[C056/SQP106]

Higher
Mechanical Engineering
Specimen Question Paper

Time: 3 hours

NATIONAL
QUALIFICATIONS

100 marks are allocated to this paper.

Attempt **all** questions in Section A (50 marks).

Attempt any **two** questions in Section B (30 marks).

Attempt **one** question in Section C (20 marks).

Calculators may be used.

SCOTTISH
QUALIFICATIONS
AUTHORITY

SECTION A

Attempt ALL questions in this Section. (50 marks)

It is recommended that you spend approximately 90 minutes on this section. *Marks*

1. A vehicle has an initial velocity of $8\,m\,s^{-1}$ and accelerates uniformly to a final velocity of $14\,m\,s^{-1}$ in a time of 12 s.

Determine:

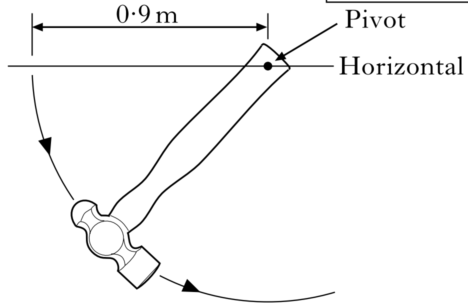
(*a*) the acceleration of the vehicle; **2**

(*b*) the displacement of the vehicle during this period. **3**

(5)

2. A hammer, as shown in Figure Q2, of mass 25 kg concentrated in the head, is released from the horizontal position so that it swings in a vertical arc of radius 0·9 m.

Figure Q2



Determine:

(*a*) the Kinetic Energy when the hammer is in the lowest position; **3**

(*b*) the velocity when the hammer is in the lowest position. **2**

(5)

3. A rotating shaft and its pulley have a moment of inertia of $50\,kg\,m^2$ about the shaft axis. The shaft is accelerated from rest to $12\,rev\,s^{-1}$ during the first 12 revolutions of its rotation against a frictional resisting torque of 300 Nm.

Calculate the total driving torque required to produce this motion. **5**

(5)

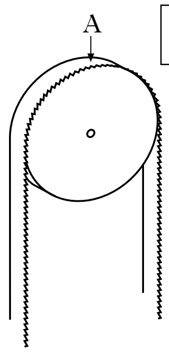
4. A motor cycle of mass 200 kg follows an unbanked curve of 30 m radius where the limiting coefficient of adhesion between the tyres and the road is 0·65.

Calculate the maximum speed in $km\,h^{-1}$ which can be achieved before sliding commences. **5**

(5)

5. The bandshaw blade in Figure Q5 takes the form of a tempered steel strip 0·8 mm thick and 20 mm wide. The strip is wrapped round a 500 mm diameter driving drum. Given that the modulus of elasticity (E) of the blade material is $230\,kN\,mm^{-2}$,

Figure Q5



(*a*) determine the maximum stress at Point A induced due to bending when the blade is at rest; **3**

(*b*) sketch the stress distribution diagram for the blade at point A, indicating significant values. **2**

(5)

6. A brass shaft is 6 mm in diameter and is tested in torsion over a gauge length of 250 mm. Just before the limit of proportionality is reached, the applied torque is 0·6 Nm and the corresponding angle of twist is 0·0183 radians.

Calculate the modulus of rigidity for brass. **5**

(5)

Marks

7. The beam shown in Figure Q7 is 10 m long, rests on two supports placed 5 m apart, and overhangs the right-hand support by 3 m. It carries a uniformly distributed load of 40 kN m^{-1} run between the supports. In addition, it carries isolated loads of 50 kN at the left-hand end, 20 kN at a point 1 m from the left-hand end, and 40 kN at the right-hand end. Also shown in Figure Q7 are the completed shear force diagram and the partially completed bending moment diagram.

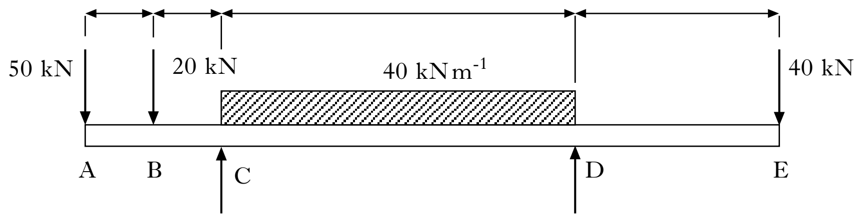
Determine:

(*a*) the reactions R_c and R_d; **2**

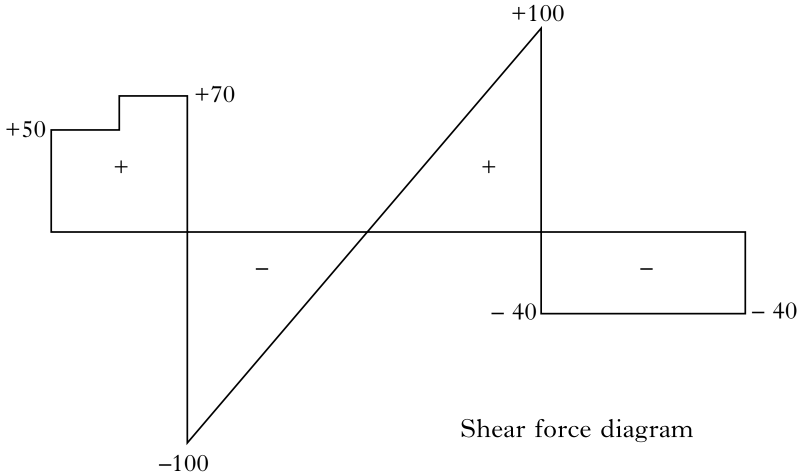
(*b*) the maximum and minimum bending moments in the beam. **3**

(5)

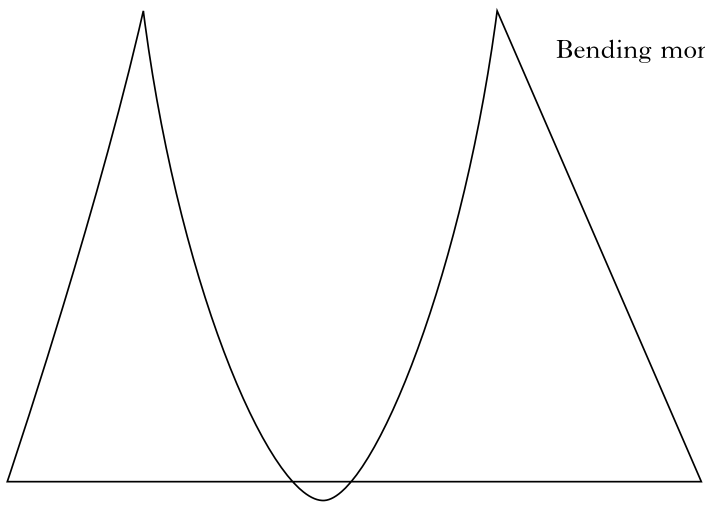
Figure Q7



Beam



Shear force diagram



Bending moment diagram

Marks

8. A closed system contains air at a pressure of 2·3 bar. The mass of air in the system is 0·08 kg and it occupies a volume of 0·03 m^3.

Determine the temperature of the air in °C. (Take R for air as 0·287 kJ kg^{-1} K^{-1}.) **5**

(5)

9. A mass of 1·5 kg of steam at a pressure of 20 bar has a total enthalpy of 3900 kJ.

(*a*) Confirm the steam is wet. **2**

(*b*) Determine the dryness fraction of the steam. **3**

(5)

10. A horizontal pipe has 0·046 $m^3 s^{-1}$ of water flowing through it. The pressure drop between entry and exit of the pipe is 25 kN m^{-2} and the cross-sectional area at entry is 8×10^{-3} m^2. The density of water is 1000 kg m^{-3}.

Determine the velocity at exit. **5**

(5)

[*END OF SECTION A*]

SECTION B

Attempt any TWO questions in this Section (30 marks). Each question is worth 15 marks.
It is recommended that you spend approximately 50 minutes on this section.

Marks

11. A load of mass 6 tonnes is to be accelerated vertically from rest at a rate of 0·95 m s^{-2} by means of a light cable passing over a hoist drum of 1·7 m diameter.

The drum mass is 800 kg and its radius of gyration is 680 mm.

Determine, neglecting friction:

(*a*) the torque in Nm required to accelerate the system; **11**

(*b*) the power required in kW, 4 seconds after the start of the lift, while acceleration continues. **4**

(15)

12. A light beam is 6 m long and simply supported at each end. The only load applied to the beam is a uniformly distributed load of 0·75 kN m^{-1} over the first 4 m of its length from the left-hand end.

(*a*) Sketch the shear force and bending moment diagrams for the beam indicating significant values. **13**

(*b*) Calculate the section modulus required to limit bending stress to 150 N mm^{-2}. **2**

(15)

13. A quantity of gas initially occupies a volume of 0·3 m^3, at a pressure of 17 bar and a temperature of 150 °C.

The gas is heated at constant pressure until its volume has increased to 0·5 m^3.

Take c_p = 1005 J kg^{-1} K^{-1} c_v = 718 J kg^{-1} K^{-1}.

(*a*) Sketch the pV diagram for this process. **2**

(*b*) Determine:

(i) the temperature of the gas after expansion; **3**

(ii) the mass of the gas; **4**

(iii) the work done during expansion; **2**

(iv) the heat transfer required; **2**

(v) the change in internal energy. **2**

(15)

[*END OF SECTION B*]

SECTION C

Attempt ONE question in this Section (20 marks). Each question is worth 20 marks.
It is recommended that you spend approximately 40 minutes on this section.

Marks

14. A new design for a marine oil engine operating on a dual cycle is indicated in Figure Q14.

At top dead centre the conditions existing in the cylinder are pressure 45 bar, volume $0{\cdot}6 \times 10^{-3}$ m^3 and temperature 21 °C.

Combustion then takes place, and on reaching the position shown in Figure Q14, the volume above the piston has increased to $2{\cdot}8 \times 10^{-3}$ m^3 and the temperature has reached its maximum value of 1200 °C.

Determine:

(*a*) the maximum pressure in the cylinder, which occurs when the maximum temperature of the gas has been reached; **3**

(*b*) the force exerted on the piston by the maximum gas pressure; **3**

(*c*) the shear stress in the hollow gudgeon pin caused by the maximum gas pressure, given that the outside diameter of the pin is 60 mm and the inside diameter of the pin is 40 mm; **4**

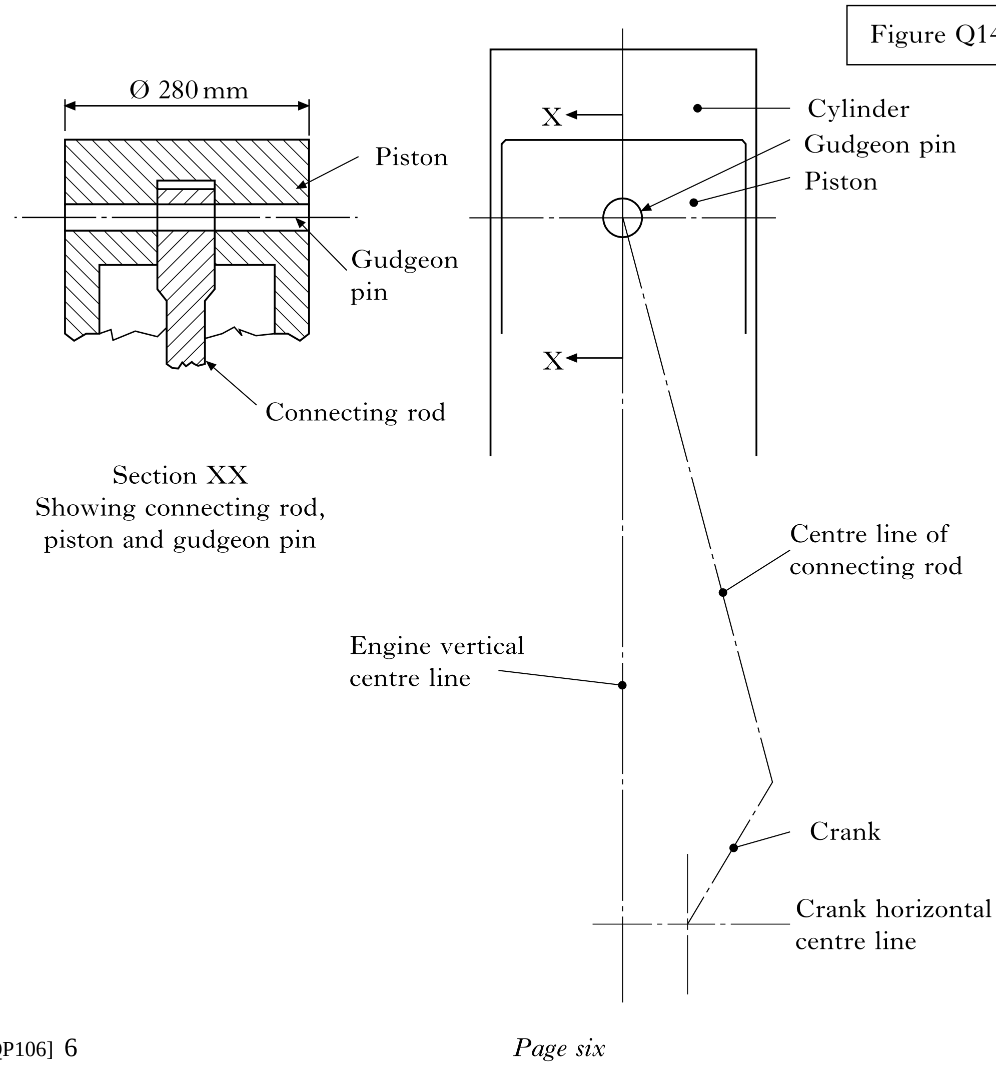
(*d*) the torque produced at the crank when the position is reached at which the crank and connecting rod are at **right angles** to each other; (The force in the connecting rod is 25 kN and the effective crank radius is 210 mm at this position.) **2**

(*e*) the resulting angular acceleration of the crank in the position in (*d*) above, given that the total mass being accelerated can be considered as 1720 kg concentrated at a radius of 188 mm and only 2% of the torque produced at the crank causes angular acceleration; **5**

(*f*) the power being developed in the cylinder at the position shown in (*d*) above, given that the engine speed in this position is 1200 rpm. **3**

(20)

Figure Q14



Marks

15. A stainless steel storage tank contains liquid ammonia with a density of $890\,kg\,m^{-3}$.

The liquid fills the tank to a height of 5 m above the centre of a flat inspection hatch. The hatch is 900 mm wide by 400 mm high and is situated on the vertical side of the tank. The hatch is used to inspect the inside of the empty tank twice a year to assess its condition.

The hatch cover is secured in position by 20 set screws of size M12 which have an outside diameter of thread of 12 mm. The radial thread depth is 0·775 mm.

(*a*) Determine the force caused on the hatch cover, given that the pressure at the surface of the liquid is 10 bar. **6**

(*b*) In order to seal the hatch cover against the pressure in the tank, the recommended tightening torque to be applied to each set screw is given by the formula:

$$\text{Recommended Torque} = 0{\cdot}4 \times F \times d$$

where F is the average force which must be applied by each set screw to balance the internal pressure in the tank and d is the outside diameter of the set screw.

Determine:

(i) the average force (F) in each of the set screws;

(ii) the recommended torque required to be applied. **4**

(*c*) For various reasons the recommended torque will cause a greater axial force in the set screws than the minimum required, calculated as F above.

(i) Determine this actual axial force and the stress caused in the set screw material, given that the actual axial force = 320 × recommended torque where the recommended torque is in Nm and axial force is in Newtons. **6**

(ii) Suggest **one** reason why the recommended torque is designed to produce a higher axial force than the force calculated in part (*b*). **2**

(*d*) Select those materials from the list given below which would meet the stress requirements, and suggest **one** other factor which should be taken into account when choosing the best material to use for the set screws.

Material	*Yield Stress* $N\,mm^{-2}$
Structural Steel	350
Austenitic Stainless Steel	210
Ferritic Stainless Steel	370
Aluminium Alloy	95
Thermosetting Plastic	68

2

(20)

[*END OF QUESTION PAPER*]

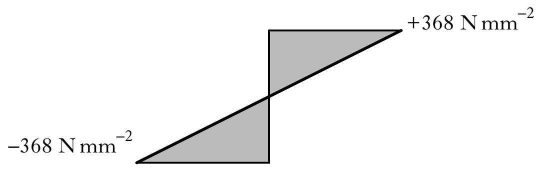
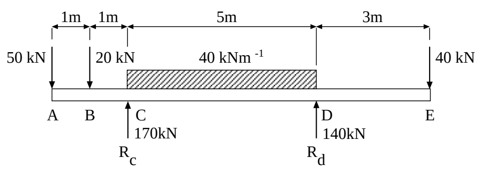
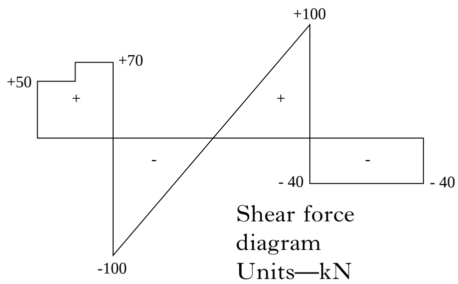
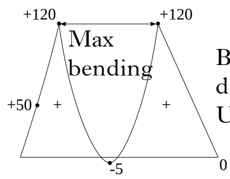
[CO56/SQP106]

Higher
Mechanical Engineering
Specimen Marking Instructions

NATIONAL
QUALIFICATIONS

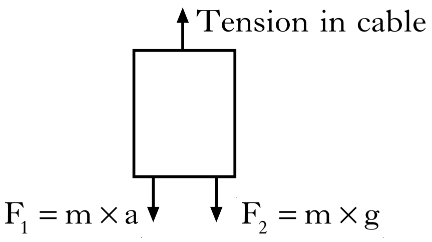
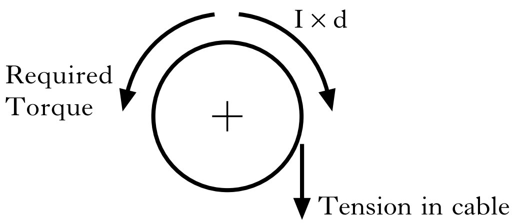
MECHANICAL ENGINEERING
SOLUTIONS
SECTION A

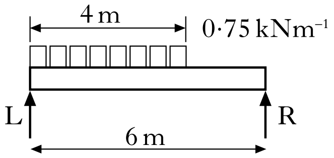
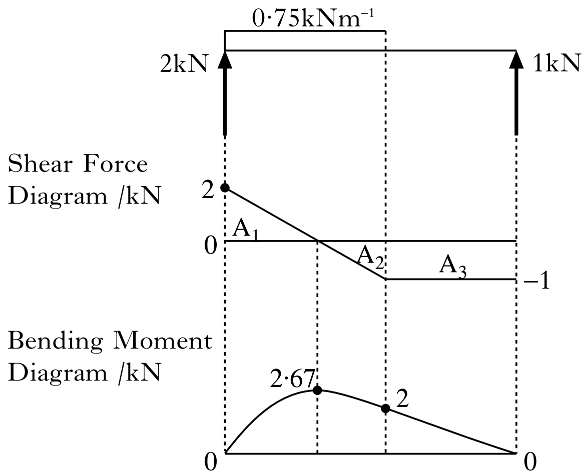
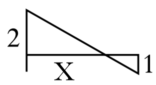
Q	Solution	Marks
1.	$u = 8\,m\,s^{-1}$ $v = 14\,m\,s^{-1}$ $t = 12\,s$	
a	$a = \frac{v-u}{t} = \frac{14-8}{12} = 0{\cdot}5\,m\,s^{-2}$	2
b	$s = ut + \frac{1}{2}at^2 = 8 \times 12 + \frac{1}{2} \times 0{\cdot}5 \times 12^2 = 132\,m$	3
	Note: it would be acceptable to adopt a solution based on the velocity/time diagram.	
	acceleration = $0{\cdot}5\,m\,s^{-2}$ distance = 132 m	(5)
2.		
a	Potential Energy = mgh = $25 \times 9{\cdot}81 \times 0{\cdot}9 = 220{\cdot}725$ J Potential Energy at the top must equal Kinetic Energy at the bottom from the law of conservation of energy Kinetic energy = 221 J	3
b	$K\,E = \frac{1}{2}mv^2$ $v = \left(\frac{2KE}{m}\right)^{\frac{1}{2}} = 4{\cdot}2\,m\,s^{-1}$	2
		(5)
3.	$I = 50\,kg\,m^2 \omega_1 = 0$ rad s^{-1} $\omega_2 = 12 \times 2\pi = 75{\cdot}4$ rad s^{-1} $\theta = 12 \times 2\pi = 75{\cdot}4$ rad $\omega_2^{\ 2} = \omega_1^{\ 2} + 2\alpha\theta \quad \therefore\ \alpha = 37{\cdot}67$ rad s^{-2} $T = I\alpha = 50 \times 37{\cdot}67 = 1885$ Nm Add to this, frictional force of 300 Nm Torque required = 2185 Nm	5 (5)
4.	Outward force $= mr\omega^2$ where $\omega = \frac{v}{r}$ force = $m\frac{v^2}{r}$ Inward force $F = \mu N \quad \therefore F = \mu mg$ At the point of sliding, inward and outward forces must be equal therefore $\mu mg = m\frac{v^2}{r} \therefore v = \sqrt{\mu gr} \rightarrow \sqrt{0{\cdot}65 \times 9{\cdot}81 \times 30} = 13{\cdot}83\,m\,s^{-1}$ Maximum speed of motor cycle = $49{\cdot}9\,km\,h^{-1}$	5 (5)

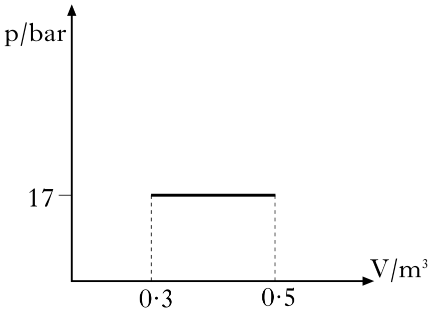
Q	Solution	Marks
5.		
a	$\frac{\sigma}{y} = \frac{M}{I} = \frac{E}{R} \Rightarrow \sigma = \frac{Ey}{R} \Rightarrow \frac{230 \times 10^3 \times 0{\cdot}4}{250} = 368 \text{N mm}^{-2}$ Max stress = 368 N mm^{-2}	3
b	 One mark for shape and one mark for the addition of values	2 (5)
6.	$\frac{\tau}{R} = \frac{G\theta}{l} = \frac{T}{J} \Rightarrow G = \frac{Tl}{J\theta}$ $\quad J = \frac{\pi d^4}{32} = \frac{\pi \times 0 \cdot 006^4}{32} = 1 \cdot 27 \times 10^{-10}$ $G = \frac{Tl}{J\theta} = \frac{0 \cdot 6 \times 0 \cdot 25}{1 \cdot 27 \times 10^{-10} \times 0 \cdot 0183} = 6 \cdot 44 \times 10^{10}$ Modulus of rigidity = 64·4 GN m^{-2}	5 (5)
7.	  Shear force diagram Units—kN  Bending moment diagram Units—kN m	
a	From SFD $\quad R_C$ = 100 + 70 = 170 kN $\quad R_D$ = 100 + 40 = 140 kN	2
b	Max BM $\quad 50 \times 1 + 70 \times 1 = 120$ kN m or $\quad 40 \times 3 = 120$ kN m Min BM $\quad 120 - \frac{1}{2} \times 100 \times 2{\cdot}5 = -5$ kN m (correct answers obtained by any valid method are acceptable)	3 (5)

Q	Solution	Marks
8.	$m = 0{\cdot}08\,kg \quad v = 0{\cdot}03\,m^3 \quad R = 0{\cdot}257\,kJ\,kg^{-1}\,K^{-1}$ $pV = mRT \qquad T = \frac{pV}{mR} = \frac{2{\cdot}3\times10^5\times0{\cdot}03}{0{\cdot}08\times0{\cdot}257\times10^3} = 335{\cdot}6K$ The temperature of the air 62·6 °C	5 (5)
9. *a* *b*	$h = \frac{H}{m} = \frac{3900}{1{\cdot}5} = 2600\ kJ\,kg^{-1}$ $@20$ bar $h_g = 2799 \therefore$ the steam must be wet since h < hg Using $h = h_f + x\,h_{fg}$ we get $x = \frac{h - h_f}{h_{fg}} = \frac{2600 - 909}{1890} = 0 \cdot 895$ the dryness fraction is 0·895	 2 3 (5)
10.	At entry volumetric flow rate = ac $0{\cdot}046 = 8\times10^{-3}$ x c $\Rightarrow$ c $= 5{\cdot}75\ m\,s^{-1}$ $\frac{c^2}{2g} + \frac{p}{\rho g} + z = total\ head \Rightarrow c_2^2 = \frac{2(p_2 - p_1)}{\rho} + c_1^2 \Rightarrow c_2^2 = 83 \cdot 06 \Rightarrow c_2 = 9 \cdot 11$ NB: working in energy rather than head is equally acceptable. The velocity at exit = 9·11 $m\,s^{-1}$	5 (5)

SECTION B

Q	Solution	Marks
11.	m = 800 kg	
	k = 680 mm	
	D = 1·7 m	
	a = 0·95 m s^{-2}	
	t = 6s	
a		
	For linear system to accelerate and to support weight	
	$F_1 = ma$	
	$F_1 = 6000 \times 0{\cdot}95 = 5700$ N	1
	$F_2 = m \times g = 6000 \times 9{\cdot}81 = 58860$ H	1
	$T = (F_1 + F_2)$ Rad $= 64560 \times \frac{1 \cdot 7}{2}$	1
	= 54876 Nm	1
	For angular system	
	$a = R\alpha$ $\therefore \alpha = \frac{0 \cdot 95 \times 2}{1 \cdot 7} = 1 \cdot 1176$ rad s^{-2}	2
	$I = mk^2$	
	$= 800 \times 0{\cdot}68^2 = 369{\cdot}92$ kgm^2	2
	$T = I\alpha$	
	$= 369{\cdot}92 \times 1{\cdot}1176 = 413{\cdot}4$ Nm	2
	For combined system	
	Torque required = 54876 + 413·4 = 55289·4 Nm or 55·29 kNm	1
b		
	$\omega_2 = \omega_1 + \alpha t$ and ω_1 = zero	
	$\omega_2 = \alpha t = 1 \cdot 1176 \times 4 = 4 \cdot 4704$ rad s^{-1}	2
	$P = T\omega = 55 \cdot 29 \times 10^3 \times 4 \cdot 4704 \times 10^{-3} = 247 \cdot 2$ kW	2
		(15)

Q	Solution	Marks
12. *a*		
	$R \times 6 = (4 \times 0{\cdot}75) \times 2 \;\Rightarrow\; R = 1\text{ kN}$	2
	$R + L = 4 \times 0{\cdot}75 \;\Rightarrow\; L = 4 \times 0{\cdot}75 - 1 = 2\text{ kN}$	1
		2 3
		
	$\dfrac{2}{x} = \dfrac{1}{4-x}$	
	$8 - 2x = x \;\Rightarrow\; x = 2{\cdot}67\text{ m}$	2
	$A_1 = \tfrac{1}{2} \times 2\cdot67 \times 2 = 2\cdot67\text{ kNm}$	1
	$A_2 = \tfrac{1}{2}(4 - 2\cdot67) \times -1 = -0\cdot67\text{ kNm}$	1
	$A_3 = -1(6-4) = -2\text{ kNm}$	1
b	$\sigma = \dfrac{M}{Z} \;\Rightarrow\; Z = \dfrac{M}{\sigma} = \dfrac{2{\cdot}67 \times 10^6}{150} = 17800\text{ mm}^3$	2
		(15)

Q	Solution	Marks
13. *a*		2
b	(i) $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$	
	$\frac{0 \cdot 3}{(273+150)} = \frac{0 \cdot 5}{T_2}$	
	T_2 =705 K or 432°C	3
	(ii) pV = mRT $\therefore m = \frac{pV}{RT} = \frac{17 \times 10^5 \times 0 \cdot 3}{(273+150)(1005-718)} = 4 \cdot 2$ kg	4
	(iii) w = Area under pV diag	
	$= 17 \times 10^5 (0{\cdot}5 - 0{\cdot}3) = 340$ kJ	2
	(iv) $Q = mc_p\Delta T = 4{\cdot}2 \times 1005\ (432 - 150) = 1190{\cdot}6$ kJ	2
	(v) $Q - w = \Delta u = 1190{\cdot}6 - 340 = 850{\cdot}6$ kJ	2
		(15)

SECTION C

Q	Solution	Marks
14.		
a	Let Top Dead Centre be condition 1	
	Hence $p_1 = 45$ bar, $V_1 = 0{\cdot}6 \times 10^{-3}$ m^3, $T_1 = 21 + 273 = 294$ k	1
	Let the position shown in the sketch be condition 2	
	Hence $V_2 = 2{\cdot}8 \times 10^{-3}$ m^3, $T_2 = 1200 + 273 = 1473$ k	
	From $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$	1
	$p_2 = \frac{p_1V_1T_2}{T_1V_2}$	
	$p_2 = \frac{45 \times 0 \cdot 6 \times 1473}{294 \times 2 \cdot 8} = 48 \cdot 313$ bar	1
b	Force on piston = Pressure × Area	1
	$= 48{\cdot}313 \times 10^5 \times \frac{\pi}{4} \times 280^2 \times 10^{-6}$	1
	= 297500 N or 297·5 kN	1
c	Pin is in double shear	1
	Shear stress = $\frac{\text{load}}{\text{shear area}}$	1
	Load = 297·5 kN	
	Shear area = $2 \times \pi(60^2 - 40^2) = 3142$ mm^2	1
	Shear stress = $\frac{297{\cdot}5 \times 10^3}{3142} = 94{\cdot}7$ N mm^{-2}	1
d	Torque = force × radius	1
	Force = 25 kN radius = 210 mm or 0·21 m	
	Torque = 25 × 0·21 = 5·25 kNm	1
e	Accelerating torque = $I \times \alpha$	1
	Hence $\alpha = \frac{\text{accel torque}}{I}$	
	Accel torque = $0{\cdot}02 \times 5{\cdot}25 \times 10^3 = 105$ Nm	1
	I = mass × rad^2 = $1720 \times 0{\cdot}188^2 = 60{\cdot}79$ kg m^2	2
	$\alpha = \frac{105}{60{\cdot}79} = 1{\cdot}73$ rad sec^{-2}	1
f	Power = torque × ang velocity	1
	$= 5{\cdot}25 \times 10^3 \times \frac{2\pi \times 1200}{60}$	1
	= 659·7 kW	1
		(20)

Q	Solution	Marks
15.		
a	The pressure in the tank alone will cause a pressure on the hatch cover of 10 bar.	1
	The fluid pressure at the middle of the hatch cover $p = \rho \times g \times h$	1
	$p = 890 \times 9{\cdot}81 \times 5 = 43654{\cdot}5\ \text{Nm}^{-2}$ or 0·4365 bar	1
	Hence total pressure at middle of hatch cover = 10·4365 bar	
	Force = pressure × area	1
	$= 10{\cdot}44 \times 10^5 \times (900 \times 400) \times 10^{-6}$	1
	= 375840 N or 375·8 kN	1
b	20 set screws are used hence load per screw $= \frac{375{\cdot}8}{20} = 18{\cdot}79$ kN	1
	Outside diameter = 12 mm	1
	From given formula Recommended torque = 0·4 × F × d	
	$= 0{\cdot}4 \times 18{\cdot}79 \times 10^3 \times 12 \times 10^{-3}$	1
	= 90·2 Nm	1
c	Stress $= \frac{\text{load}}{\text{area}}$	1
	Load = axial force	1
	From given formula Axial force = 320 × recommended torque = 320 × 90·2	
	= 28861·4 N or 28·86 kN	1
	This value of axial force is 54% higher than that required to produce the force of 18·79 kN required for part *b*.	
	This extra force is required to ensure that the set screw when tightened against the frictional resistance of the thread can still apply the necessary axial force.	2
	Area of set screw supporting the axial load	1
	$= \frac{\pi}{4} \times$ core dia^2	1
	$= \frac{\pi \times 10{\cdot}45^2}{4} = 85{\cdot}77\ \text{mm}^2$	
	Hence stress $= \frac{28 \cdot 86 \times 10^3}{85 \cdot 77} = 336 \cdot 5\ \text{N mm}^{-2}$	1
d	The stress in the set screws requires that either structural steel or ferritic steel is selected. Since the tank is made of stainless steel and there is a possibility of ammonia causing corrosion to structural steel then ferritic stainless steel screws would be best choice.	2
		(20)