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MARITIME AND COASTGUARD AGENCY

STCW 95 MANAGEMENT ENGINEER REG. III/2 (UNLIMITED)

Applied Mechanics 040-31
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Note:-

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Every effort has been made to see that there are no errors (typographical or otherwise) in the material presented. However, it is still possible that there are a few errors (serious or otherwise).We would be thankful to the reader, if they are brought to my attention at the following e-mail address: ***ulheyogesh@gmail.com***

Q.2

A body of mass 100 kg is to be pulled along a horizontal plane, where the coefficient of friction between the contact surfaces has a constant value of 0.4.

If a force is applied to the body at an angle of 45° above the horizontal plane:

(a) sketch the force diagram indicating the interacting forces and relevant angles; (4)

(b) calculate EACH of the following:

(i) the magnitude of the force that will slide the body at constant speed; (6)

(ii) the magnitude and direction of the minimum force that will move the body. (6)

Solution-

(a)

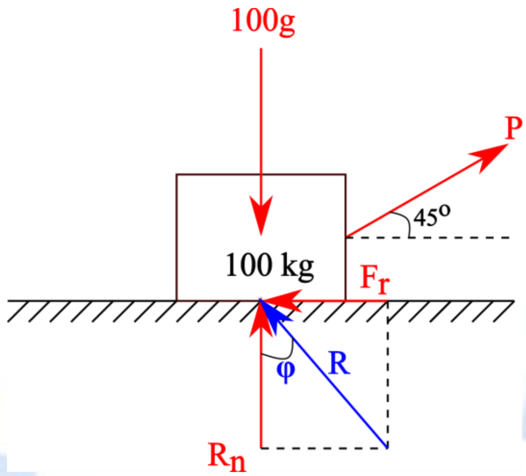
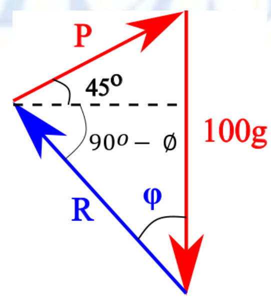


Fig: - Force Diagram

(b) (i)

$\mu = 0.4 \Rightarrow \emptyset = \tan^{-1}\mu = \tan^{-1}0.4 = 21.8^o$



By sine rule

$$\frac{P}{\sin\emptyset} = \frac{100\ g}{\sin(45+90-\emptyset)}$$

$$p = \frac{100 \times 9.81 \times \sin 21.8}{\sin(45+90-21.8)}$$

$$P = 396.36\ N$$

Therefore, 396.36 N of force will slide the body at steady speed.

(b) (ii)

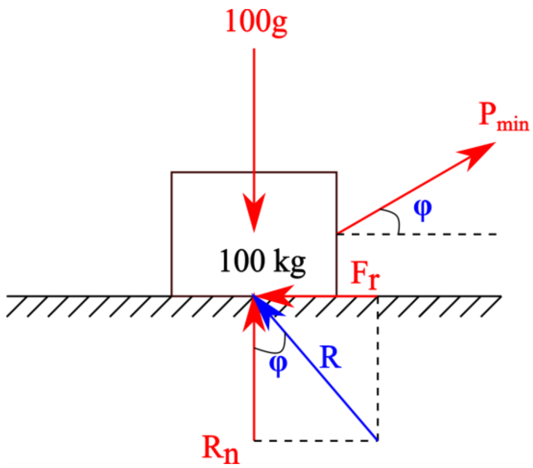
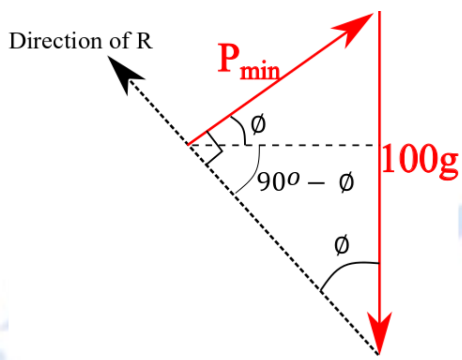


Fig: Force Diagram



$$\sin Ø = \frac{P_{min}}{100\ g} \quad \Rightarrow \quad P_{min} = 100\ g\ \times \sin Ø = 364.312\ N$$

Therefore, the magnitude of the minimum force is 364.312 N and its direction is 21.8^o horizontal.

Q.4

A single-start worm rotates a 50-tooth worm-wheel in a simple lifting machine. The system is driven by an effort wheel that is 250 mm in diameter.

(a) If the effort required lifting a mass of 700 kg is 125 N with an overall efficiency 35%, calculate EACH of the following;

- **(i) the mechanical advantage of the lifting machine; (2)**
- **(ii) the velocity ratio of the lifting machine; (2)**
- **(iii) the diameter of the load wheel; (4)**
- **(iv) the time taken to raise the load 1.5 m if the effort wheel rotates at a constant speed of 50 rpm; (4)**

(b) Sketch the arrangement (4)

Solution-

$t = 50, \quad D_{Effort} = 250\ mm = 0.25\ m, \quad W = 700\ kg = 700g\ N = 6867\ N,$

$P = 125\ N, \quad \eta = 35\% = 0.35$

(a)(i)

$$Mechanical\ Advantage = MA = \frac{W}{P} = \frac{6867}{125} = 54.936$$

Therefore, the mechanical advantage of the lifting machine is 54.936.

(a)(ii)

$$\eta = \frac{Mechanical\ Advantage}{Velocity\ Ratio} = \frac{MA}{VR}$$

$$VR = \frac{MA}{\eta} = \frac{54.936}{0.35} = 156.96$$

Therefore, the velocity ratio of the lifting machine is 156.96.

(a)(iii)

For single start worm and worm wheel

$$VR = \frac{D_{Effort} \times t}{D_{Load}}$$

$$D_{Load} = \frac{D_{Effort} \times t}{VR} = \frac{0.25 \times 50}{156.96} = 0.0796\ m = 79.6\ mm$$

Therefore, the diameter of the load wheel is 79.6 mm.

(a)(iv)

$$Distance\ moved\ by\ the\ load\ = \ 1.5\ m$$

$$N_{Effort} = 50\ rpm$$

$$VR = \frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ load}$$

$$Distance\ moved\ by\ effort = VR \times Distance\ moved\ by\ load = 156.96 \times 1.5$$

$$= 235.44\ m$$

$$Velocity\ of\ effort\ = V_{Effort} = \omega_{Effort} \times R_{Effort} = \frac{2\pi N_{Effort}}{60} \times \frac{D_{Effort}}{2}$$

$$= \frac{2\pi \times 50}{60} \times \frac{0.25}{2} = 0.6544\ m/s$$

$$Time\ taken\ by\ load\ to\ move\ 1.5\ m = time\ taken\ by\ effort\ to\ move\ 235.44\ m$$

$$= \frac{Distance\ moved\ by\ effort}{Velocity\ of\ effort} = \frac{235.44}{0.6544} = 359.78\ sec$$

Therefore, time taken by the load move 1.5 m is 359.78 sec.

(b)

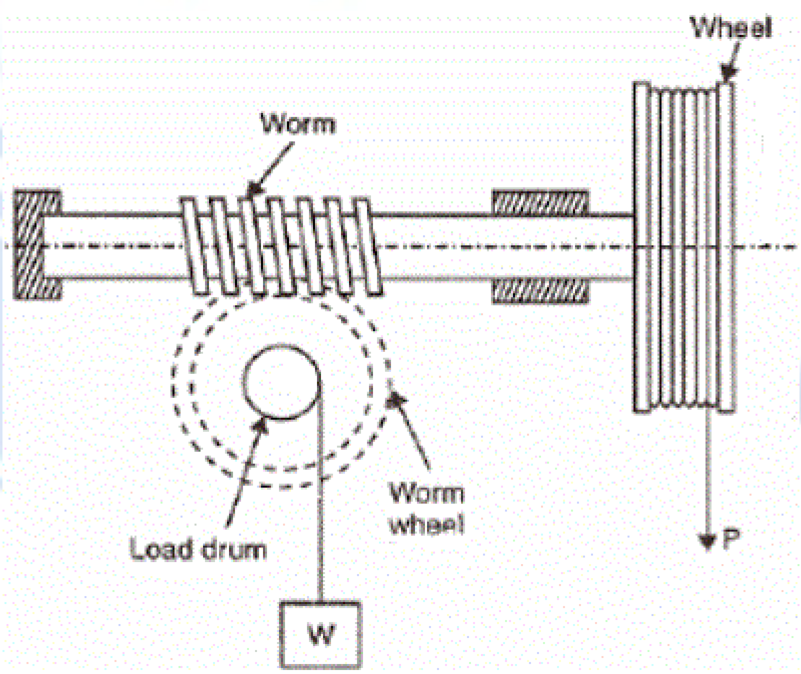


Fig:- Worm and Worm-Wheel

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Q.5

A piston reciprocates with simple harmonic motion when driven by an engine with a constant speed of 120 rpm. When the piston is 0.75 m from mid-stroke position it has an instantaneous velocity equivalent to 0.6 of its maximum velocity.

Calculate EACH of the following:

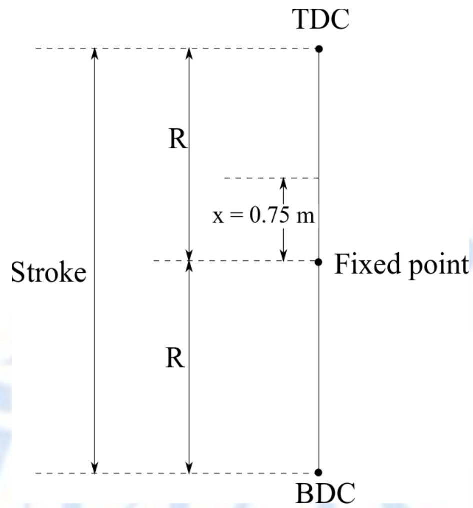
(a) the stroke of the engine; (8)

(b) the velocity of the piston when it is 0.7 m from top dead centre; (4)

(c) the maximum acceleration of the piston. (4)

Solution-

$$N = 120\, rev/min, \quad \Rightarrow \omega = \frac{2\pi N}{60} = \frac{2\pi \times 120}{60} = 12.566\, rad/sec$$



$$x = 0.75\, m$$

$$V = 0.6 \times V_{max}$$

$$\Rightarrow \omega\sqrt{R^2 - x^2} = 0.6 \times \omega \times R$$

$$\Rightarrow R^2 - x^2 = 0.36 \times R^2$$

$$\Rightarrow 0.64 \times R^2 = x^2$$

$$\Rightarrow 0.64 \times R^2 = 0.75^2$$

$$\Rightarrow R^2 = \frac{0.75^2}{0.64}$$

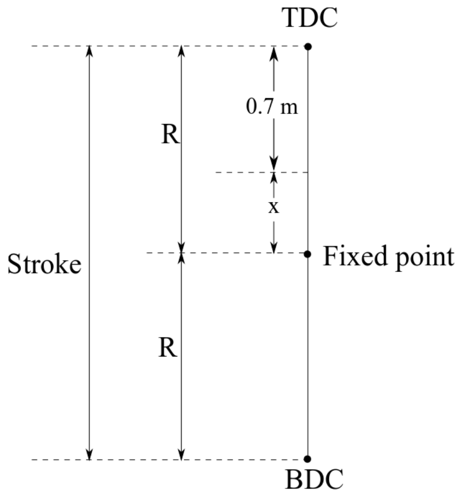
$$\Rightarrow R = 0.9375\, m\ (\boldsymbol{Amplitude\ of\ SHM})$$

(a)

$$Stroke = 2 \times R = 2 \times 0.9375 = 1.875\, m$$

Therefore, the stroke of the engine is 1.875 m.

(b)



$x = R - 0.7 = 0.9375 - 0.7 = 0.2375\ m$

$v = \omega\sqrt{R^2 - x^2} = 12.566\sqrt{0.9375^2 - 0.2375^2} = 11.396\ m/s$

Therefore, the velocity of the piston when it is 0.7 m from TDC is 11.396 m/s.

(c)

$a_{max} = \omega^2 \times R = 12.566^2 \times 0.9375 = 148.03\ m/s^2$

Therefore, the maximum acceleration of the piston is 148.03 m/s^2.

Q.6

A loaded truck of mass 5 tonne is travelling on rails at 7 m/s and collides with an unloaded truck of mass 2 tonne travelling at 3 m/s in the same direction. After collision the trucks move as a single body:

(a) Define the terms *elastic* and *inelastic collisions*; (2)

(b) Calculate EACH of the following:

- **(i) the velocity of the combined mass; (6)**
- **(ii) the change in kinetic energy; (4)**
- **(iii) the distance travelled by the trucks after the collision against a constant resistive force of 1400 N. (4)**

Solution-

(a)

Elastic collision: - In this type of collision, total kinetic energy of the system before collision remains same as total kinetic energy after collision.

Inelastic collision:- In this type of collision, total kinetic energy of the system before collision is not same as total kinetic energy after collision.

(b) (i)

$m_1 = 5\ tonne = 5000\ kg, \quad v_1 = 7\ m/s$

$m_2 = 2\ tonne = 2000\ kg, \quad v_2 = 3 m/s$

From conservation of momentum,

$$Total\ momentum\ before\ collision = Total\ momentum\ after\ collision$$

$$\Rightarrow m_1 v_1 + m_2 v_2 = (m_1 + m_2) \times V_{common}$$

$$\Rightarrow v_{common} = \frac{m_1 v_1 + m_2 v_2}{(m_1 + m_2)} = \frac{5000 \times 7 + 2000 \times 3}{5000 + 2000} = 5.857\ m/s$$

Therefore, the velocity of the combined mass is 5.857 m/s.

(b)(ii)

$$Change\ in\ kinetic\ energy = KE\ before\ collision - KE\ after\ collision$$

$$= \frac{m_1 {v_1}^2}{2} + \frac{m_2 {v_2}^2}{2} - \frac{(m_1 + m_2){v_{common}}^2}{2}$$

$$= \frac{5000 \times 7^2}{2} + \frac{2000 \times 3^2}{2} - \frac{(5000 + 2000) \times 5.857^2}{2}$$

$$= 11434.42\ J\ (Reduction)$$

Therefore, the change in kinetic energy is 11434.42 J (reduction).

(b)(iii)

$F = 1400\ N$

By Newton's second law of motion

$$\sum F = m \times a$$

$$-F = (5000 + 2000) \times a_{common}$$

$$\Rightarrow -1400 = 7000 \times a_{common}$$

$$\Rightarrow a_{common} = -0.2\ m/\ s^2$$

$$V_{common1} = 5.857\ m/s$$

$$V_{common2} = 0\ m/s$$

From equation of motion

$$v^2 = u^2 + 2as$$

$$\Rightarrow s = \frac{v^2 - u^2}{2a}$$

$$\therefore Distance\ travelled = \frac{v_{common2}{}^2 - v_{common1}{}^2}{2 \times a_{common}} = \frac{0 - 5.857^2}{2 \times (-0.2)} = 85.76\ m$$

Therefore, the distance travelled by trucks after the collision is 85.76 m.

Q.7

A solid rectangular beam carries a uniformly distributed load of 10 kN/m over its entire span of 6 m which is simply supported at both ends, as shown in Fig Q7. The beam has a breadth 100 mm and a maximum bending stress of 70 MN/m^2.

Calculate EACH of the following:

(a) the magnitude and position of the maximum bending moment; (2)

(b) the minimum depth of the beam; (8)

(c) the minimum dimensions of a replacement solid square beam under these loading conditions. (2)

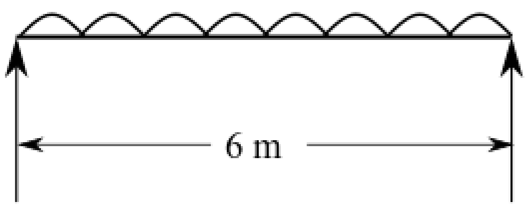
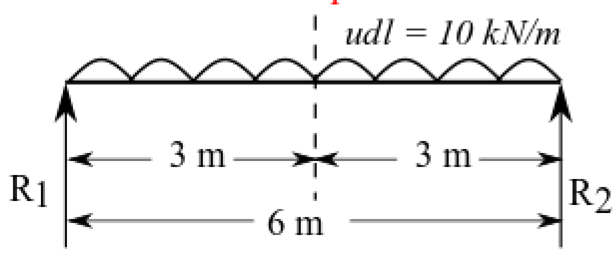
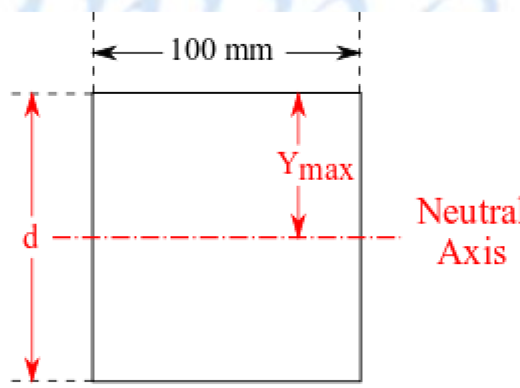


Fig Q7

Solution-

(a)





Cross-section of the beam

$$f_{max} = 70\ MN/m^2 = 70 \times 10^6\ N/m^2$$

$$R_1 = R_2 = \frac{Total\ load}{2} = \frac{10 \times 6}{2} = 30\ kN$$

Maximum bending moment is at the mid-span and it is calculated as

$$M = R_1 \times 3 - 10 \times 3 \times \frac{3}{2} = 30 \times 3 - 10 \times 3 \times 1.5 = 45\ kNm$$

Therefore, maximum bending moment is 45 kNm and it occurs at the mid-span of the beam.

(b)

From bending equation

$$\frac{M}{I} = \frac{f_{max}}{y_{max}}$$

$$\Rightarrow \frac{45\times10^3}{\frac{bd^3}{12}} = \frac{70\times10^6}{\frac{d}{2}}$$

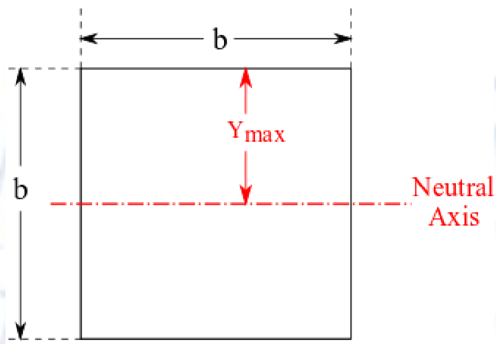
$$\Rightarrow \frac{45\times10^3}{\frac{bd^2}{6}} = 70\times10^6$$

$$\Rightarrow \frac{45\times10^3}{\frac{0.1\times d^2}{6}} = 70\times10^6$$

$$\Rightarrow d = \sqrt{\frac{45\times10^3\times6}{0.1\times70\times10^6}} = 0.196\,m = 196\,mm$$

Therefore, the minimum depth of the beam is 196 mm.

(c)



Square cross-section of the beam

From bending equation

$$\frac{M}{I} = \frac{f_{max}}{y_{max}}$$

$$\Rightarrow \frac{M}{\frac{b^4}{12}} = \frac{f_{max}}{\frac{b}{2}}$$

$$\Rightarrow b = \sqrt[3]{\frac{6M}{f_{max}}} = \sqrt[3]{\frac{6\times45\times10^3}{70\times10^6}} = 0.1568\,m = 156.8\,mm$$

Therefore, size of square cross-section is 156.8 mm.

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Q.8

A close coiled helical spring with mean coil diameter 40 mm is made from 5 mm diameter wire. The stress in the wire must not exceed 250 N/mm^2 at the maximum spring deflection of 20 mm.

Calculate EACH of the following:

(a) the number of coils in the spring; (8)

(b) the load which causes maximum deflection; (6)

(c) the energy stored within the spring at maximum deflection. (2)

Note: Modulus of Rigidity for wire = 88 kN/mm^2

Solution

$$Mean\ coil\ Diameter = D = 40\ mm = 0.04\ m$$

$$Wire\ diameter = d = 5\ mm = 0.005\ m$$

$$\tau_{max} = 250\ N/mm^2 = 250 \times 10^6\ N/m^2$$

$$Maximum\ spring\ deflection = \delta = 20\ mm = 0.02\ m$$

$$G = 88\ kN/mm^2 = 88 \times 10^9\ N/m^2$$

(a)

We know that,

$$\delta = \frac{8WD^3n}{Gd^4} \quad \Rightarrow \quad n = \frac{\delta G d^4}{8WD^3} \quad --------- \quad (i)$$

We also know that,

$$\tau_{max} = \frac{8WD}{\pi d^3} \quad \Rightarrow \quad W = \frac{\pi d^3 \tau_{max}}{8D} = \frac{\pi \times 0.005^3 \times 250 \times 10^6}{8 \times 0.04} = 306.796\ N$$

Substitute value W in equation (i)

$$(i) \Rightarrow n = \frac{\delta G d^4}{8WD^3} = \frac{0.02 \times 88 \times 10^9 \times 0.005^4}{8 \times 306.796 \times 0.04^3} = 7$$

Therefore, the number of coils in the spring is 7.

(b)

The load which causes maximum deflection is 306.796 N.

(c)

$$Energy\ stored\ in\ spring = \frac{W \times \delta}{2} = \frac{306.796 \times 0.02}{2} = 3.068\ J$$

Therefore, the energy stored within the spring at maximum deflection is 3.068 J.

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Q.9

A composite component consists of a steel rod, which is 250 mm long with diameter of 35 mm, which is firmly attached to an aluminium rod 625 mm in length as shown in Fig Q9. When the component has a tensile load of 32 kN applied to it the extension of the steel and aluminium sections are identical.

Calculate EACH of the following:

(a) the diameter of the aluminium rod; (8)

(b) the stress in each section of the component; (4)

(c) the total extension of the component. (4)

Note: Modulus of Elasticity for steel = 200 GN/m^2

Modulus of Elasticity for aluminium = 70 GN/m^2

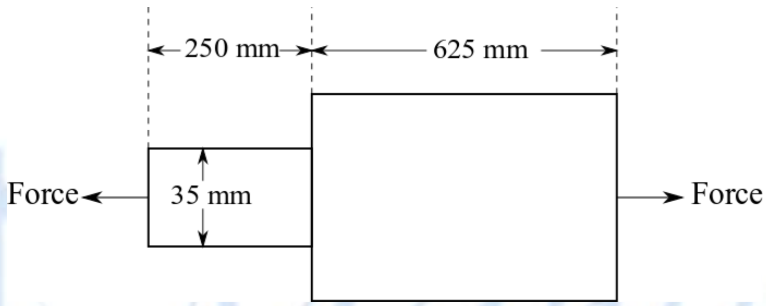
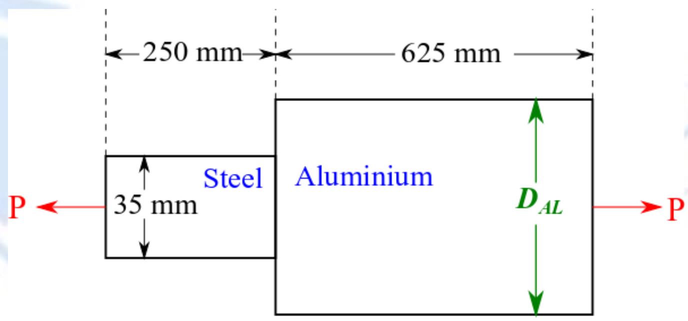


Fig Q9

Solution-



$$P = 32\ kN = 32 \times 10^3\ N$$

$$E_{St} = 200\ GN/m^2 = 200 \times 10^9\ N/m^2$$

$$E_{AL} = 70\ GN/m^2 = 70 \times 10^9\ N/m^2$$

(a)

$$Extension\ of\ steel = Extension\ of\ Aluminium$$

$$\Rightarrow \Delta l_{St} = \Delta l_{AL}$$

$$\Rightarrow \frac{Pl_{St}}{A_{St}E_{St}} = \frac{Pl_{AL}}{A_{AL}E_{AL}}$$

$$\Rightarrow \frac{0.25}{\frac{\pi}{4} \times 0.035^2 \times 200 \times 10^9} = \frac{0.625}{\frac{\pi}{4} \times {D_{AL}}^2 \times 70 \times 10^9}$$

$$\Rightarrow D_{AL} = \sqrt{\frac{0.625 \times 0.035^2 \times 200}{0.25 \times 70}} = 0.09354\, m = 93.54\, mm$$

Therefore, the diameter of the aluminium rod is 93.54 mm.

(b)

$$\sigma_{St} = \frac{P}{A_{St}} = \frac{32 \times 10^3}{\frac{\pi}{4} \times 0.035^2} = 33.26 \times 10^6\, N/m^2 = 33.26\, MN/m^2$$

$$\sigma_{AL} = \frac{P}{A_{AL}} = \frac{32 \times 10^3}{\frac{\pi}{4} \times 0.09354^2} = 4.656 \times 10^6\, N/m^2 = 4.656\, MN/m^2$$

Therefore, stress in the steel section is 33.26 MN/m^2 and stress in aluminium section is 4.656 MN/m^2.

(c)

$$\Delta l_{total} = \Delta l_{St} + \Delta l_{Al} = 2 \times \Delta l_{St} = 2 \times \frac{\sigma_{St} l_{St}}{E_{st}} = 2 \times \frac{33.26 \times 10^6 \times 0.25}{200 \times 10^9}$$

$$= 8.315 \times 10^{-5}\, m = 0.08315\, mm$$

Therefore, the total extension of the component is 0.08315 mm.