have to do is appeal to the relation

$$i_c = \frac{G_s - 1}{1+e}$$

Substituting G_s = 2.65 and e = 0.50 gives

$$i_c = \frac{2.65 - 1}{1+0.5} = \boxed{1.1}$$

► The correct answer is **B**.

Part B: Before determining the critical hydraulic gradient, we require the void ratio of the soil, which follows as

$$e = \frac{n}{1-n} = \frac{0.35}{1-0.35} = 0.54$$

The critical hydraulic gradient is then

$$i_c = \frac{G_s - 1}{1+e} = \frac{2.65 - 1}{1+0.54} = 1.07$$

With a factor of safety of 2.0 against piping, the corresponding hydraulic gradient is calculated as

$$i = \frac{i_c}{2} = \frac{1.07}{2} = 0.535$$

However, $i = h/L$, where h = 1.85 m is the upward seepage head and L is the depth of soil. Solving for L, the result is

$$i = 0.535 = \frac{1.85}{L} \rightarrow L = \frac{1.85}{0.535} = 3.46 \text{ m}$$

Deducting the available flow path of 1.25 m (= the thickness of the underlying soil), the depth of coarse sand required is

$$H = 3.46 - 1.25 = \boxed{2.21 \text{ m}}$$

► The correct answer is **C**.

P.14 ■ Solution

The equivalent permeability is taken as the geometric mean of horizontal and vertical permeabilities, i.e.,

$$k_e = \sqrt{k_h k_v} = \sqrt{(3 \times 10^{-2}) \times (1 \times 10^{-2})} = 1.73 \times 10^{-2} \text{ mm/s}$$

or, equivalently, k_e = 1.73×10^{-5} m/s. The seepage loss per meter length of the dam is computed with the formula

$$q = k_e H \frac{N_f}{N_d}$$

where H is the level of the full reservoir, N_f is the number of flow channels, and N_d is the number of head drops. Substituting the pertaining variables yields

$$q = (1.73 \times 10^{-5}) \times 30 \times \frac{4}{16} = 1.3 \times 10^{-4} \text{ m}^3/\text{s}$$

$$\therefore \boxed{Q = 130 \text{ mL/s}}$$

► The correct answer is **A**.

► ANSWER SUMMARY

Problem 1	**1A**	B
	1B	B
Problem 2		D
Problem 3	**3A**	C
	3B	B
Problem 4		C
Problem 5		B
Problem 6	**6A**	Open-ended pb.
	6B	A
Problem 7		A
Problem 8		B
Problem 9		D
Problem 10		B
Problem 11		D
Problem 12		A
Problem 13	**13A**	B
	13B	C
Problem 14		A

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