



# GATE 2024 Exam Solutions



## CIVIL ENGINEERING

*Exam held on*  
**04/02/2024**  
**Afternoon Session**



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### SECTION - A

### GENERAL APTITUDE

- Q.1** Visualize a cube that is held with one of the four body diagonals aligned to the vertical axis. Rotate the cube about this axis such that its view remains unchanged. The magnitude of the minimum angle of rotation is
- (a)  $120^\circ$  (b)  $90^\circ$   
(c)  $180^\circ$  (d)  $60^\circ$

**Ans. (a)**

End of Solution

- Q.2 Statements:**
1. All heroes are winners.
  2. All winners are lucky people.

**Inferences:**

- I. All lucky people are heroes.
- II. Some lucky people are heroes.
- III. Some winners are heroes.

Which of the above inferences can be logically deduced from statements 1 and 2?

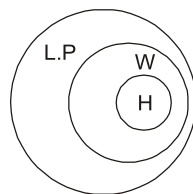
- (a) Only I and II (b) Only I and III  
(c) Only II and III (d) Only III

**Ans. (c)**

Conclusion 1 ×

Conclusion 2 ✓

Conclusion 3 ✓



End of Solution

- Q.3** A student was supposed to **multiply** a positive real number  $p$  with another positive real number  $q$ . Instead, the student **divided**  $p$  by  $q$ . If the percentage error in the student's answer is 80%, the value of  $q$  is

- (a) 2 (b)  $\sqrt{5}$   
(c) 5 (d)  $\sqrt{2}$

**Ans. (b)**

$$\frac{R \times q - \frac{R}{q}}{R \times q} = \frac{80}{100} = \frac{4}{5}$$

$$\frac{Rq - \frac{R}{q}}{Rq} = \frac{4}{5}$$

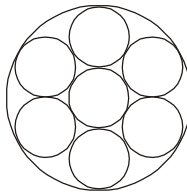
$$1 - \frac{1}{q^2} = \frac{4}{5}$$

$$\frac{1}{q^2} = \frac{1}{5}$$

$$q = \sqrt{5}$$

End of Solution

- Q.4** Seven identical cylindrical chalk-sticks are fitted tightly in a cylindrical container. The figure below shows the arrangement of the chalk-sticks inside the cylinder.



The length of the container is equal to the length of the chalk-sticks. The ratio of the occupied space to the empty space of the container is

- (a)  $9/2$  (b)  $5/2$   
(c) 3 (d)  $7/2$

**Ans. (d)**

$$\text{Volume of outer cylinder} = \pi R^2 h$$

$$\text{Volume of smaller cylinder} = \pi r^2 h$$

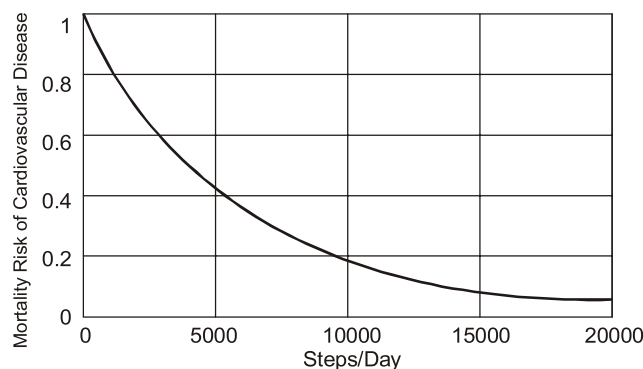
$$R = 3r$$

Ratio of occupied space to empty space

$$= \frac{7 \times \pi r^2 h}{9\pi r^2 h - 7 \times \pi r^2 h} = \frac{7}{2}$$

End of Solution

- Q.5** The plot below shows the relationship between the mortality risk of cardiovascular disease and the number of steps a person walks per day. Based on the data, which one of the following options is true?



- (a) For any 5000 increment in steps/day the largest risk reduction occurs on going from 15000 to 20000.
- (b) The risk reduction on increasing the steps/day from 0 to 5000 is less than the risk reduction on increasing the steps/day from 15000 to 20000.
- (c) The risk reduction on increasing the steps/day from 0 to 10000 is less than the risk reduction on increasing the steps/day from 10000 to 20000.
- (d) For any 5000 increment in steps/day the largest risk reduction occurs on going from 0 to 5000.

**Ans. (d)**

**End of Solution**

**Q.6** In the given text, the blanks are numbered (i)-(iv). Select the best match for all the blanks. Yoko Roi stands (i) as an author for standing (ii) as an honorary fellow, after she stood (iii) her writings that stand (iv) the freedom of speech.

- |              |           |           |          |
|--------------|-----------|-----------|----------|
| (a) (i) down | (ii) out  | (iii) by  | (iv) in  |
| (b) (i) down | (ii) out  | (iii) for | (iv) in  |
| (c) (i) out  | (ii) down | (iii) in  | (iv) for |
| (d) (i) out  | (ii) down | (iii) by  | (iv) for |

**Ans. (c)**

**End of Solution**

**Q.7** If the sum of the first 20 consecutive positive odd numbers is divided by  $20^2$ , the result is

- |           |        |
|-----------|--------|
| (a) 1     | (b) 20 |
| (c) $1/2$ | (d) 2  |

**Ans. (c)**

The sum of first  $n$  odd natural number =  $n^2$

$$\therefore \text{Result is } \frac{20^2}{20^2} = 1$$

**End of Solution**

**Q.8** The ratio of the number of girls to boys in class VIII is the same as the ratio of the number of boys to girls in class IX. The total number of students (boys and girls) in classes VIII and IX is 450 and 360, respectively. If the number of girls in classes VIII and IX is the same, then the number of girls in each class is

- |         |         |
|---------|---------|
| (a) 200 | (b) 175 |
| (c) 250 | (d) 150 |

**Ans. (a)**



	Class VIII	Class IX
Total students	450	360
Number of girls	G	G
Number of boys	450 – G	360 – G

According to question,

$$\frac{G}{450 - G} = \frac{360 - G}{G}$$

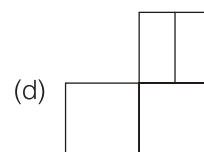
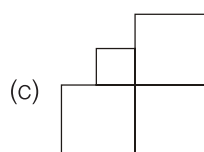
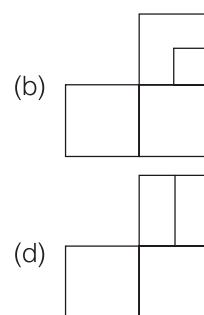
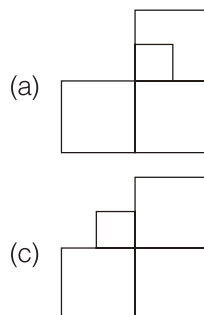
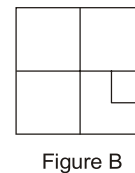
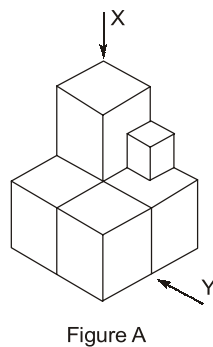
$$G^2 = 360 \times 450 - 450 G - 360 G + G^2$$

$$810 G = 360 \times 450$$

$$G = \frac{360 \times 450}{810} = 200$$

End of Solution

- Q.9** Five cubes of identical size and another smaller cube are assembled as shown in Figure A. If viewed from direction X, the planar image of the assembly appears as Figure B.



**Ans. (b)**

End of Solution

**Q.10** If '→' denotes increasing order of intensity, then the meaning of the words [drizzle → rain → downpour] is analogous to [\_\_\_\_\_ → quarrel → feud].

Which one of the given options is appropriate to fill the blank?

- |            |            |
|------------|------------|
| (a) bog    | (b) dither |
| (c) bicker | (d) dodge  |

**Ans. (c)**

Bicker → To argue about un-important thing or issue

Quarrel → Angry, argument or disagreement

Feud → Angry or serious argument between two people that continues for long period of time.

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- Q.3** Which one of the following saturated fine-grained soils can attain a negative Skempton's pore pressure coefficient (A)?
- (a) Over-consolidated clays
  - (b) Lightly-consolidated clays
  - (c) Quick clays
  - (d) Normally-consolidated clays

**Ans. (a)**

End of Solution

- Q.4** Various stresses in jointed plain concrete pavement with slab size of 3.5 m × 4.5 m are denoted as follows:

Wheel load stress at interior =  $S_{wl}^i$

Wheel load stress at edge =  $S_{wl}^e$

Wheel load stress at corner =  $S_{wl}^c$

Warping stress at interior =  $S_t^i$

Warping stress at edge =  $S_t^e$

Warping stress at corner =  $S_t^c$

Frictional stress between slab and supporting layer =  $S_f$

The critical stress combination in the concrete slab during a summer midnight is

- |                              |                              |
|------------------------------|------------------------------|
| (a) $S_{wl}^c + S_t^c + S_f$ | (b) $S_{wl}^c + S_t^c$       |
| (c) $S_{wl}^e + S_t^e - S_f$ | (d) $S_{wl}^e + S_t^e + S_f$ |

**Ans. (b)**

During summer at night, maximum stress combination occur due to load and warping stresses at corner.

End of Solution

- Q.5** The function  $f(x) = x^3 - 27x + 4$ ,  $1 \leq x \leq 6$  has
- (a) Minima point
  - (b) Maxima point
  - (c) Saddle point
  - (d) Inflection point

**Ans. (a)**

$$f(x) = x^3 - 27x + 4$$

$$f'(x) = 3x^2 - 27$$

$$f'(x) = 0$$

$$\Rightarrow 3x^2 - 27 = 0$$

$$3x^2 = 27$$

$$x^2 = 9$$

$$x = \pm 3$$

$$f''(x) = 6x$$

$$f''(x)|_{x=3} = 6 \times 3 = 18 > 0$$

$$f''(x) > 0$$

At  $x = 3$ , there will point of minima.

Hence option (a) is answer.

End of Solution

- Q.6** To finalize the direction of a survey, four surveyors set up a theodolite at a station  $P$  and performed all the temporary adjustments. From the station  $P$ , each of the surveyors observed the bearing to a tower located at station  $Q$  with the same instrument without shifting it. The bearings observed by the surveyors are  $30^\circ 30' 00''$ ,  $30^\circ 29' 40''$ ,  $30^\circ 30' 20''$  and  $30^\circ 31' 20''$ . Assuming that each measurement is taken with equal precision, the most probable value of the bearing is

- (a)  $30^\circ 29' 40''$  (b)  $30^\circ 30' 20''$   
(c)  $30^\circ 31' 20''$  (d)  $30^\circ 30' 00''$

**Ans. (b)**

$$\begin{aligned} \text{Most probable value} &= \frac{30^\circ 30' 00'' + 30^\circ 29' 40'' + 30^\circ 30' 20'' + 30^\circ 31' 20''}{4} \\ &= 30^\circ 30' 20'' \end{aligned}$$

End of Solution

- Q.7** Consider the following data for a project of 300 days duration.

Budgeted Cost of Work Scheduled (BCWS) = Rs. 200

Budgeted Cost of Work Performed (BCWP) = Rs. 150

Actual Cost of Work Performed (ACWP) = Rs. 190

The 'schedule variance' for the project is

- (a) (-)50 days (b) (-)Rs 50  
(c) (+)50 days (d) (+)Rs 50

**Ans. (b)**

Schedule Variance is given by,

$$SV = BCWP - BCWS$$

here, BCWP = Rs. 150

BCWS = Rs. 200

$$\therefore SV = 150 - 200$$

$$= (-) \text{ Rs. } 50$$

A negative variance indicates a behind-schedule condition.

End of Solution

- Q.8** What is the CORRECT match between the survey instruments/parts of instruments shown in the table and the operations carried out with them?

Instruments/Parts of instruments	Operations
P - Bubble tube	i - Tacheometry
Q - Plumb bob	ii - Minor movements
R - Tangent screw	iii - Centering
S - Stadia cross-wire	iv - Levelling

- (a) P-iv, Q-iii, R-ii, S-i                      (b) P-ii, Q-iii, R-iv, S-i  
(c) P-i, Q-iii, R-ii, S-iv                      (d) P-iii, Q-iv, R-i, S-ii

**Ans. (a)**

End of Solution

- Q.9** Which one of the following products is NOT obtained in anaerobic decomposition of glucose?

- (a)  $H_2O$     (b)  $CH_4$   
(c)  $H_2S$     (d)  $CO_2$

**Ans. (c)**

End of Solution

- Q.10** A 2 m wide rectangular channel is carrying a discharge of  $30 \text{ m}^3/\text{s}$  at a bed slope of 1 in 300. Assuming the energy correction factor as 1.1 and acceleration due to gravity as  $10 \text{ m/s}^2$ , the critical depth of flow (in meters) is \_\_\_\_\_ (rounded off to 2 decimal places).

**Ans. (2.91) (2.85 to 2.95)**

Discharge,  $Q = 30 \text{ m}^3/\text{s}$

$g = 10 \text{ m/s}^2$

Width of channel,  $B = 2 \text{ m}$

Now, Discharge intensity,  $q = \frac{Q}{B} = \frac{30}{2} = 15 \text{ m}^3/\text{s/m}$

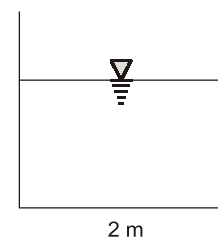
Now critical energy,  $E_c$  is given as

$$E_c = y_c + \alpha \cdot \frac{v^2}{2g}$$

$$\Rightarrow E_c = y_c + \alpha \cdot \frac{q^2}{2g \cdot y_c^2}$$

$$\Rightarrow 1.5y_c = y_c + \alpha \cdot \frac{q^2}{2g \cdot y_c^2}$$

$$\Rightarrow 0.5y_c = \alpha \cdot \frac{q^2}{2g \cdot y_c^2}$$



$$\Rightarrow y_c^3 = \alpha \cdot \frac{q^2}{g}$$

$$\Rightarrow y_c = \left( \frac{\alpha \cdot q^2}{g} \right)^{1/3}$$

$$\Rightarrow y_c = \left( \frac{1.1 \times 15^2}{20} \right)^{1/3} = 2.914 \text{ m}$$

**Alternatively,**

At critical condition,

$$\frac{\alpha Q^2}{g} = \frac{A_c^3}{T_c}$$

Where,

$A_c$  = Critical area of flow =  $(By_c) = 2y_c$

$T_c$  = Critical top width =  $B = 2 \text{ m}$

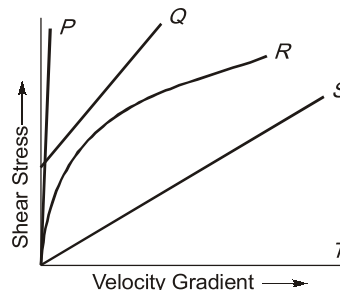
$$\Rightarrow \frac{1.1 \times 30^2}{10} = \frac{(2y_c)^3}{2}$$

$$\Rightarrow \frac{1.1 \times 30^2}{40} = y_c^3$$

$$\Rightarrow y_c = 2.914 \text{ m}$$

End of Solution

**Q.11** The following figure shows a plot between shear stress and velocity gradient for materials/fluids P, Q, R, S, and T.



Which one of the following options is CORRECT?

- (a) P → Ideal Fluid; Q → Ideal Bingham plastic  
R → Non-Newtonian fluid; T → Real solid
- (b) P → Ideal Fluid; Q → Ideal Bingham plastic  
R → Non-Newtonian fluid; S → Newtonian fluid
- (c) P → Real solid; Q → Ideal Bingham plastic  
S → Newtonian fluid; T → Ideal Fluid
- (d) P → Real solid; Q → Newtonian fluid  
R → Ideal Bingham plastic; T → Ideal Fluid

**Ans. (c)**

End of Solution





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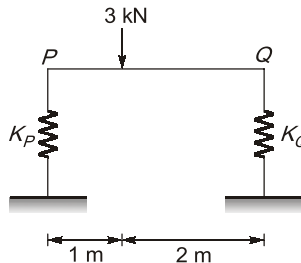
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**Q.12** A 3 m long, horizontal, rigid, uniform beam  $PQ$  has negligible mass. The beam is subjected to a 3kN concentrated vertically downward force at 1 m from  $P$ , as shown in the figure. The beam is resting on vertical linear springs at the ends  $P$  and  $Q$ . For the spring at the end  $P$ , the spring constant  $K_P = 100\text{kN/m}$ .



(Figure NOT to scale)

If the beam DOES NOT rotate under the application of the force and displaces only vertically, the value of the spring constant  $K_Q$  (in kN/m) for the spring at the end  $Q$

- (a) 200 (b) 50  
(c) 100 (d) 150

Ans. (b)

Let  $V_P$  and  $V_Q$  be forces in spring and stiffness of spring at  $Q$  is  $k_Q$ .

From equilibrium equations,

$$\Sigma F_v = 0$$

$$V_P + V_Q = 3$$

Also,

$$\Sigma M_P = 0$$

$$\Rightarrow V_Q \times 3 - 3 \times 1 = 0$$

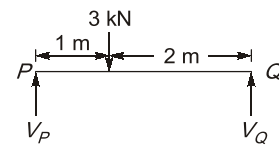
$$\Rightarrow V_Q = 1 \text{ kN and } V_P = 2 \text{ kN}$$

Now,

$$\delta_P = \delta_Q$$

$$\Rightarrow \frac{2}{100} = \frac{1}{k_Q}$$

$$\Rightarrow k_Q = 50 \text{ kN/m}$$



**End of Solution**

**Q.13** A simply supported, uniformly loaded, two-way slab panel is torsionally unrestrained. The effective span lengths along the short span ( $x$ ) and long span ( $y$ ) directions of the panel are  $l_x$  and  $l_y$ , respectively. The design moments for the reinforcements along the  $x$  and  $y$  directions are  $M_{ux}$  and  $M_{uy}$ , respectively. By using Rankine-Grashoff method, the ratio  $M_{ux}/M_{uy}$  is proportional to

- (a)  $(ly/lx)^2$  (b)  $ly/lx$   
(c)  $lx/l_v$  (d)  $(lx/ly)^2$

Ans. (a)

By Rankine Grashoff method,

$$Mu_x = \frac{r^4}{1+r^4} w_u \times \frac{L_x^2}{8}$$

$$Mu_y = \frac{1}{1+r^4} w_u \times \frac{L_y^2}{8}$$

Now,

$$\frac{Mu_x}{Mu_y} = r^4 \cdot \frac{L_x^2}{L_y^2} = \left(\frac{L_y}{L_x}\right)^4 \times \left(\frac{L_x}{L_y}\right)^2 = \left(\frac{L_y}{L_x}\right)^2$$

End of Solution

**Q.14** What is the CORRECT match between the air pollutants and treatment techniques given in the table?

Air pollutants	Treatment techniques
P - NO <sub>2</sub>	i - Flaring
Q - SO <sub>2</sub>	ii - Cyclonic separator
R - CO	iii - Lime scrubbing
S - Particles	iv - NH <sub>3</sub> injection

(a) P-i, Q-ii, R-iii, S-iv

(b) P-ii, Q-iii, R-iv, S-i

(c) P-ii, Q-i, R-iv, S-iii

(d) P-iv, Q-iii, R-i, S-ii

Ans. (d)

End of Solution

**Q.15** A partial differential equation

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0$$

is defined for the two-dimensional field  $T : T(x, y)$ , inside a planar square domain of size 2 m × 2 m. Three boundary edges of the square domain are maintained at value  $T = 50$ , whereas the fourth boundary edge is maintained at  $T = 100$ .

The value of  $T$  at the center of the domain is

(a) 75.0

(b) 62.5

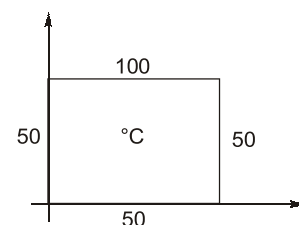
(c) 87.5

(d) 50.0

Ans. (b)

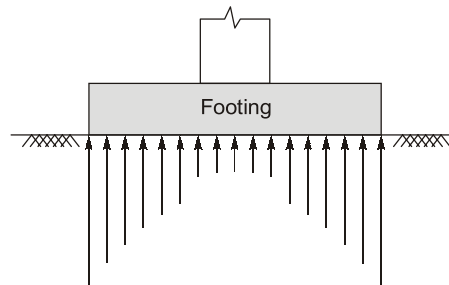
Temperature at centre = Average of temp at sides

$$= \frac{50 + 50 + 50 + 100}{4} = 62.5$$



End of Solution

**Q.16** The contact pressure distribution shown in the figure belongs to a



- (a) flexible footing resting on a cohesionless soil.
- (b) rigid footing resting on a cohesive soil.
- (c) flexible footing resting on a cohesive soil.
- (d) rigid footing resting on a cohesionless soil.

**Ans. (b)**

End of Solution

**Q.17** The statements  $P$  and  $Q$  are related to matrices  $A$  and  $B$ , which are conformable for both addition and multiplication.

$$P : (A + B)^T = A^T + B^T$$

$$Q : (AB)^T = A^T B^T$$

Which one of the following options is CORRECT?

- (a)  $P$  is TRUE and  $Q$  is FALSE
- (b)  $P$  is FALSE and  $Q$  is TRUE
- (c) Both  $P$  and  $Q$  are FALSE
- (d) Both  $P$  and  $Q$  are TRUE

**Ans. (a)**

$P$  : it is obviously true because transpose is distributed over addition. i.e.  $(A + B)^T = A^T + B^T$

$Q$  : it is false because in matrix multiplication Transpose should follow Reversal law i.e.  $(AB)^T = B^T A^T$ .

End of Solution

**Q.18** In general, the outer edge is raised above the inner edge in horizontal curves for

- (a) Railways and Taxiways only
- (b) Highways, Railways, and Taxiways
- (c) Highways and Railways only
- (d) Highways only

**Ans. (c)**

In highways and railways, the outer edge is raised above the inner edge in horizontal curve.

End of Solution



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**Q.19** Consider the statements  $P$  and  $Q$ .

$P$ : In a Pure project organization, the project manager maintains complete authority and has maximum control over the project.

$Q$ : A Matrix organization structure facilitates quick response to changes, conflicts, and project needs.

Which one of the following options is CORRECT?

- (a) Both  $P$  and  $Q$  are TRUE
- (b)  $P$  is TRUE and  $Q$  is FALSE
- (c)  $P$  is FALSE and  $Q$  is TRUE
- (d) Both  $P$  and  $Q$  are FALSE

**Ans. (a)**

$P$ : In a pure project organisation, the project manager has the complete authority and control over the project.

$Q$ : In a matrix organisation, employees have more than one boss and work on multiple teams. This leads to quick response to changes, conflicts and project needs.

End of Solution

**Q.20** Consider two Ordinary Differential Equations (ODEs):

$$P: \frac{dy}{dx} = \frac{x^4 + 3x^2y^2 + 2y^4}{x^3y}$$

$$Q: \frac{dy}{dx} = \frac{-y^2}{x^2}$$

Which one of the following options is CORRECT?

- (a)  $P$  is a non-homogeneous ODE and  $Q$  is an exact ODE.
- (b)  $P$  is a nonhomogeneous ODE and  $Q$  is not an exact ODE.
- (c)  $P$  is a homogeneous ODE and  $Q$  is not an exact ODE.
- (d)  $P$  is a homogeneous ODE and  $Q$  is an exact ODE.

**Ans. (b)**

$P \Rightarrow$  non-homogeneous

$$Q: \frac{dy}{dx} = \frac{-y^2}{x^2}$$

$$x^2 dy + y^2 dx = 0$$

$$\left. \begin{aligned} y^2 dx + x^2 dy &= 0 \\ M dx + N dy &= 0 \end{aligned} \right\} \text{Compare it}$$

$$M = y^2, \quad N = x^2$$

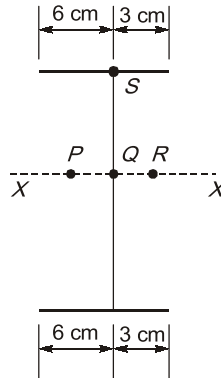
$$\frac{\partial M}{\partial y} = 2y, \quad \frac{\partial N}{\partial x} = 2x$$

$$\frac{\partial M}{\partial y} \neq \frac{\partial N}{\partial x}$$

$\Rightarrow$  So,  $Q$  is non-exact option (b).

End of Solution

- Q.21** For a thin-walled section shown in the figure, points  $P$ ,  $Q$ , and  $R$  are located on the major bending axis  $X - X$  of the section. Point  $Q$  is located on the web whereas point  $S$  is located at the intersection of the web and the top flange of the section.



(Figure NOT to scale)

Qualitatively, the shear center of the section lies at

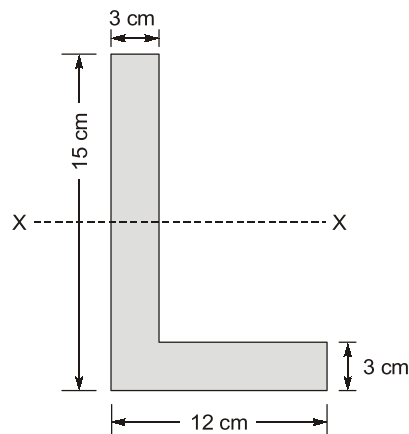
- (a)  $P$  (b)  $S$   
(c)  $R$  (d)  $Q$

**Ans. (c)**

Position of shear centre will be at  $R$ .

End of Solution

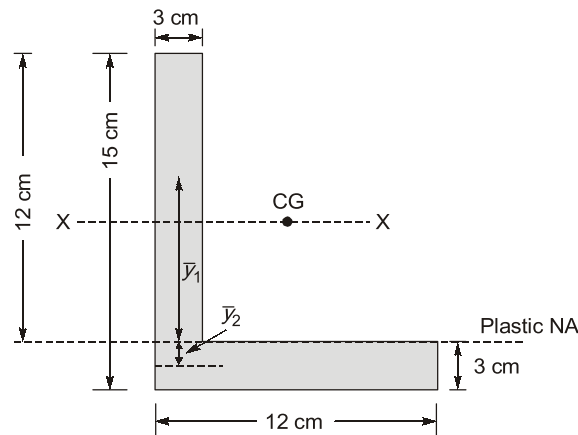
- Q.22** The steel angle section shown in the figure has elastic section modulus of  $150.92 \text{ cm}^3$  about the horizontal  $X - X$  axis, which passes through the centroid of the section.



(Figure NOT to scale)

The shape factor of the section is \_\_\_\_\_ (rounded off to 2 decimal places).

Ans. (1.79)(1.76 - 1.84)



$$\begin{aligned}\text{Gross area, Area} &= b_e t \\ &= (15 + 12 - 3) \times 3 \\ &= 72 \text{ cm}^2\end{aligned}$$

Location of plastic neutral axis

$$A_1 = A_2 = 36 \text{ cm}^2$$

where  $A_1$  is the area above plastic N.A. and  $A_2$  is the area below plastic N.A.

$$\begin{aligned}\therefore Z_{Px} &= \frac{A}{2}(\bar{y}_1 + \bar{y}_2) = \frac{72}{2} \left( 6 + \frac{3}{2} \right) \\ &= 270 \text{ cm}^3\end{aligned}$$

$$\Rightarrow \text{Shape factor, S.F.} = \frac{Z_P}{Z_e} = \frac{270}{150.92} = 1.79$$

End of Solution

**Q.23** A reinforced concrete pile of 10 m length and 0.7 m diameter is embedded in a saturated pure clay with unit cohesion of 50 kPa. If the adhesion factor is 0.5, the net ultimate uplift pullout capacity (in kN) of the pile is \_\_\_\_\_ (rounded off to the nearest integer).

Ans. (550)(548 - 551)

Length of pile,  $L = 10 \text{ m}$ , Diameter of pile,  $d = 0.7 \text{ m}$

Cohesion,  $C = 50 \text{ kPa}$

Adhesion factor,  $\alpha = 0.5$

Net ultimate uplift pullout capacity,

$$\begin{aligned}T &= \alpha C \pi d L = 0.5 \times 50 \times \pi \times 0.7 \times 10 = 549.78 \text{ kN} \\ &= 550 \text{ kN}\end{aligned}$$

End of Solution



**Q.24** The longitudinal sections of a runway have gradients as shown in the table.

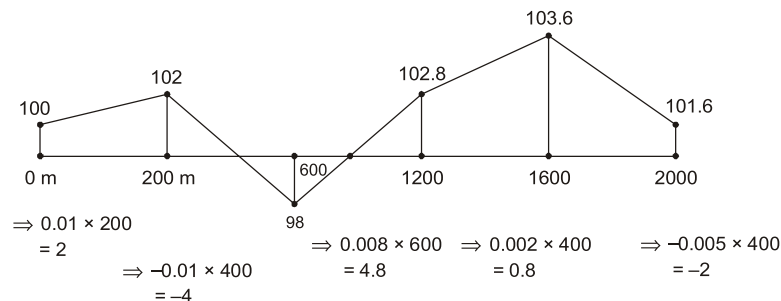
End to end for sections of runway (m)	Gradient (%)
0 to 200	+ 1.0
200 to 600	– 1.0
600 to 1200	+ 0.8
1200 to 1600	+ 0.2
1600 to 2000	– 0.5

Consider the reduced level (RL) at the starting point of the runway as 100 m.

The effective gradient of the runway is

- (a) 0.28%                      (b) 0.18%
- (c) 0.02%                     (d) 0.35%

Ans. (a)



$$\begin{aligned}\text{Gradient} &= \frac{\text{Highest elevation} - \text{Lowest elevation}}{\text{Length}} \\ &= \frac{103.6 - 98}{2000} \times 100 = 0.28\%\end{aligned}$$

**End of Solution**

**Q.25** The structural design method that DOES NOT take into account the safety factors on the design loads is

- (a) limit state method. (b) ultimate load method.  
(c) load factor method. (d) working stress method.

Ans. (d)

**End of Solution**

**Q.26** A hypothetical multimedia filter, consisting of anthracite particles (specific gravity: 1.50), silica sand (specific gravity: 2.60), and ilmenite sand (specific gravity: 4.20), is to be designed for treating water/wastewater. After backwashing, the particles should settle forming three layers: coarse anthracite particles at the top of the bed, silica sand in the middle, and small ilmenite sand particles at the bottom of the bed.

Assume

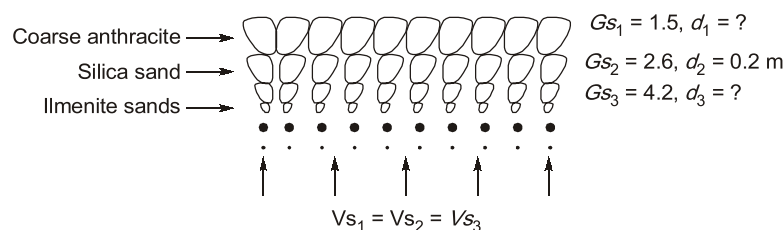
- (i) Slow discrete settling (Stoke's law is applicable)
- (ii) All particles are spherical

(iii) Diameter of silica sand particles is 0.20 mm

The CORRECT option fulfilling the diameter requirements for this filter media is

- (a) diameter of anthracite particles is slightly less than 0.35 mm and diameter of ilmenite particles is slightly greater than 0.141 mm.
- (b) diameter of anthracite particles is slightly greater than 0.35 mm and diameter of ilmenite particles is slightly less than 0.141 mm.
- (c) diameter of anthracite particles is slightly greater than 0.64 mm and diameter of ilmenite particles is slightly less than 0.10 mm.
- (d) diameter of anthracite particles is slightly less than 0.64 mm and diameter of ilmenite particles is slightly less than 0.10 mm.

**Ans. (a)**



$$\frac{1}{18\mu}(G_{s1} - 1)\rho g d_1^2 = \frac{\rho g}{18\mu}(G_{s2} - 1)d_2^2 = \frac{\rho g}{18\mu}(G_{s3} - 1)d_3^2$$

$$\frac{\rho g}{18\mu}(G_s - 1)d_1^2 = \frac{\rho g}{18\mu}(G_{s2} - 1)d_2^2 = \frac{\rho g}{18\mu}(G_{s3} - 1)d_3^2$$

$$(G_{s1} - 1)d_1^2 = (G_{s2} - 1) \cdot d_2^2$$

$$(1.5 - 1)d_1^2 = (2.6 - 1) \times (0.2)^2$$

$$d_1 = 0.357 \text{ m}$$

$$(G_{s2} - 1)d_2^2 = (G_{s3} - 1) \cdot d_3^2$$

$$(2.6 - 1) \times (0.2)^2 = (4.2 - 1)d_3^2$$

$$d_3 = 0.141 \text{ mm}$$

**NOTE :** The logic is that if we are creating 3 layers for better filtration and if we want those layers to be intact, even after backwashing, then we need to ensure that as the backwashing is stopped, each layer settles with the same velocity so that the stratification is maintained as it is.

End of Solution



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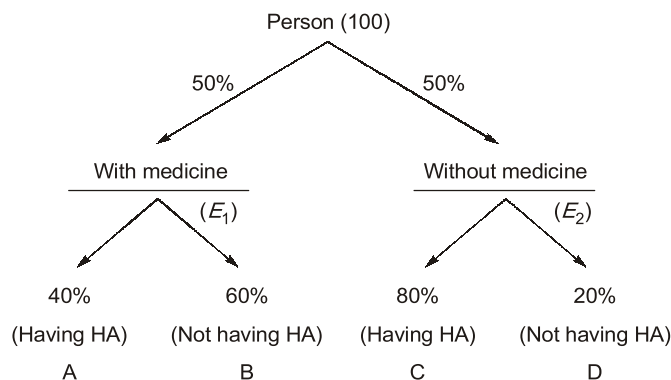
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- Q.27** In a sample of 100 heart patients, each patient has 80% chance of having a heart attack without medicine X. It is clinically known that medicine X reduces the probability of having a heart attack by 50%. Medicine X is taken by 50 of these 100 patients. The probability that a randomly selected patient, out of the 100 patients, takes medicine X and has a heart attack is
- (a) 40% (b) 60%  
(c) 30% (d) 20%

**Ans. (d)**



$$P\left(\frac{A}{E_1}\right) = 50\% \times 40\% = \frac{50}{100} \times \frac{40}{100} = \frac{20}{100} = 20\%$$

End of Solution

- Q.28** A circular settling tank is to be designed for primary treatment of sewage at a flow rate of 10 million liters/day. Assume a detention period of 2.0 hours and surface loading rate of 40000 liters/ m<sup>2</sup>/ day. The height (in meters) of the water column in the tank is \_\_\_\_\_ (rounded off to 2 decimal places).

**Ans. (3.33)(3.25 - 3.45)**

Discharge,  $Q = 10 \text{ MLD}$

Discharge,  $t_d = 2 \text{ hr}$

Overflow rate,  $V_0 = 40000 \text{ litres/m}^2/\text{day}$

Now, volume of tank,  $V = Q \times t_d$

$$= 10 \times 10^6 \times \left(\frac{2}{24}\right) \times 10^{-3}$$

$$= 833.33 \text{ m}^3$$

Also, surface area of tank,

$$sA = \frac{Q}{V_0} = \frac{10 \times 10^6}{40000} = 250 \text{ m}^2/\text{day}$$

Note : However, if sludge zone is also considered, then volume of tank,

$$V = D^2(0.785H + 0.011D)$$

And, surface area of tank,

$$sA = \frac{\pi D^2}{4}$$

where D is diameter of tank

$$\text{Now, height of tank} = \frac{V}{dA} = \frac{D^2(0.785H + 0.011D)}{\frac{\pi D^2}{4}}$$

$$= \frac{4}{\pi} (0.785H + 0.011D)$$

Now,  $V = 833.33 \text{ m}^3$

Also,  $SA = \frac{\pi D^2}{4} = 250$

$\Rightarrow D = 17.84 \text{ m}$

So,  $\frac{833.33}{250} = \frac{4}{\pi} (0.785H + 0.011D)$

$\Rightarrow 3.33 = \frac{4}{\pi} (0.785H + 0.011 \times 17.84)$

$\Rightarrow H = 3.33 \text{ m}$

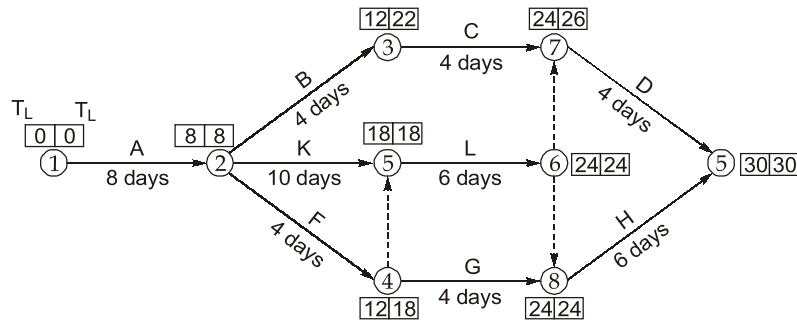
End of Solution

**Q.29** The table shows the activities and their durations and dependencies in a project.

Activity	Duration (Days)	Depends on
A	8	-
B	4	A
C	4	B
D	4	C, L
F	4	A
G	4	F
H	6	G, L
K	10	A
L	6	F, K

The total duration (in days) of the project is \_\_\_\_\_ (in integer).

Ans.  $(30)(30 - 30)$



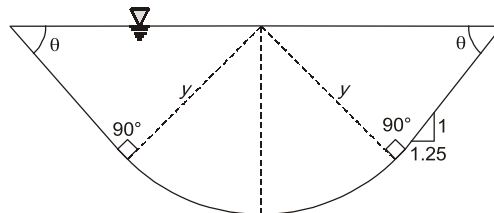
Critical path is along A – B – L – H and project duration is 30 days.

**End of Solution**

**Q.30** A round-bottom triangular lined canal is to be laid at a slope of 1 in 1500, to carry a discharge of 25 m<sup>3</sup>/s. The side slopes of the canal cross-section are to be kept at 1.25H : 1V. If Manning's roughness coefficient is 0.013, the flow depth (in meters) will be in the range of

- (a) 1.94 to 1.97                      (b) 2.39 to 2.42  
(c) 2.24 to 2.27                      (d) 2.61 to 2.64

Ans. (b)



From the figure,  $\tan\theta = \frac{1}{1.25}$

$$\theta = 38.66^\circ = 38.66^\circ \times \frac{\pi}{180^\circ} = 0.675 \text{ radians}$$

Also,

$$\cot\theta = 1.25$$

Cross sectional area,  $A = y^2 (\theta + \cot\theta)$

$$= y^2 [0.675 + 1.25] = 1.925 y^2$$

Perimeter,

$$P = 2y (\theta + \cot\theta)$$

Now, Hydraulic radius,  $R = \frac{A}{P} = \frac{y^2 (\theta + \cot \theta)}{2y (\theta + \cot \theta)} = \frac{y}{2}$

Now, Discharge,  $Q = A \times \frac{1}{n} R^{2/3} S^{1/2}$

$$\Rightarrow 25 = (1.925y^2) \times \frac{1}{0.013} \times \left(\frac{y}{2}\right)^{2/3} \times \left(\frac{1}{1500}\right)^{1/2}$$

$$\Rightarrow y = 2.404 \text{ m}$$

**End of Solution**

- Q.31** A vertical summit curve on a freight corridor is formed at the intersection of two gradients, +3.0% and -5.0%.  
 Assume the following:  
 Only large-sized trucks are allowed on this corridor  
 Design speed = 80 kmph  
 Eye height of truck drivers above the road surface = 2.30 m  
 Height of object above the road surface for which trucks need to stop = 0.35 m  
 Total reaction time of the truck drivers = 2.0 s  
 Coefficient of longitudinal friction of the road = 0.36  
 Stopping sight distance gets compensated on the gradient  
 The design length of the summit curve (in meters) to accommodate the stopping sight distance is \_\_\_\_\_ (rounded off to 2 decimal places).

**Ans. (117.93)(117.5 - 118.5)**

$$\begin{aligned} n_1 &= +3\% \\ n_2 &= -5\% \\ v &= 80 \text{ km/h} \\ h_1 &= 2.30 \text{ m} \\ h_2 &= 0.35 \text{ m} \\ t_r &= 2 \text{ sec.} \\ f &= 0.36 \end{aligned}$$

$$\text{Deflection angle, } N = |n_1 - n_2| = 8\%$$

Now stopping sight distance, S is given as

$$\begin{aligned} S &= 0.278V_r + \frac{v^2}{254f} \\ &= 0.278 \times 80 \times 2 + \frac{80^2}{254 \times 0.36} = 114.47 \text{ m} \end{aligned}$$

Now assume, length of summit curve ( $L_s$ ) is greater than stopping sight distance.

$$\begin{aligned} L_s &= \frac{NS^2}{2[\sqrt{h_1} + \sqrt{h_2}]^2} = \frac{0.08 \times (114.47)^2}{2[\sqrt{2.3} + \sqrt{0.35}]^2} \\ &= 117.93 \text{ m} > 114.47 \end{aligned}$$

End of Solution



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**Q.32** A rectangular channel is 4.0 m wide and carries a discharge of 2.0 m<sup>3</sup>/s with a depth of 0.4 m. The channel transitions to a maximum width contraction at a downstream location, without influencing the upstream flow conditions. The width (in meters) at the maximum contraction is \_\_\_\_\_ (rounded off to 2 decimal places).

**Ans. (3.53)(3.45 - 3.60)**

Width of channel,  $B = 4$  m

Discharge,  $Q = 2$  m<sup>3</sup>/s

Depth of flow,  $y = 0.4$  m

Now,

$$E_1 = y_1 + \frac{V^2}{2y} = y_1 + \frac{Q^2}{2gA^2}$$

$$= 0.4 + \frac{(2)^2}{2 \times 9.81 \times (4 \times 0.4)^2} = 0.4796 \text{ m}$$

At maximum contraction

$$\Rightarrow E_1 = E_{\min} = 1.5y_c$$

where  $y_c$  is depth at section of critical maximum contraction

$$0.4796 = 1.5 y_c$$

$$y_c = 0.3197 \text{ m}$$

Now,

$$\left( \frac{q^2}{g} \right)^{1/3} = 0.3197$$

$$\Rightarrow \left( \frac{q^2}{9.81} \right)^{1/3} = 0.3197$$

$$\Rightarrow q = 0.566 \text{ m}^3/\text{s}/\text{m}$$

Now,

$$\frac{Q}{B_{\min}} = 0.566$$

where,  $B_{\min}$  is width at maximum contraction section.

$$\Rightarrow B_{\min} = \frac{2}{0.566} = 3.533 \text{ m}$$

**Alternatively,**

$$B_{\min} = \sqrt{\frac{27Q^2}{8gE_1^3}}$$

Where,

$$E_1 = 0.4796 \text{ m}$$

So,

$$B_{\min} = \sqrt{\frac{27 \times 2^2}{8 \times 9.81 \times 0.4796^3}} = 3.53 \text{ m}$$

End of Solution

**Q.33** A horizontal curve of radius 1080 m (with transition curves on either side) in a Broad Gauge railway track is designed and constructed for an equilibrium speed of 70kmph. However, a few years after construction, the Railway Authorities decided to run express trains on this track. The maximum allowable cant deficiency is 10 cm. The maximum restricted speed (in kmph) of the express trains running on this track is \_\_\_\_\_ (rounded off to the nearest integer).

Ans. (113)(112 - 114)

$$R = 1080 \text{ m}$$

$$V_{avg} = 70 \text{ km/h}$$

$$C_D = 10 \text{ cm}$$

$G = 1.75 \text{ m}$

Now,

$$e_{\text{theoretical}} = e_{\text{act.}} + \text{CD}$$

$$e_{\text{theoretical}} = \frac{GV^2}{127R} + CD$$

$$\frac{GV_{\max}^2}{127R} = 0.1625$$

$$V_{\max.} = 112.855 \text{ km/h}$$

$$V_{\max.} = 113 \text{ km/h}$$

**End of Solution**

**Q.34** A homogeneous, prismatic, linearly elastic steel bar fixed at both the ends has a slenderness ratio ( $l/r$ ) of 105, where  $l$  is the bar length and  $r$  is the radius of gyration. The coefficient of thermal expansion of steel is  $12 \times 10^{-6}/^{\circ}\text{C}$ . Consider the effective length of the steel bar as  $0.5l$  and neglect the self-weight of the bar.

The differential increase in temperature (rounded off to the nearest integer) at which the bar buckles is

- (a) 85 °C                      (b) 250 °C  
(c) 400 °C                  (d) 298 °C

Ans. (d)

$$\frac{Pe}{A} = \alpha \Delta T E$$

$$\frac{\pi^2 E}{\lambda^2} = \alpha \Delta T E$$

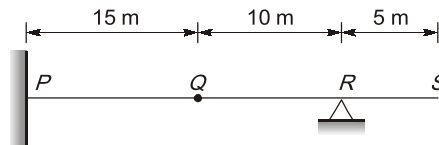
$$\Rightarrow \Delta T = \frac{\pi^2}{\alpha \cdot \lambda^2} = \frac{\pi^2}{\alpha \left[ \frac{0.5L}{R} \right]^2} \quad \left[ \because \lambda = \frac{L}{R} \right]$$

$$= \frac{\pi^2}{12 \times 10^{-6} \times [0.5 \times 105]^2} = 298^\circ\text{C}$$



**End of Solution**

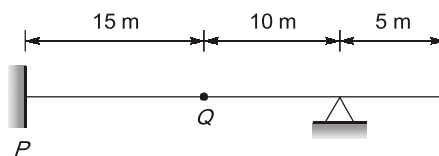
- Q.35** The horizontal beam  $PQRS$  shown in the figure has a fixed support at point  $P$ , an internal hinge at point  $Q$ , and a pin support at point  $R$ . A concentrated vertically downward load ( $V$ ) of 10 kN can act at any point over the entire length of the beam.



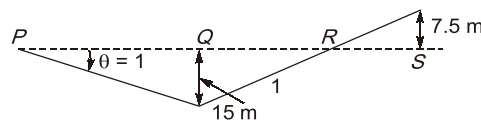
(Figure NOT to scale)

The maximum magnitude of the moment reaction (in kN.m) that can act at the support  $P$  due to  $V$  is \_\_\_\_\_ (in integer).

**Ans. (150)(150 - 150)**



ILD for moment at  $P$ ,



$\therefore$  Maximum moment at  $P$  will be when load is at  $Q$ ,  
 $\Rightarrow (BM)_{\max} = 10 \text{ kN} \times 15 \text{ m} = 150 \text{ kN-m}$

End of Solution

- Q.36** A drained triaxial test was conducted on a saturated sand specimen using a stress-path triaxial testing system. The specimen failed when the axial stress reached a value of  $100 \text{ kN/m}^2$  from an initial confining pressure of  $300 \text{ kN/m}^2$ .

The angle of shearing plane (in degrees) with respect to horizontal is \_\_\_\_\_ (rounded off to the nearest integer).

**Ans. (49)(49 - 50)**

Given:  $\sigma_d = 100 \text{ kN/m}^2$ ,  $\sigma_3 = 300 \text{ kN/m}^2$

Now,  $\sigma_1 = \sigma_3 \tan^2 \alpha + 2c \tan \alpha$

$$\Rightarrow (\sigma_d + \sigma_3) = \sigma_3 \times \tan^2 \alpha$$

$$\Rightarrow (100 + 300) = 300 \tan^2 \alpha$$

$$\Rightarrow 400 = 300 \tan^2 \alpha$$

$$\tan^2 \alpha = \frac{4}{3},$$

$$\tan \alpha = 1.1547 = \tan^{-1}(1.1547) = 49.10^\circ \simeq 49^\circ$$

$$\left[ \therefore \alpha = 45^\circ + \frac{\phi}{2} \right]$$

End of Solution



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- Q.37** A 500 m long water distribution pipeline  $P$  with diameter 1.0 m, is used to convey  $0.1 \text{ m}^3/\text{s}$  of flow. A new pipeline  $Q$ , with the same length and flow rate, is to replace  $P$ . The friction factors for  $P$  and  $Q$  are 0.04 and 0.01, respectively. The diameter of the pipeline  $Q$  (in meters) is (rounded off to 2 decimal places).

**Ans. (0.75)(0.73 - 0.77)**

Here,

$$h_{fP} = h_{fQ}$$

$$\frac{8q^2}{\pi^2 g} \times \frac{0.04 \times L}{(1)^5} = \frac{8q^2}{\pi^2 g} \times \frac{0.01 \times L}{D^5}$$

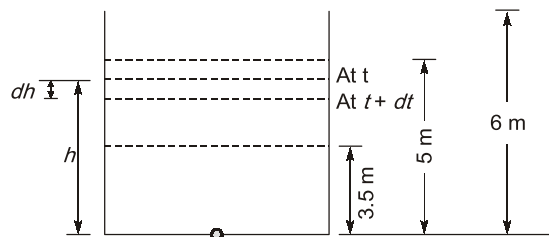
where  $q$  is discharge and  $L$  is length of pipeline.

$$D = \left(\frac{1}{4}\right)^{1/5} = 0.75 \text{ m}$$

**End of Solution**

- Q.38** A  $2 \text{ m} \times 1.5 \text{ m}$  tank of 6 m height is provided with a 100 mm diameter orifice at the center of its base. The orifice is plugged and the tank is filled up to 5 m height. Consider the average value of discharge coefficient as 0.6 and acceleration due to gravity ( $g$ ) as  $10 \text{ m/s}^2$ . After unplugging the orifice, the time (in seconds) taken for the water level to drop from 5 m to 3.5 m under free discharge condition is \_\_\_\_\_ (rounded off to 2 decimal places).

**Ans. (103.98)(103.4 - 104.5)**



Coefficient of discharge,  $C_d = 0.6$

Acceleration due to gravity,  $g = 10 \text{ m/s}^2$

$$\text{Area, } A = (2 \times 1.5) \text{ m}^2 = 3 \text{ m}^2$$

Let, in  $dt$  time, the water level decreases by ' $dh$ '.

$$-Adh = C_d \times a \times \sqrt{2gh} \cdot dt$$

$$\frac{-A}{aC_d\sqrt{2g}} \cdot \frac{dh}{\sqrt{h}} = dt$$

Integrating it,

$$\frac{-A}{aC_d\sqrt{2g}} \int_{H_1}^{H_2} \frac{dh}{\sqrt{h}} = \int_0^T dt$$

$$\frac{A}{aC_d\sqrt{2g}} \int_{H_2}^{H_1} \frac{dh}{\sqrt{h}} = T$$

$$\frac{A}{C_d a\sqrt{2g}} \times [2\sqrt{h}]_{H_2}^{H_1} = T$$

$$T = \frac{2A}{C_d a\sqrt{2g}} (\sqrt{H_1} - \sqrt{H_2})$$

$$= \frac{2 \times (2 \times 1.5)}{0.6 \times \frac{\pi}{4} \times 0.1^2 \times \sqrt{2 \times 10}} \times (\sqrt{5} - \sqrt{3.5})$$

$$= 103.98 \text{ sec}$$

End of Solution

**Q.39** A critical activity in a project is estimated to take 15 days to complete at a cost of Rs. 30,000. The activity can be expedited to complete in 12 days by spending a total amount of Rs. 54,000. Consider the statements *P* and *Q*.

*P*: It is economically advisable to complete the activity early by crashing, if the indirect cost of the project is Rs. 8,500 per day.

*Q*: It is economically advisable to complete the activity early by crashing, if the indirect cost of the project is Rs. 10,000 per day.

Which one of the following options is CORRECT?

- (a) Both *P* and *Q* are TRUE
- (b) *P* is TRUE and *Q* is FALSE
- (c) *P* is FALSE and *Q* is TRUE
- (d) Both *P* and *Q* are FALSE

**Ans. (a)**

End of Solution

**Q.40** In the context of pavement material characterization, the CORRECT statement(s) is/are

- (a) The toughness and hardness of road aggregates are determined by Los Angeles abrasion test and aggregate impact test, respectively.
- (b) The load penetration curve of CBR test may need origin correction due to the non-vertical penetrating plunger of the loading machine.
- (c) In compacted bituminous mix, Voids in the Mineral Aggregate (VMA) is equal to the sum of total volume of air voids ( $V_v$ ) and total volume of bitumen ( $V_b$ ).
- (d) Grading of normal (unmodified) bitumen binders is done based on viscosity test results.

**Ans. (b, c, d)**

End of Solution

**Q.41** Consider the statements  $P$ ,  $Q$ , and  $R$ .

$P$  : Compacted fine-grained soils with flocculated structure have isotropic permeability.

$Q$  : Phreatic surface/line is the line along which the pore water pressure is always maximum.

$R$  : The piping phenomenon occurring below the dam foundation is typically known as blowout piping.

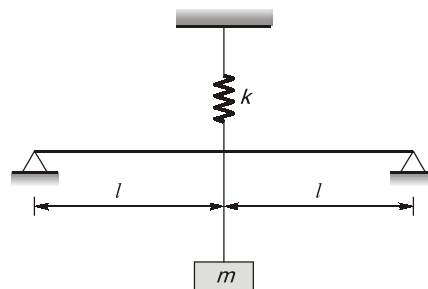
Which of the following option(s) is/are CORRECT?

- (a)  $P$  is FALSE and  $Q$  is TRUE
- (b) Both  $Q$  and  $R$  are FALSE
- (c) Both  $P$  and  $R$  are TRUE
- (d)  $P$  is TRUE and  $R$  is FALSE

**Ans.** (b, d)

End of Solution

**Q.42** A linearly elastic beam of length  $2l$  with flexural rigidity  $EI$  has negligible mass. A massless spring with a spring constant  $k$  and a rigid block of mass  $m$  are attached to the beam as shown in the figure.



The natural frequency of this system is

- |   |  |
|---|--|
| <p>(a) <math>\sqrt{\frac{6Elk}{(kl^3 + 6EI)m}}</math></p> <p>(c) <math>\sqrt{\frac{kl^3 + 48EI}{ml^3}}</math></p> | <p>(b) <math>\sqrt{\frac{48Elk}{(kl^3 + 48EI)m}}</math></p> <p>(d) <math>\sqrt{\frac{kl^3 + 6EI}{ml^3}}</math></p> |
|---|--|

**Ans.** (d)

Here, weight ( $mg$ ) is shared by the beam and top spring and the deflection in beam and top spring will be same.

$\therefore$  Beam and top spring will be in parallel.

**Beam stiffness:**

$$K_{\text{beam}} = \frac{48EI}{(2l)^3} = \frac{6EI}{l^3}$$

Equivalent stiffness:

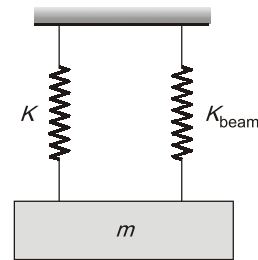
$$K_{eq} = K + K_{beam}$$

$$= K + \frac{6EI}{l^3}$$

∴ Natural frequency,

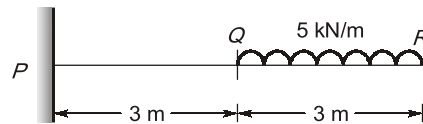
$$w_n = \sqrt{\frac{K_{eq}}{m}} = \sqrt{\frac{K + \frac{6EI}{l^3}}{m}}$$

$$= \sqrt{\frac{Kl^3 + 6EI}{ml^3}} \text{ rad/s}$$



End of Solution

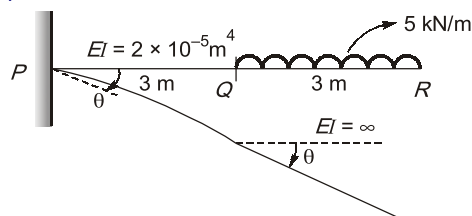
- Q.43** For the 6 m long horizontal cantilever beam  $PQR$  shown in the figure,  $Q$  is the midpoint. Segment  $PQ$  of the beam has flexural rigidity  $EI = 2 \times 10^5 \text{ kN.m}^2$  whereas the segment  $QR$  has infinite flexural rigidity. Segment  $QR$  is subjected to uniformly distributed, vertically downward load of  $5 \text{ kN/m}$ .



(Figure NOT to scale)

The magnitude of the vertical displacement (in mm) at point  $Q$  is \_\_\_\_\_ (rounded off to 3 decimal places).

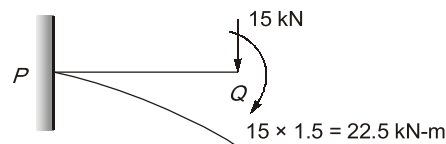
**Ans.** (1.18)(1.17 - 1.19)



∴  $QR$  will remain straight

[Transferring UDL to point load and moment at  $Q$ ]

From principle of superposition,



Deflection at  $Q$ ,  $\delta_Q = \frac{PL^3}{3EI} + \frac{ML^2}{2EI} = \frac{15 \times 3^3}{3 \times 2 \times 10^5} + \frac{22.5 \times 3^2}{2 \times 2 \times 10^5} = 1.181 \text{ mm}$

End of Solution



- Q.44** Consider the statements  $P$  and  $Q$  related to the analysis/design of retaining walls.
- $P$  : When a rough retaining wall moves toward the backfill, the wall friction force/resistance mobilizes in upward direction along the wall.
- $Q$  : Most of the earth pressure theories calculate the earth pressure due to surcharge by neglecting the actual distribution of stresses due to surcharge.
- Which one of the following options is CORRECT?
- $P$  is FALSE and  $Q$  is TRUE
  - Both  $P$  and  $Q$  are TRUE
  - $P$  is TRUE and  $Q$  is FALSE
  - Both  $P$  and  $Q$  are FALSE

**Ans. (b)**

**End of Solution**

- Q.45** Consider two matrices  $A = \begin{bmatrix} 2 & 1 & 4 \\ 1 & 0 & 3 \end{bmatrix}$  and  $B = \begin{bmatrix} -1 & 0 \\ 2 & 3 \\ 1 & 4 \end{bmatrix}$

The determinant of the matrix  $AB$  is \_\_\_\_\_ (in integer).

**Ans. (10)**

$$A = \begin{bmatrix} 2 & 1 & 4 \\ 1 & 0 & 3 \end{bmatrix}_{2 \times 3}, \quad B = \begin{bmatrix} -1 & 0 \\ 2 & 3 \\ 1 & 4 \end{bmatrix}_{3 \times 2}$$

Then,

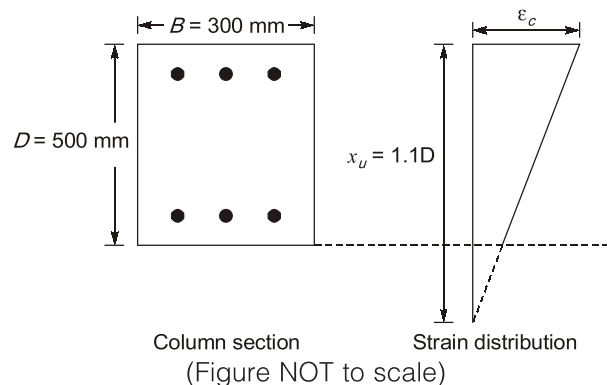
$$AB = \begin{bmatrix} 4 & 19 \\ 2 & 12 \end{bmatrix}$$

So,

$$|AB| = (4)(12) - (2)(19) = 48 - 38 = 10$$

**End of Solution**

- Q.46** A concrete column section of size 300 mm × 500 mm as shown in the figure is subjected to both axial compression and bending along the major axis. The depth of the neutral axis ( $x_u$ ) is 1.1 times the depth of the column, as shown.



The maximum compressive strain ( $\epsilon_c$ ) at highly compressive extreme fiber in concrete,

where there is no tension in the section, is \_\_\_\_\_  $\times 10^{-3}$  (rounded off to 2 decimal places).

**Ans. (3.27)(3.20 - 3.35)**

$$\epsilon_{c, \max} = 0.0035 - 0.75 \epsilon_{c, \min}$$

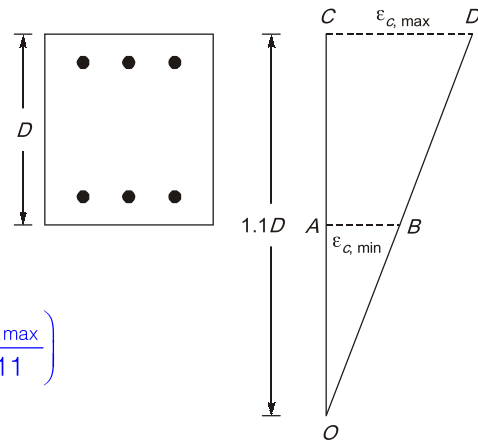
From similar  $\Delta$ ,  $\Delta OAB$  and  $\Delta OCD$ ,

$$\frac{\epsilon_{c, \min}}{0.1D} = \frac{\epsilon_{c, \max}}{1.1D}$$

$$\Rightarrow \epsilon_{c, \min} = \frac{\epsilon_{c, \max}}{11}$$

$$\Rightarrow \epsilon_{c, \max} = 0.0035 - 0.75 \left( \frac{\epsilon_{c, \max}}{11} \right)$$

$$\Rightarrow \epsilon_{c, \max} = 3.27 \times 10^{-3}$$



End of Solution

**Q.47** Three vectors  $\vec{p}$ ,  $\vec{q}$ , and  $\vec{r}$  are given as

$$\vec{p} = \hat{i} + \hat{j} + \hat{k}$$

$$\vec{q} = \hat{i} + 2\hat{j} + 3\hat{k}$$

$$\vec{r} = 2\hat{i} + 3\hat{j} + 4\hat{k}$$

Which of the following is/are CORRECT?

- (a)  $\vec{p} \times (\vec{q} \times \vec{r}) = (\vec{p} \times \vec{q}) \times \vec{r}$
- (b)  $\vec{r} \cdot (\vec{p} \times \vec{q}) = (\vec{q} \times \vec{p}) \cdot \vec{r}$
- (c)  $\vec{p} \times (\vec{q} \times \vec{r}) + \vec{q} \times (\vec{r} \times \vec{p}) + \vec{r} \times (\vec{p} \times \vec{q}) = \vec{0}$
- (d)  $\vec{p} \times (\vec{q} \times \vec{r}) = (\vec{p} \cdot \vec{r})\vec{q} - (\vec{p} \cdot \vec{q})\vec{r}$

**Ans. (b, c, d)**

By observation  $\vec{p} + \vec{q} - \vec{r} = \vec{0}$  (or  $\vec{r} = \vec{p} + \vec{q}$ ) i.e.  $\vec{p}$ ,  $\vec{q}$  and  $\vec{r}$  are L.D.  $\Rightarrow \vec{p}$ ,  $\vec{q}$ ,  $\vec{r}$  lies on same plane i.e.  $\vec{p}$ ,  $\vec{q}$ ,  $\vec{r}$  are coplanar  $\Rightarrow$  S.T.P = 0.

Hence option (c) is correct.

Option (b) is also correct as it is the standard result.

Now checking option (a);  $\vec{p} \times (\vec{q} \times \vec{r}) + \vec{q} \times (\vec{r} \times \vec{p}) + \vec{r} \times (\vec{p} \times \vec{q})$

$$= \vec{p} \times [\vec{q} \times (\vec{p} + \vec{q})] + \vec{q} \times [(\vec{p} + \vec{q}) \times \vec{p}] + \vec{r} \times (\vec{p} \times \vec{q})$$

$$= \vec{p} \times (\vec{q} \times \vec{p}) + 0 + 0 + \vec{q} \times (\vec{q} + \vec{p}) - \vec{r} \times (\vec{q} \times \vec{p})$$

$$= (\vec{q} \times \vec{p})[\vec{p} + \vec{q} - \vec{r}] = (\vec{q} \times \vec{p})(\vec{0}) = \vec{0}$$

Hence (a) is also correct.

End of Solution

- Q.48** Differential levelling is carried out from point  $P$  (BM: +200.000 m) to point  $R$ . The readings taken are given in the table.

Points	Staff readings (m)		Remarks
	Back Sight	Fore Sight	
P	(-) 2.050		BM: +200.000 m
Q	1.050	0.950	Q is a change point
R		(-) 1.655	

Reduced Level (in meters) of the point  $R$  is \_\_\_\_\_ (rounded off to 3 decimal places).

**Ans. (199.705)(199.101 - 201.010)**

$$\Sigma BS - \Sigma FS = \text{Last RL} - \text{First RL}$$

$$(1.05 - 2.05) - (0.95 - 1.655) = (RL)_R - 200$$

$$RL_R = 199.705 \text{ m}$$

End of Solution

- Q.49** A homogeneous earth dam has a maximum water head difference of 15 m between the upstream and downstream sides. A flownet was drawn with the number of potential drops as 10 and the average length of the element as 3 m. Specific gravity of the soil is 2.65. For a factor of safety of 2.0 against piping failure, void ratio of the soil is (rounded off to 2 decimal places).

**Ans. (0.65)(0.63 - 0.67)**

$$\text{Total head loss, } h_L = 15 \text{ m}$$

$$\text{Number of equipotential drops, } N_d = 10$$

$$\text{Average length, } L = 3 \text{ m}$$

$$\text{Specific gravity, } G = 2.65$$

$$\text{Factor of safety, } FOS = 2$$

$$\text{Hydraulic gradient, } i = \frac{h_L}{L} = \frac{15}{3} = 0.5$$

$$\text{Now, } FOS = \frac{i_c}{i}, \text{ where } i_c \text{ is critical hydraulic gradient}$$

$$\Rightarrow 2 = \frac{i_c}{0.5}$$

$$\Rightarrow i_c = 1$$

$$\Rightarrow i_c = \frac{G-1}{1+e}$$

$$\Rightarrow 1 = \frac{2.65-1}{1+e}$$

$$\Rightarrow e = 0.65$$

End of Solution

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- Q.50** The consolidated data of a spot speed study for a certain stretch of a highway is given in the table.

Speed range (kmph)	Number of observations
0-10	7
10-20	31
20-30	76
30-40	129
40-50	104
50-60	78
60-70	29
70-80	24
80-90	13
90-100	9

The “upper speed limit” (in kmph) for the traffic sign is

- (a) 50 (b) 55  
(c) 70 (d) 65

**Ans. (b)**

Speed range (kmph)	Number of observations	Cumulative number of Vehicles	Cumulative %age Passed
0 - 10	7	7	1.4%
10 - 20	31	38	7.6%
20 - 30	76	114	22.8%
30 - 40	129	243	48.6%
40 - 50	104	347	69.4%
50 - 60	78	425	85%
60 - 70	29	454	90.8%
70 - 80	24	478	95.6%
80 - 90	13	491	98.2%
90 - 100	9	500	100%
$\Sigma N = 500$			

Upper speed limit is corresponding to 85% of cumulative vehicles passed.

$$\therefore \text{Upper speed limit} = \frac{50 + 60}{2} = 55 \text{ kmph}$$

End of Solution

- Q.51** The expression for computing the effective interest rate ( $i_{eff}$ ) using continuous compounding for a nominal interest rate of 5% is

$$i_{eff} = \lim_{m \rightarrow \infty} \left( 1 + \frac{0.05}{m} \right)^m - 1$$

The effective interest rate (in percentage) is \_\_\_\_\_  
(rounded off to 2 decimal places).

Ans. (5.13)(5.1 - 5.4)

$$i_{\text{eff}} = \lim_{m \rightarrow \infty} \left( 1 + \frac{0.05}{m} \right)^m - 1$$

$$y = e^{\lim_{x \rightarrow \infty} mx} \left[ 1 + \frac{0.05}{m} - 1 \right]^m ; 1^\infty \text{ form}$$

$$y = e^{\lim_{x \rightarrow \infty} mx} \left[ 1 + \frac{0.05}{m} - 1 \right]$$

$$y = e^{\lim_{x \rightarrow \infty} mx} \left[ 1 + \frac{0.005}{m} - 1 \right]$$

$$y = e^{\lim_{x \rightarrow \infty} 0.05}$$

Finally,

$$y = e^{0.05} - 1$$

$$y = 0.05127 \simeq 5.13\%$$

**End of Solution**

**Q.52** An organic waste is represented as  $C_{240}O_{200}H_{180}N_5S$ .

(Atomic weights: S-32, H-1, C-12, O-16, N-14).

Assume complete conversion of S to  $SO_2$  while burning.

$SO_2$  generated (in grams) per kg of this waste is \_\_\_\_\_  
(rounded off to 1 decimal place).

Ans. (10.1)(9.9 - 10.2)

Molecular weight of  $C_{240}O_{200}H_{180}N_5S$  is given as :

$$12 \times 240 + 16 \times 200 + 1 \times 180 + 14 \times 5 + 32 = 6362 \text{ gm}$$

$$SO_2 \text{ generated} \Rightarrow \frac{64}{6362} \times 1000 \text{ gm/kg}$$

$$= 10.059 \text{ gm/kg} \simeq 10.1 \text{ gm/kg}$$

**End of Solution**

**Q.53** The in-situ percentage of voids of a sand deposit is 50%. The maximum and minimum densities of sand determined from the laboratory tests are  $1.8 \text{ g/cm}^3$  and  $1.3 \text{ g/cm}^3$ , respectively. Assume the specific gravity of sand as 2.7.

The relative density index of the in-situ sand is \_\_\_\_\_  
(rounded off to 2 decimal places).

Ans. (13)(12.80 - 13.20)

$$\text{Minimum dry density, } \gamma_{d\min} = 1.3 \text{ g/cm}^3$$

$$\text{Maximum dry density, } \gamma_{d\max} = 1.8 \text{ g/cm}^3$$

$$\text{Specific gravity of soil solids, } G = 2.7$$

$$\text{Porosity of soil, } n = 0.5$$

$$\text{Void ratio, } e = \frac{n}{1-n} = \frac{0.5}{0.5} = 1$$

$$\text{In situ dry density, } \gamma_d = \frac{Gp_w}{1+e} = \frac{2.7 \times 1}{1+1} = 1.35 \text{ g/cm}^3$$

$$\text{Now, Relative density, RD} = \frac{\frac{1}{\gamma_{dmin}} - \frac{1}{\gamma_d}}{\frac{1}{\gamma_{dmin}} - \frac{1}{\gamma_{dmax}}} = \frac{\frac{1}{1.3} - \frac{1}{1.35}}{\frac{1}{1.3} - \frac{1}{1.8}} = 0.13 \approx 13\%$$

End of Solution

- Q.54** A storm with a recorded precipitation of 11.0 cm, as shown in the table, produced a direct run-off of 6.0 cm.

Time from start (hours)	1	2	3	4	5	6	7	8
Recorded cumulative precipitation (cm)	0.5	1.5	3.1	5.5	7.3	8.9	10.2	11.0

The  $\phi$ -index of this storm is \_\_\_\_\_ cm/hr (rounded off to 2 decimal places).

**Ans.** (0.64)(0.62 - 0.66)

Time from start (hr)	1	2	3	4	5	6	7	8
Accumulated precipitation (cm)	0.5	1.5	3.1	5.5	7.3	8.9	10.2	11.0
Incremental precipitation (cm)	0.5	1	1.6	2.4	1.8	1.6	1.3	0.8
Rainfall intensity (cm/hr)	0.5	1	1.6	2.4	1.6	1.6	1.3	0.8

$$\begin{aligned} \text{Total infiltration, } I &= \text{Total rainfall} - \text{Total runoff} \\ &= 11 - 6 = 5 \text{ cm} \end{aligned}$$

$$\therefore \text{W-index} = \frac{5}{8} = 0.625 \text{ cm/hr}$$

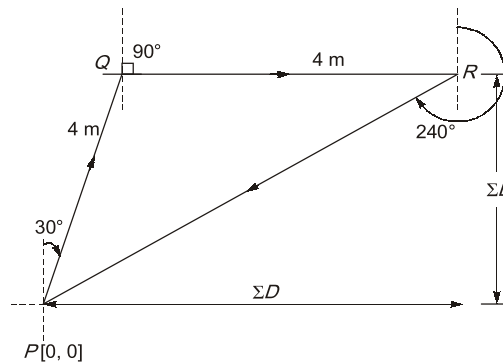
As the 1 hour rainfall is less than W-index.

$$\text{So, } \phi\text{-index} = \frac{5 - 0.5 \times 1}{(8 - 1)} = 0.6428 \text{ cm/hr}$$

End of Solution

- Q.55** A child walks on a level surface from point  $P$  to point  $Q$  at a bearing of  $30^\circ$ , from point  $Q$  to point  $R$  at a bearing of  $90^\circ$  and then directly returns to the starting point  $P$  at a bearing of  $240^\circ$ . The straight-line paths  $PQ$  and  $QR$  are 4 m each. Assuming that all bearings are measured from the magnetic north in degrees, the straight-line path length  $RP$  (in meters) is (rounded off to the nearest integer).

Ans. (7)(7 - 8)



$$\begin{aligned}
 \text{Horizontal distance of traverse from } P \text{ to } R &= \Sigma D \\
 &= PQ \sin 30^\circ + QR \sin 90^\circ \\
 &= 4 \times \frac{1}{2} + 4 \times 1 \\
 &= 6 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 \text{Vertical distance of traverse from } P \text{ to } R &= \Sigma L \\
 &= PQ \cos 30^\circ + QR \cos 90^\circ \\
 &= 4 \times \frac{\sqrt{3}}{2} = 2\sqrt{3}
 \end{aligned}$$

$$\begin{aligned}
 \Rightarrow PR &= \sqrt{(\Sigma L)^2 + (\Sigma D)^2} \\
 &= \sqrt{(2\sqrt{3})^2 + (6)^2} = \sqrt{48} = 6.928 \text{ m} \simeq 7 \text{ m}
 \end{aligned}$$

End of Solution

■■■■