DETAILED SOLUTIONS

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ESE 2024 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 14

Section A : Renewable Sources of Energy + Industrial & Maintenance Engineering + Robotics & Machatronics

Section B : Theory of Machines-1

Section C : Strength of Materials and Engineering Mechanics-2

ANSWER KEY

1.	(a)	**16.**	(a)	**31.**	(d)	**46.**	(a)	**61.**	(d)
2.	(b)	**17.**	(b)	**32.**	(c)	**47.**	(c)	**62.**	(c)
3.	(a)	**18.**	(a)	**33.**	(c)	**48.**	(d)	**63.**	(b)
4.	(c)	**19.**	(a)	**34.**	(c)	**49.**	(b)	**64.**	(d)
5.	(d)	**20.**	(a)	**35.**	(b)	**50.**	(a)	**65.**	(b)
6.	(a)	**21.**	(a)	**36.**	(a)	**51.**	(b)	**66.**	(c)
7.	(c)	**22.**	(b)	**37.**	(d)	**52.**	(d)	**67.**	(d)
8.	(a)	**23.**	(c)	**38.**	(c)	**53.**	(a)	**68.**	(a)
9.	(c)	**24.**	(a)	**39.**	(c)	**54.**	(b)	**69.**	(c)
10.	(d)	**25.**	(a)	**40.**	(a)	**55.**	(b)	**70.**	(d)
11.	(d)	**26.**	(b)	**41.**	(a)	**56.**	(d)	**71.**	(d)
12.	(b)	**27.**	(b)	**42.**	(a)	**57.**	(c)	**72.**	(a)
13.	(a)	**28.**	(d)	**43.**	(d)	**58.**	(c)	**73.**	(c)
14.	(b)	**29.**	(c)	**44.**	(b)	**59.**	(d)	**74.**	(b)
15.	(b)	**30.**	(b)	**45.**	(b)	**60.**	(c)	**75.**	(c)

DETAILED EXPLANATIONS

1. (a)

- Air mass (AM) : It is the ratio of the path length of beam radiation through the atmosphere to the path length if the sun were at zenith.
- At sea level, AM = 1, when the sun is at zenith or directly overhead.

2. (b)

Pyranometer covers total hemispherical solar radiation with a view angle of 2π steradians.

4. (c)

- Statement 2 is correct for lower convective zone.
- Non-convective zone occupying more than half the depth of the pond. In this zone, both temperature as well as concentration increase with depth. It serves as an insulating layer from heat losses in the upward direction.

5. (d)

The solar air heater is compact, cheap and less complicated system, in which the pressure inside the collector does not become very high.

6. (a)

$$\text{Solidity, } \sigma = \frac{Nb}{2\pi R} = \frac{28 \times 0.40}{2 \times \frac{22}{7} \times 3.5} = 0.51$$

7. (c)

Generally, cut-in speed is around 14 km/h and cut-out speed is around 90 km/h.

8. (a)

The amplitude of tidal range reduces steadily from spring tide to neap tide, and then increases with the same pattern to the next spring tides. This monthly cycle occurs due to one revolution of the moon around the earth. Both the tides cycles, namely the daily and monthly cycles at a particular location repeat in a most orderly fashion and are predictable.

9. (c)

Average power generated during one filling or emptying process

$$= \frac{A\rho g R^2}{2 \times 22350}$$

$$= 225AR^2 \text{ kW}$$

The double effect tidal plant generates double energy per tidal cycle. So, the theoretical average power generated in a double effect, single-basin is given by

$$P = P_{filling} + P_{emptying}$$

$$= 2 \times 225AR^2 \text{ kW}$$

$$= 450AR^2 \text{ kW}$$

11. (d)

Fuel cell type	Operating temperature (°C)
Alkaline Fuel Cell (AFC)	70 – 100
Proton Exchange Membrane Fuel Cell (PEMFC)	50 – 100
Phosphoric Acid Fuel Cell (PAFC)	160 – 210
Molten Carbonate Fuel Cell (MCFC)	650
Solid Oxide Fuel Cell (SOFC)	800 – 1000

12. (b)

The voltage efficiency of a fuel cell is given by,

$$\eta_v = \frac{\text{Closed circuit voltage}}{\text{Open circuit voltage}}$$

$$= \frac{V_o - V_p}{V_o} = \frac{V_c}{V_o} = \frac{0.72}{1.40} = 0.5143 \text{ or } 51.43\%$$

13. (a)

- For optimum biogas production, pH can be varied between 6.8 to 7.8.
- At pH of 6.2, acid conditions prevail which restrain the growth of methanogenic bacteria.
- Control on pH should be exercised by adding alkali when it drops below 6.6.

14. (b)

Spectrometric Oil Analysis Program (SOAP) is a maintenance tool used to check the condition of the oil lubricated mechanical systems. It is used in situations where breakdowns are expensive such as military services and civil-aviation companies.

16. (a)

- The technology of first generation robots is fully developed and at present about 80% robots in use in the industry are of this kind. These robots are repeating, non-servo, pick and place or point-to-point kind.
- Second generation robots exhibit path-control capabilities.

17. (b)

Cartesian configuration gives large work volume but has a low dexterity.

18. (a)

Perspective transformation matrix is useful in vision systems and is set to zero vector wherever no perspective views are involved.

19. (a)

The bifilar stepper motors are also referred as universal motors as they are operated either in bipolar mode or unipolar mode by connecting the windings in parallel or in serial.

20. (a)

Closed loop control system is complicated and expensive, whereas open loop control system is very simple and less costly.

21. (a)

A system is said to be a real-time system if there is total correctness of an operation. This depends upon not only the operation's logical correctness, but also the time in which it is performed and used. It may be the point where the operation's application can be considered (within context) to be mission critical.

22. (b)

The repair and maintenance work for the mechatronic system is complex.

24. (a)

$$\text{Sensitivity} = \frac{\text{Output}}{\text{Input}} = \frac{14-0}{340}$$

$$= 0.0412 \text{ V/deg}$$

25. (a)

$$\text{Average resolution} = \frac{14}{900} = 0.0156 \text{ V}$$

26. (b)

Advantages of LVDT:

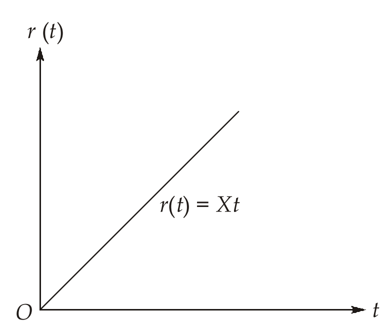
- It has a high range upto 1 m.
- Less wear problem
- It has low hysteresis
- It has infinite resolution
- The power consumption is less
- The output is highly linear and accurate.

28. (d)

Logic OR valve or shuttle valve : A logic function requires at least one input device to be active in order to cause the output. The pneumatic logic OR function is obtained by a shuttle valve.

30. (b)

Mathematically, a ramp function is represented by



31. (d)

$$\text{Controller output (\%)} = \frac{\text{Current ouput – Minimum ouput}}{\text{Maximum output – Minimum output}}$$

$$= \frac{18-6}{24-6} \times 100 = 66.67\% \simeq 67\%$$

32. (c)

Microprocessor :

- It has no internal memory.
- It is based on Von-Newman architecture, where the program and data are stored in same memory module.
- It has many instructions to move data between memory and CPU.

34. (c)

$$\text{Economic order quantity, EOQ} = \frac{\sqrt{2DC_0}}{C_h}$$

$$= \sqrt{\frac{2 \times 400 \times 12 \times 12}{2}} = 240 \text{ units/ order}$$

35. (b)

$$\text{Expected time, } t_e = \frac{t_0 + 4t_m + t_p}{6}$$

$$= \frac{9 + 4 \times 12 + 18}{6} = \frac{25}{2} \text{ minutes}$$

$$\text{Standard deviation, } \sigma = \frac{t_p - t_0}{6} = \frac{18-9}{6} = \frac{3}{2}$$

36. (a)

Given : F_{t-1} = 68 cars; D_{t-1} = 72 cars ; α = 0.25

Forecast for August month is given by

$$F_t = F_{t-1} + \alpha(D_{t-1} + F_{t-1})$$

$$= 68 + 0.25(72 - 68)$$

$$= 69 \text{ cars}$$

37. (d)

- Process layout has greater flexibility.
- Multiple product can be produced simultaneously.
- There is scope for expansion as the capacity of different production lines can be increased.

38. (c)

When the motion between two elements of a pair is possible in more than one direction but is made to have motion only in one direction by using some external means, it is a successfully constrained motion.

- A shaft in a footstep bearing may have vertical motion apart from rotary motion. But due to load applied on the shaft it is constrained to move in that direction.
- A valve of an IC engine is kept on the seat by the force of a spring.

39. (c)

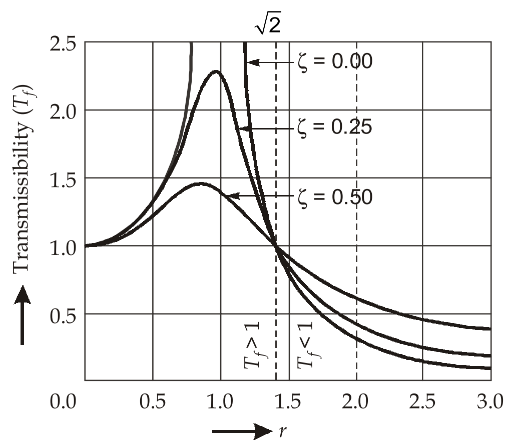


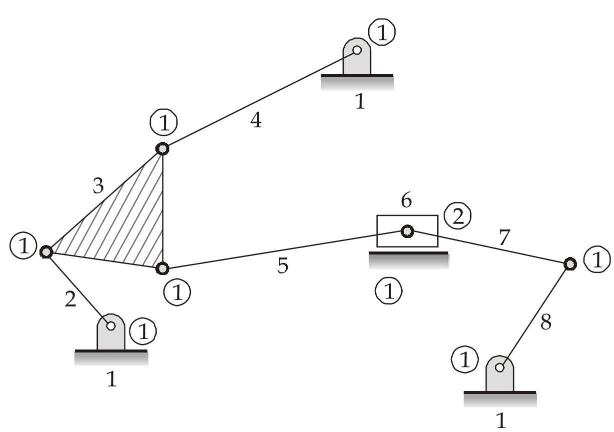
Fig: Variation of Transmissibility with frequency ratio

For an under damped harmonic oscillator, $\xi < 1$

and when $\frac{\omega}{\omega_n} > \sqrt{2}$, the value of transmissibility is less than 1 and the value of transmissibility decreases as the damping is decreased.

Hence, for $\xi < 1$ vibration isolation is most effective when operated with an excitation frequency (ω) such that $\frac{\omega}{\omega_n} > \sqrt{2}$.

40. (a)



$$\text{Total number of links, } l = 8$$
$$\text{Total number of binary joints, } j = 10$$

$$\text{Total number of higher pairs, } h = 0$$
$$\text{Degree of freedom, } F = 3(l-1) - 2j - h$$
$$= 3(8-1) - 2(10) - 0 = 1$$

Note : One ternary joint is equivalent to two binary joints.

41. (a)

Oldham's coupling:

- It has two turning and two sliding pairs.
- It is an inversion of double slider crank chain.
- It is used to connect two parallel shafts when the distance between their axes is small.
- It can not tolerate angular misalignment, it is use to connect shaft having lateral misalignment.

42. (a)

$$\text{Length of slotted bar, } L = 750 \text{ mm}$$
$$\text{Length of crank, } r = 90 \text{ mm}$$
$$\text{Length of connecting rod, } l = 250 \text{ mm}$$

For crank and slotted lever quick return motion mechanism, the stroke length is given as,

$$\text{Stroke length} = \frac{2Lr}{l} = \frac{2 \times 750 \times 90}{250}$$
$$= 540 \text{ mm}$$

43. (d)

Given : $l = 400$ mm; $r = 80$ mm; $\omega = 20$ rad/s

The maximum angular speed of connecting rod is given as

$$[\omega_{CR}]_{max} = \frac{\omega}{n} = \frac{\omega}{\left(\frac{l}{r}\right)} = \frac{20}{\left(\frac{400}{80}\right)}$$
$$= \frac{20}{5} = 4 \text{ rad/s}$$

44. (b)

Given : $M = 25$ kg; $m = 5$ kg; $f = 18$ N

Coefficient of insensitiveness for a porter governor is given as:

$$\text{Coefficient of insensitiveness} = \frac{f}{(M+m)g} = \frac{18}{(25+5)\times 10} = 0.06$$

45. (b)

Given : $a = 100$ mm; $b = 50$ mm; Lift = 20 mm

$$\text{Range of radii} = r_2 - r_1$$
$$= \frac{a}{b} \times \text{Lift}$$
$$= \frac{100}{50} \times 20 = 40 \text{ mm}$$

46. (a)

Given : QRR = 1.5, T_1 = 3s, T_2 = ?

$$\text{Quick return ratio, QRR} = \frac{\text{Duration of cutting stroke } (T_1)}{\text{Duration of return stroke } (T_2)}$$

$$\Rightarrow \quad T_2 = \frac{T_1}{QRR} = \frac{3}{1.5} = 2s$$

$$\text{Cycle time, } T_c = T_1 + T_2 = 3 + 2 = 5\text{s}$$

$$\text{Operating speed, } \omega = \frac{2\pi}{T_c} = \frac{2\pi}{5} = 1.2566 \text{ rad/s} \simeq 1.26 \text{ rad/s}$$

47. (c)

Given : AB = 2 m, BC = 4 m, CD = 6 m, ω_{AB} = 3 rad/s

Since, $AB \perp BC$ and $BC \perp CD$. So, the entire bar BC will have only horizontal component of velocity in other words the angular velocity of BC is zero at the instant.

$$V_B = V_C$$

$$(AB) \times \omega_{AB} = (CD) \times \omega_{CD}$$

$$\Rightarrow \quad \omega_{CD} = \frac{AB \times \omega_{AB}}{CD} = \frac{2 \times 3}{6}$$

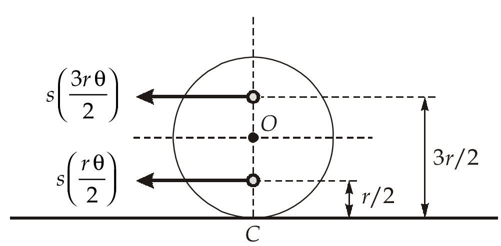
$$= 1 \text{ rad/s}$$

48. (d)

On giving a small rotation to the disc of 'θ' in CW direction:

$$\text{Compression in the right side spring} = \left(\frac{r}{2}\right)\theta = \frac{r\theta}{2}$$

$$\text{Elongation in the left side spring} = \left(r + \frac{r}{2}\right)\theta = \frac{3r\theta}{2}$$



Taking torque about point C:

$$s\left(\frac{r\theta}{2}\right)\frac{r}{2} + s\left(\frac{3r\theta}{2}\right)\frac{3r}{2} = -I_C\ddot{\theta}$$

$$\frac{1}{4}sr^2\theta + \frac{9}{4}sr^2\theta = -\left[\frac{mr^2}{2} + mr^2\right]\ddot{\theta}$$

$$\Rightarrow \quad \frac{3}{2}mr^2\ddot{\theta} + \frac{10}{4}sr^2\theta = 0$$

$$\Rightarrow \qquad \ddot{\theta} + \frac{5s}{3m}\theta = 0$$

On comparing the above equation with $\ddot{\theta} + \omega_n^2 \theta$

We get, $$\omega_n = \sqrt{\frac{5s}{3m}}$$

49. (b)

Given : $m_2 = 2\, m_1$; $s_2 = 4s_1$, $C_{c_1} = 0.4$ kg/s

The critical damping coefficient is given as:

$$C_c = 2\sqrt{sm}$$

$$\Rightarrow \qquad \frac{(C_c)_2}{(C_c)_1} = \sqrt{\frac{s_2 m_2}{s_1 m_1}}$$

$$\Rightarrow \qquad (C_c)_2 = (C_c)_1 \times \sqrt{\frac{s_2 m_2}{s_1 m_1}}$$

$$= 0.4 \times \sqrt{\frac{4s_1}{s_1} \times \frac{2m_1}{m_1}} = 0.4 \times \sqrt{8} = 1.13 \text{ kg/s}$$

50. (a)

Given : d = 50 mm; t = 40 mm; S_{us} = 210 MPa; ω = 2 rad/s; C_s = ±5% = 0.10; L_s = 80 mm

Ultimate shear force for one hole $= S_{us} \times \pi dt$

$= 210 \times \pi \times 50 \times 40$

$$= 210 \times \frac{22}{7} \times 50 \times 40$$

$= 1320000$ N $= 1320$ kN

$$\text{Average shear force} = \frac{F_{max} - 0}{2} = \frac{1320}{2} = 660 \text{ kN}$$

Energy required for one hole $= F_{avg} \times t$

$= 660 \times (40 \times 10^{-3})$

$= 26.4$ kNm or kJ

51. (b)

12 holes per minute ⇒ 1 hole per 5 seconds ⇒ cycle time = 5 seconds

$$\text{Power of motor required} = \frac{\text{Energy required for one hole}}{\text{Cycle time}}$$

$$= \frac{26.4}{5} = 5.28 \text{ kW}$$

52. (d)

Cycle time, T_c = 5 sec

Actual operation time, T_a,

Stroke length = L_s = 80 mm

⇒ 2 × 80 mm movement in one cycle time

⇒ 2 × 80 mm movement in 5 seconds

⇒ 40 mm movement in $\frac{5}{160} \times 40$ seconds

⇒ T_a = 1.25 seconds

Maximum energy stored, $(\Delta E)_{max}$ = $E_{1,hole} - (P_{motor} \times T_a)$

= 26.4 – (5.28 × 1.25)

= 19.8 kJ

53. (a)

Given that: $2\ddot{x} + 9\dot{x} + 8x = 0$

$$\Rightarrow \quad \ddot{x} + \frac{9}{2}\dot{x} + 4x = 0$$

Comparing the above equation with the standard equation:

$$\ddot{x} + (2\xi\omega_n)\dot{x} + \omega_n^2 x = 0$$

We get,

$$\omega_n^2 = 4$$

$$\Rightarrow \quad \omega_n = 2$$

and $2\xi\omega_n = \frac{9}{2}$

$$\Rightarrow \quad \xi = \frac{9}{2} \times \frac{1}{2\omega_n}$$

$$= \frac{9}{2} \times \frac{1}{2 \times 2} = \frac{9}{8} = 1.125$$

Since $\xi > 1$. So it is an over damped system.

54. (b)

$$\xi = \frac{C}{C_c} = \frac{9}{8}$$

⇒ Critical damping coefficient, C_c = 8 N.s/m

⇒ Actual damping coefficient, C = 9 N.s/m

55. (b)

Given : D = 100 mm; L = 1 m; e = 324 μm; $\frac{\omega}{\omega_n} = 0.80$

The transverse displacement of the shaft is given as

$$y = \frac{e}{\left(\frac{\omega_n}{\omega}\right)^2 - 1} = \frac{324}{\left(\frac{1}{0.80}\right)^2 - 1}$$

$$= \frac{324}{\left(\frac{9}{16}\right)} = 576\ \mu\text{m}$$

56. (d)

The angular acceleration of the connecting rod is given as:

$$\alpha_{CR} = -\frac{\omega^2}{n} \times \sin\theta$$

Hence, the magnitude of angular acceleration is maximum when θ = 90° or θ = 270°, i.e. crank is perpendicular to the line of stroke.

57. (c)

$$\text{Moment of resistance} = \text{Maximum bending moment}$$

$$\sigma \cdot \frac{bd^2}{6} = \frac{wl}{4}$$

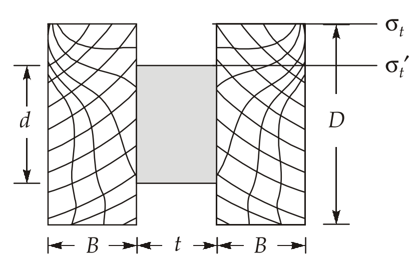
$$\therefore \quad \sigma \times \frac{20 \times 20^2}{6} = \frac{400 \times 800}{4}$$

$$\therefore \quad \sigma = \frac{400 \times 800 \times 6}{20 \times 20^2 \times 4}$$

$$\therefore \quad \sigma = 60\ \text{MPa}$$

58. (c)

Refer figure,



Let the stress in extreme timber fiber be σ_t

Then the stress in timber at extreme surface of steel,

$$\sigma_t' = \sigma \cdot \frac{d/2}{D/2} = \sigma \cdot \frac{d}{D}$$

Then if the stress in the extreme steel fibre is to reach maximum value,

$$\sigma_s = m\sigma_t' \qquad \left[\text{Modular ratio, } m = \frac{E_s}{E_t}\right]$$

$$130 = \frac{210}{12} \times 10 \times \frac{d}{D}$$

or
$$\frac{D}{d} = \frac{210 \times 10}{12 \times 130} = 1.346 \simeq 1.35$$

60. (c)

- For a beam with two axes of symmetry the shear centre coincides with the centroid.
- For sections having one axis of symmetry shear centre does not coincide with the centroid, though it lies on the axis of symmetry.

61. (d)

Maximum horizontal shear stress occurs at the mid depth

$\therefore$
$$\tau_{max} = \frac{3}{2} \times \tau_{avg}$$
$$= \frac{3}{2} \times \frac{F}{bh} \times 2 = \frac{3F}{bh} = \frac{3 \times 50 \times 10^3}{100 \times 300}$$
$$= 5 \text{ MPa}$$

62. (c)

For a simply supported beam with central point load W, we have

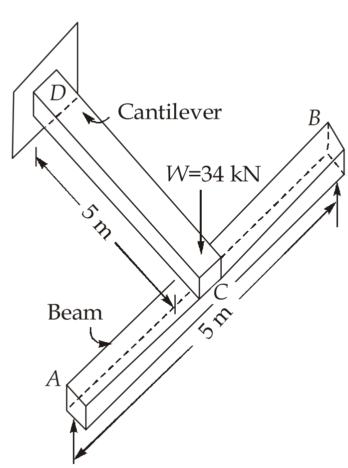
$$\text{Slope, } \theta = \frac{WL^2}{16EI}$$

$$\text{Deflection, } \delta = \frac{WL^3}{48EI}$$

Now,
$$\delta = \frac{WL^2}{16EI} \times \frac{L}{3} = \theta \cdot \frac{L}{3}$$

or
$$\delta = 1.8° \times \frac{\pi}{180} \times \frac{5}{3} = 52.35 \text{ mm}$$

63. (b)



Let the load shared by the cantilever be 'P'

For the cantilever, $$\Delta_C = \frac{PL^3}{3EI}$$

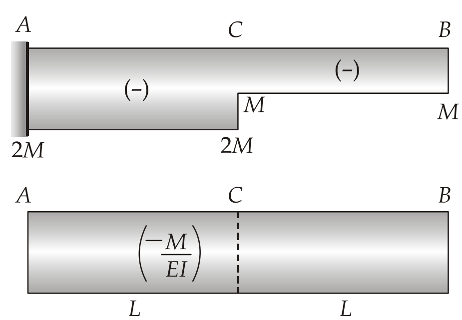
For the beam, $$\Delta_S = \frac{(W-P)L^3}{48EI}$$

$\therefore$ $$\frac{PL^3}{3EI} = \frac{(W-P)L^3}{48EI}, \text{ on solving we get}$$

$\therefore$ $$P = \frac{W}{17} = \frac{34}{17} = 2 \text{ kN}$$

64. (d)

BMD for the given beam



For deflection at B,

$$\delta_{B/A} = \frac{-M}{EI} \times L \times \frac{L}{2} - \frac{M}{EI} \times L \times \frac{3L}{2}$$

$$= \frac{-ML^2}{EI}\left[\frac{1}{2} + \frac{3}{2}\right] = -\frac{2ML^2}{EI}$$

(–)Ve sign indicates downward deflection.

65. (b)

We have

$$\frac{U}{\text{Volume}} = \frac{\tau^2}{4G}\left(\frac{D^2+d^2}{D^2}\right) \text{ for a hollow shaft}$$

or $$\frac{\tau^2}{3G} = \frac{\tau^2}{4G}\left(1 + \frac{d^2}{D^2}\right)$$

$\therefore$ $$\frac{4}{3} = 1 + \frac{d^2}{D^2}$$

or $$\frac{D}{d} = \sqrt{3}$$

66. (c)

$$\text{Inside diameter, } D_i = D_o - 2t = 50 - 2 \times 5 = 40 \text{ mm}$$

$$\text{Permissible stress, } \sigma_y = \frac{240}{3} = 80 \text{ MPa}$$

$$\text{Maximum shear stress, } \tau_{max} = \frac{80}{2} = 40 \text{ MPa}$$

or
$$\frac{16TD}{\pi(D^4 - d^4)} = 40$$

$$\frac{16 \times T \times 50}{\pi(50^4 - 40^4)} = 40$$

∴
$$T = \frac{40 \times \pi \times (50^4 - 40^4)}{16 \times 50}$$

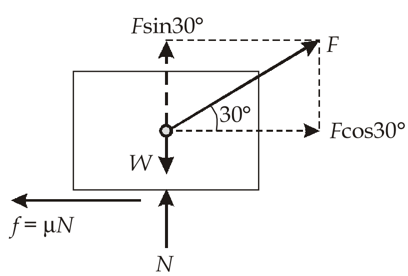
$$T = 579.6 \text{ Nm}$$

67. (d)

Parallel planes normal to the axis do not warp or distort after torsion.

68. (a)

Given : $W = 200$ N, $\mu = 0.5$



$\Sigma F_V = 0$;
$$W = F\sin 30° + N$$

⇒
$$N = W - F\sin 30° \quad ...(i)$$

and $\Sigma F_H = 0$;
$$F\cos 30° = \mu N = \mu[W - F\sin 30°]$$

⇒
$$F\cos 30° = 0.5[200 - F\sin 30°]$$

⇒
$$F = \frac{0.5 \times 200}{\cos 30° + 0.5 \times \sin 30°}$$

$$= \frac{100}{\frac{\sqrt{3}}{2} + \frac{1}{4}} = \frac{400}{2\sqrt{3} + 1}$$

$$= 89.6 \text{ N}$$

69. (c)

Given : W = 1000 N; μ_R = 0.25 mm; D = 800 mm; R = 400 mm

Minimum horizontal force required at the centre of the wheel to roll the wheel is

$$P = \mu_R \times \frac{W}{R}$$

$$= 0.25 \times \frac{1000}{400} = 0.625 \text{ N}$$

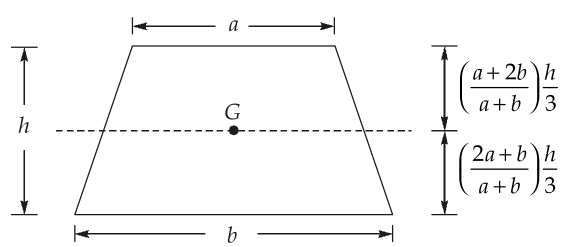
70. (d)

Bifilar suspension and Trifilar suspension methods are used to determine the mass moment of inertia of a rigid body.

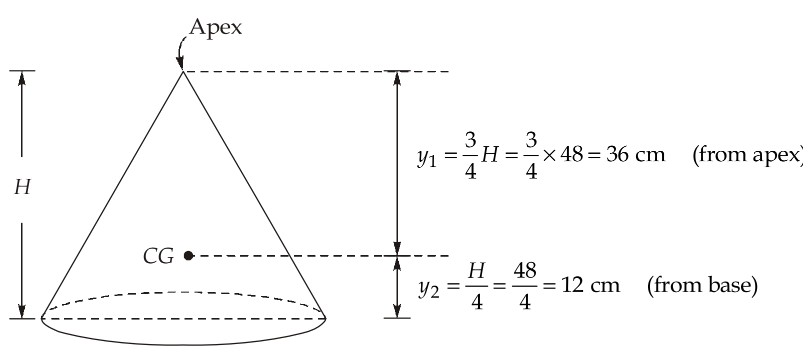
71. (d)

The centre of percussion (COP) is the place on a bat or rocket where it may be struck without causing reaction at the support.

72. (a)

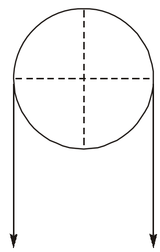


73. (c)



Hence, distance of CG from apex is 36 cm.

74. (b)



$$\text{Angle of wrap, } \theta = \pi$$

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

$$\Rightarrow \quad \frac{250}{50} = e^{\pi\mu}$$

$$\Rightarrow \quad \mu = \frac{1}{\pi}\ln\left(\frac{250}{50}\right)$$

$$= \frac{1}{\pi}\ln(5)$$

75. (c)

Beam of uniform strength has same maximum bending stress all along the length.

❍❍❍❍