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Cambridge **TECHNICALS LEVEL 3**

ENGINEERING

Combined feedback on the January 2017 exam paper (including selected exemplar candidate answers and commentary)

Unit 3 – Principles of mechanical engineering

Version 1

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CONTENTS

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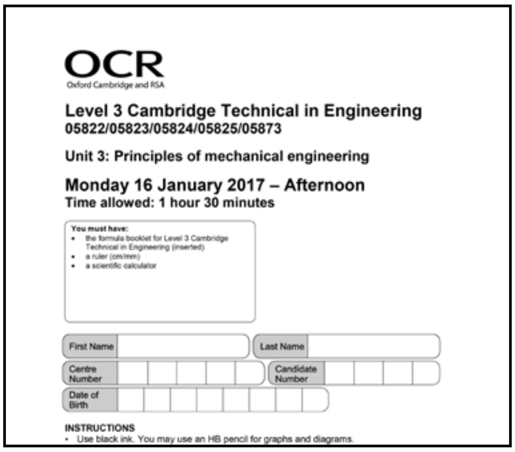
INTRODUCTION

TThis resource brings together the questions from the January 2017 examined unit (Unit 3), the marking guidance and the exemplar answers into one place for easy reference.

We've also included candidate exemplar answers with commentaries for Question 4.

The marking guidance and the examiner's comments are taken straight from the Report to Centre for this question paper.

The Question Paper and Mark Scheme are available from: https://interchange.ocr.org.uk/



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Level 3 Cambridge Technical in Engineering
05822/05823/05824/05825/05873

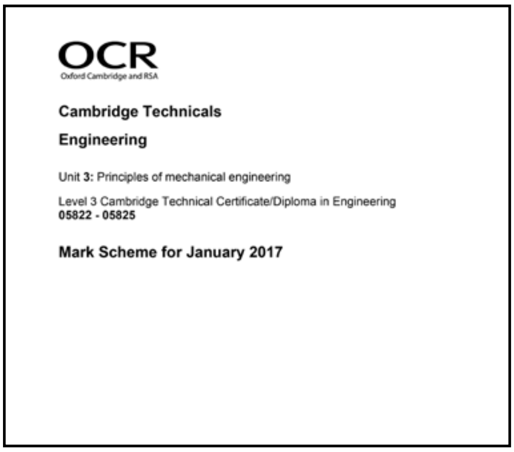
Unit 3: Principles of mechanical engineering

Monday 16 January 2017 – Afternoon
Time allowed: 1 hour 30 minutes

You must have:
- the formula booklet for Level 3 Cambridge Technical in Engineering (inserted)
- a ruler (cm/mm)
- a scientific calculator

First Name | Last Name
Centre Number | Candidate Number
Date of Birth

INSTRUCTIONS
- Use black ink. You may use an HB pencil for graphs and diagrams.



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Cambridge Technicals

Engineering

Unit 3: Principles of mechanical engineering

Level 3 Cambridge Technical Certificate/Diploma in Engineering
05822 - 05825

Mark Scheme for January 2017

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Question 1

1 Fig. 1 shows a steel tube with length 50 mm. The outside diameter is 20 mm and the inside diameter is 14 mm.

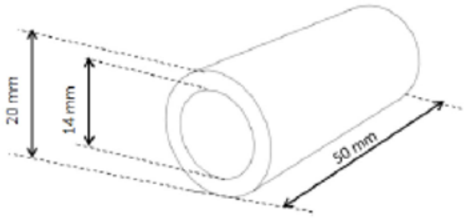

Fig. 1

(i) Calculate the cross-sectional area of this tube. Give your answer in mm².

$A = \pi \times 10^2 - \pi \times 7^2$

160 (160.22 – 160.3) **[2]**

(ii) Convert your answer from part (i) into m².

$(160 \div 1000^2)$
$= 1.6 \times 10^{-4}$ (m²) or 0.00016 **[1]**

(iii) The tube is subjected to an axial compressive force of 14 000 N. Calculate the axial stress in the steel under this force. You must provide the units of your answer.

$14000 \div 0.00016$

$= 87000000$ N/m² or Pa or equivalent **[2]**

OR $14000 \div 160.22 = 87.4$ N/mm² or MPa

(iv) Under this loading the tube reduces to a length of 49.978 mm. Calculate the axial strain in the tube.

(Change in length =)50 – 49.978 (= 0.022)
Strain = change in length ÷ original length
= 0.0022/50 **[2]**
4.4×10^{-4} or 0.00044

(v) Using the value of stress calculated in part (iii) and the value of strain calculated in part (iv), calculate Young's modulus for the steel used in the tube.

$$E = \frac{\sigma}{g} = \frac{87390762}{0.00044} = 1.986 \times 10^{11} \text{ Pa or } 199 \text{ GPa}$$ **[2]**

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(vi) The tube is replaced with a solid bar with the same outside diameter and the same length. The solid bar is made of the same steel as the tube and is subject to the same compressive force of 14 000 N. State, without performing any further calculations, whether the magnitude of each of your values calculated in parts (iii), (iv) and (v) would become larger, smaller or stay the same.

Part (iii) ....

Part (iv) ....

Part (v) ....

iii) smaller
iv) smaller
v) unchanged

[1]

Mark scheme guidance

1 i)

Method mark for use of circle formula to calculate area of smaller and larger circle. Condone no explicit indication of subtraction.
Ignore units

1 ii)

Allow ECF part i)
Ignore units

1 iii)

Correct unit required for second mark.
Allow 88000000 N/ m^2

1 iv)

Method mark calculation of change in length.
Maximum 1 mark if unit shown
Synoptic mark from Unit 2:LO4

1 v)

Numbers substituted into formula. Allow ECF from parts iii & iv
Correct calculation – correct unit required

1 vi)

All must be correct for 1 mark.

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Question 2

2 (i) A toy rocket of mass 3 kg is fired into the air, by means of a catapult, with an initial vertical speed of 13 m s^{-1}. Assume that the rocket remains in flight under the influence of gravity with no other forces resisting its motion. Calculate the maximum height reached by the rocket.

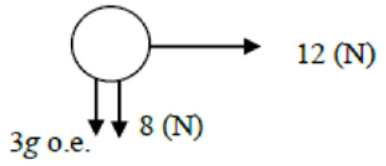
$v^2 = u^2 + 2as$

$0 = 13^2 + 2 \times (-9.8)s$ *or* $0 = 169 - 19.6s$

$s = 8.6$ m (8.62 for 9.8, 8.61 for 9.81)

[2]

(ii) Draw a diagram showing **all** the forces acting on the rocket at this moment in time. You may represent the rocket as a particle.



(iii) Calculate the **vertical** deceleration of the rocket at this moment in time.

$\Sigma F = ma$

$3g + 8 = 3a$

$a = 12.5 (\text{m s}^{-2})$

[2]

(iv) Calculate the magnitude of the resultant force acting on the rocket.

$\text{Resultant} = \sqrt{37.4^2 + 12^2}$

39 (N) (39.28)

[2]

(v) Calculate the direction of this resultant force relative to the vertical.

$\theta = tan^{-1}\left(\frac{12}{37.4}\right)$

17.8 (degrees)

[2]

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Mark scheme guidance

2 i)

Selection of correct equation and input of correct values for u, v and a. Allow omission of negative sign in front of a for this mark. Ignore sign with BOD

2 ii)

Force arrows must have arrowheads. Allow Force arrows not connected to object.
Accept any sensible object shape (eg box/rocket/dot etc).
12 N force must be horizontal, can point to left or right
3g force and 8 N must both be shown acting downwards.
Acceptable equivalents for 3g include mg, 29.4, W, 3×9.8

Award 1 of 2 marks for 2 out of 3 forces correct. OR 1 mark for horizontal force drawn and labelled correctly and single vertical resultant drawn and labelled correctly.

2 iii)

Evidence of application of N2L.
Allow ECF from ii)
Allow use of mg or $3 \times 9.8 = 29.4$
Ignore unit, ignore sign. Allow ECF from ii)

2 iv)

Calculation of resultant using 2 orthogonal forces. ECF diagram from part iii).
Ignore unit

2 v)

use of $\tan^{-1}$ with 2 components. ECF components from iii/iv.

Allow ECF parts iii/iv. Allow 17.7 degrees.
Synoptic mark from Unit 1:LO4

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Question 3

3 (a) A beam with uniform density has a cross-sectional area of 0.51 m^2 and a length of 8 m.

(i) Calculate the volume of the beam.

(0.51 × 8)
4.1 (4.08) (m^3) [1]

(ii) The beam is made from concrete with a density of 2400 kg m^{-3}. Calculate the mass of the beam.

(2400 × 4.08)
9792 (kg) (or 9840 if 4.1 used) [1]

(iii) Calculate the weight of the beam in Newtons.

($W = mg$ = 9792 × 9.8 =) 95961.6 (N) [1]

(b) Fig. 2 shows the beam supported at points A and B. Point A is at the left end of the beam while point B is 2 m from the right end of the beam. A force of 34 000 N acts at an upward angle of 30° at the right end of the beam as shown.

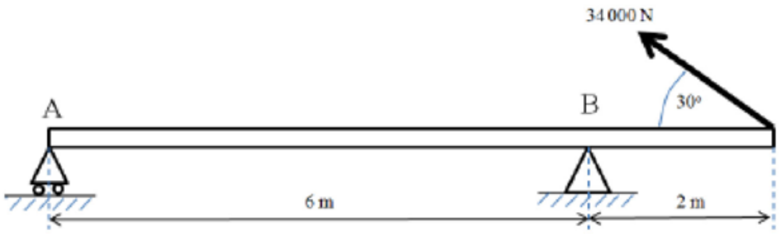

Fig. 2

(i) The 34 000 N force can be resolved into two components which act perpendicular to and parallel to the beam. Calculate the magnitude of the **perpendicular** component.

34000 sin 30 or 17000 (N) [1]

(ii) Name the type of support indicated at point A.

Roller (support) [1]

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(iii) Calculate the support reactions at points A and B due to the combined 34 000 N force and the self-weight of the beam as calculated in part **(a) (ii)**. You may neglect the component of the 34 000 N force parallel to the beam and consider only the perpendicular component.

Self-weight of 95962 N correctly shown or implied.
Correct expression taking moments about point A:

$R_b \times 6 + 17000 \times 8 = 95962 \times 4$

$R_b = 41308$ N

Vertical equilibrium: $R_a + R_b + 17000 = 95962$

$R_a = 37654$ N

[5]

Mark scheme guidance

3 a) ii)

Allow ECF part i).

3 a) iii)

Allow ECF part i), accept sensible rounding.
Synoptic mark from Unit 2:LO2

3 b) i)

Accept no mention of 17000 as long as calculation seen

3 b) iii)

Can be shown on fig.2 or on own diagram or implied in subsequent working.

Allow correct expression taking moments about B

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Question 4

4 (a) Fig. 3 shows a semi-circular plate of radius 45 mm. The plate has uniform density and is aligned within a Cartesian coordinate system with the origin O, as shown.

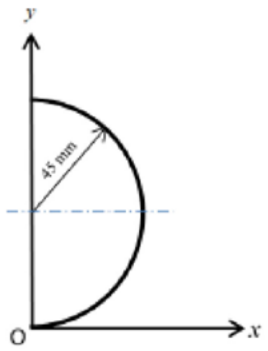

Fig. 3

Calculate the coordinates, $\bar{x}$ and $\bar{y}$, of the centroid of this semi-circular plate.

19.1 (19.09859), 45

[2]

(b) Fig. 4 shows a rectangular plate, ABCD, which has uniform density. The plate is 400 mm long and 150 mm wide.

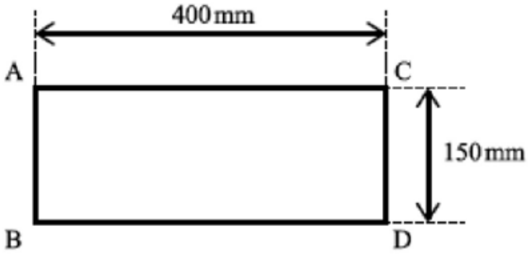

Fig. 4

The plate is freely suspended in a state of equilibrium from corner A. Calculate the angle that side AB makes with the vertical.

$\theta = tan^{-1}\left(\frac{200}{75}\right)$

= 69.4(°) or 110.6(°)

[2]

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(c) Fig. 5 shows a cantilever beam with length 15 m attached to a wall. The total weight of the beam is modelled by a vertical downward force of 20 N acting at a point 6 m from the wall. A vertical upward force of 100 N acts at the other end of the beam.

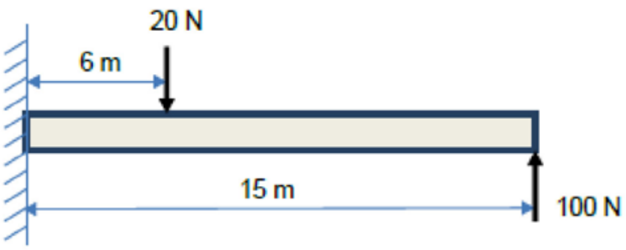


Fig. 5

(i) Calculate the vertical reaction at the wall.

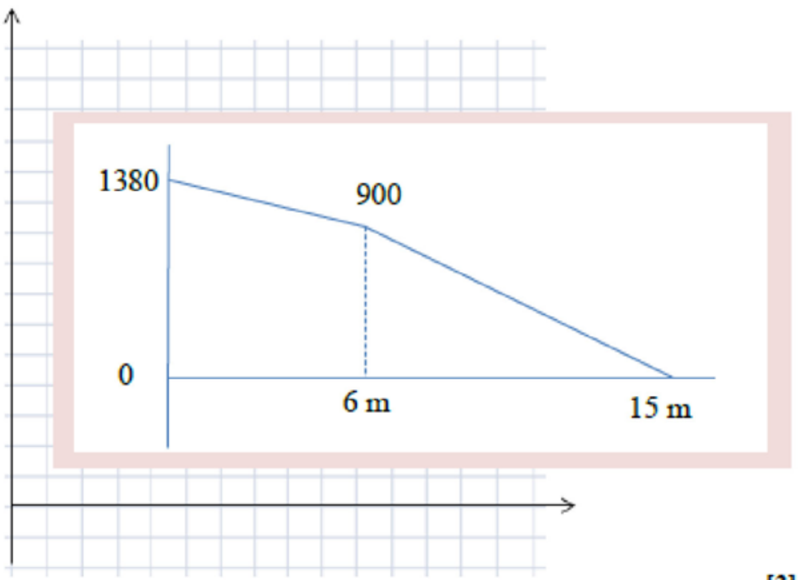
80 (N) (downwards) **[1]**

(ii) Calculate the bending moment at the wall.

(M =) 100 ×15 – 20 x 6

1380 Nm **[2]**

(iii) Draw a labelled bending moment diagram for the beam on the grid below.



[3]

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Mark scheme guidance

4 a)

1 per co-ordinate. Award 1 mark if correct co-ordinates found but not indicated which is which, or written wrong way around.

4 c) i)

Do not allow 80 N upwards

4 c) ii)

Ignore sign

4 c) iii)

Values of 1380 (Nm) at 0(m) and/or 0 (Nm) at only 15(m) indicated.

Calculation of 900 (Nm) at 6 (m) seen or indicated on diagram.

Diagram correctly drawn as shown (All values indicated on diagram all in the same quadrant. Straight lines connecting values. (allow hand-drawn as long as intention of straight line is clear).

Condone all values in the negative quadrant.

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Exemplar candidate work

Question 4 - Low level answer

4 **(a)** Fig. 3 shows a semi-circular plate of radius 45 mm. The plate has uniform density and is aligned within a Cartesian coordinate system with the origin O, as shown.

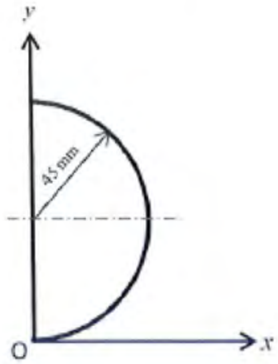

Fig. 3

Calculate the coordinates, $\bar{x}$ and $\bar{y}$, of the centroid of this semi-circular plate.

$\frac{4r}{3\pi}$ $\frac{4 \times 45}{3 \times \pi} = 19.1$ ✓✓

.... [2] 2

$\bar{y} = 45$ $\bar{x} = 19.1$

(b) Fig. 4 shows a rectangular plate, ABCD, which has uniform density. The plate is 400 mm long and 150 mm wide.

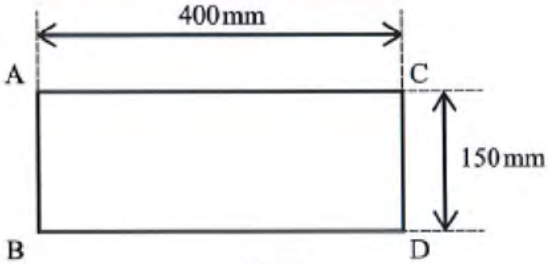

Fig. 4

The plate is freely suspended in a state of equilibrium from corner A. Calculate the angle that side AB makes with the vertical.

.... ^

.... [2] 0

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(c) Fig. 5 shows a cantilever beam with length 15 m attached to a wall. The total weight of the beam is modelled by a vertical downward force of 20 N acting at a point 6 m from the wall. A vertical upward force of 100 N acts at the other end of the beam.

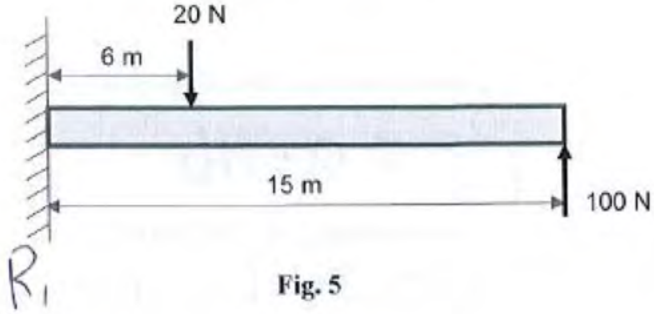


Fig. 5

(i) Calculate the vertical reaction at the wall.

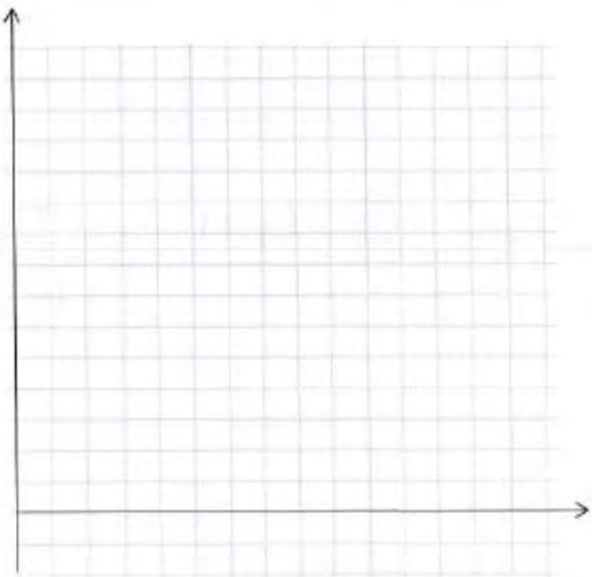
$R_1 = 100 - 20$
$R_1 = 80N \uparrow$ ✓ .... **[1]** 1

(ii) Calculate the bending moment at the wall.

$100 - 20 = 80N \uparrow \times 15 = 1200N$ ✗

.... **[2]** 0

(iii) Draw a labelled bending moment diagram for the beam on the grid below.



^

[3] 0

3

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Commentary

- The answer to part (a) correctly calculates and states the coordinates of the centroid, and so scores both available marks. Note however that the inclusion of units (mm) is preferred.
- In part (b) no answer or workings are written down so scores zero.
- In part (c) (i) some benefit of doubt is given to award the mark for correct value of 80N. Strictly, this should be "downwards" – the arrow is ignored somewhat generously here.
- In part (c) (ii) the answer is incorrect and the workings do not merit a compensation mark – so scores zero.
- In part (c) (iii) no attempt has been made to draw bending moment diagram so scores zero.

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Exemplar candidate work

Question 4 - Medium level answer

4 **(a)** Fig. 3 shows a semi-circular plate of radius 45 mm. The plate has uniform density and is aligned within a Cartesian coordinate system with the origin O, as shown.

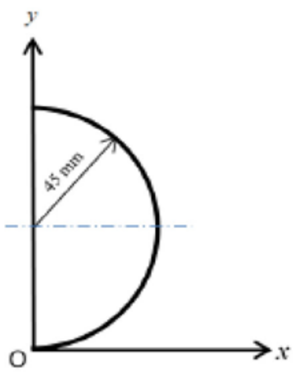

Fig. 3

Calculate the coordinates, $\bar{x}$ and $\bar{y}$, of the centroid of this semi-circular plate.

This is a candidate style answer.

$\bar{x}$ = 19.1mm
$\bar{y}$ = 45 mm

[2]

(b) Fig. 4 shows a rectangular plate, ABCD, which has uniform density. The plate is 400 mm long and 150 mm wide.

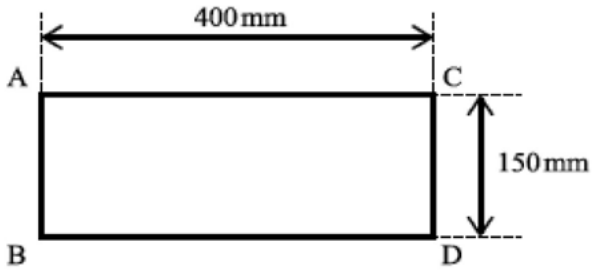

Fig. 4

The plate is freely suspended in a state of equilibrium from corner A. Calculate the angle that side AB makes with the vertical.

This is a candidate style answer.

$$\theta = tan^{-1}\left(\frac{200}{75}\right)$$
$$= 20.6°$$

[2]

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(c) Fig. 5 shows a cantilever beam with length 15 m attached to a wall. The total weight of the beam is modelled by a vertical downward force of 20 N acting at a point 6 m from the wall. A vertical upward force of 100 N acts at the other end of the beam.

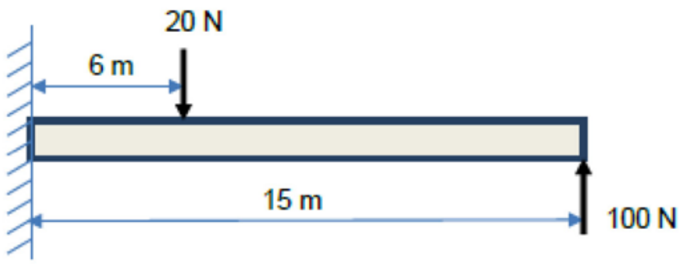


Fig. 5

(i) Calculate the vertical reaction at the wall.

This is a candidate style answer.

80 N (downwards) [1]

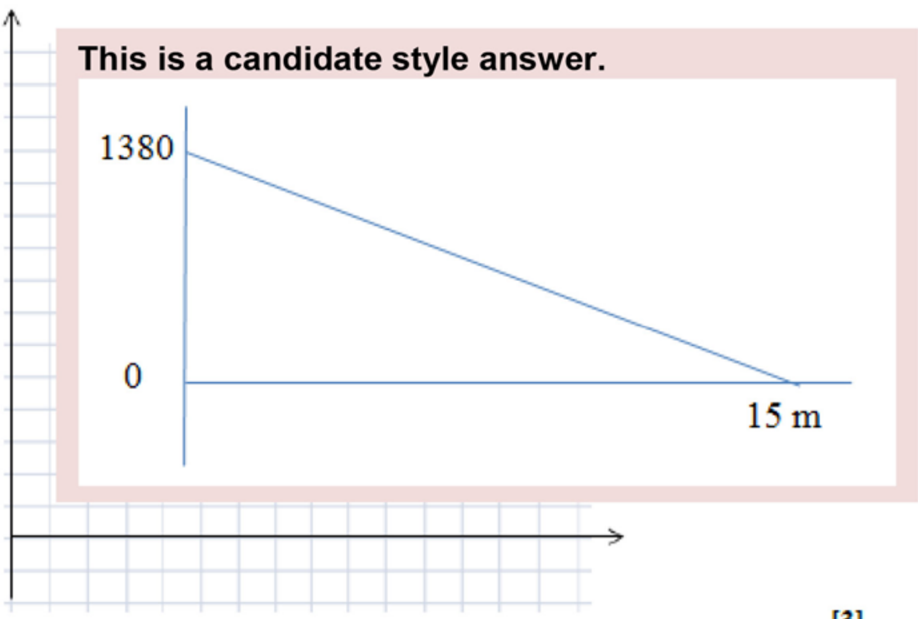
(ii) Calculate the bending moment at the wall.

This is a candidate style answer.

M = 100 ×15 – 20 x 6 [2]

(iii) Draw a labelled bending moment diagram for the beam on the grid below.

This is a candidate style answer.



[3]

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Commentary

- Answer the 4(a) is same as low level answer but with the addition of units.
- Answer to 4(b) is incorrect ($tan^{-1}\left(\frac{75}{200}\right)$ seems to have been calculated) but correct expression scores one mark.
- Answer to 4ci is given corrcetly with correct direction clearlystated.
- 4(c)(ii) scores 1 marl for correct expression. Value not calculated so 2nd mark not scored.
- 4(c)(iii)scores 1 mark. Form of graph is not calculated but 1380(Nm) at 0m and 0(Nm) at 15m correctly shown.

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Exemplar candidate work

Question 4 - High level answer

(a) Fig. 3 shows a semi-circular plate of radius 45 mm. The plate has uniform density and is aligned within a Cartesian coordinate system with the origin O, as shown.

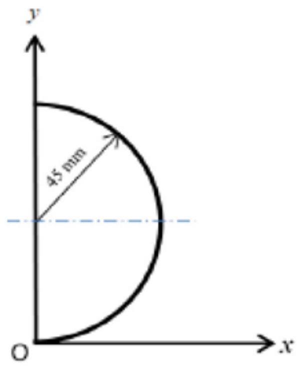

Fig. 3

Calculate the coordinates, $\bar{x}$ and $\bar{y}$, of the centroid of this semi-circular plate.

This is a candidate style answer.

$\bar{x}$ = 19.1mm
$\bar{y}$ = 45 mm

[2]

(b) Fig. 4 shows a rectangular plate, ABCD, which has uniform density. The plate is 400 mm long and 150 mm wide.

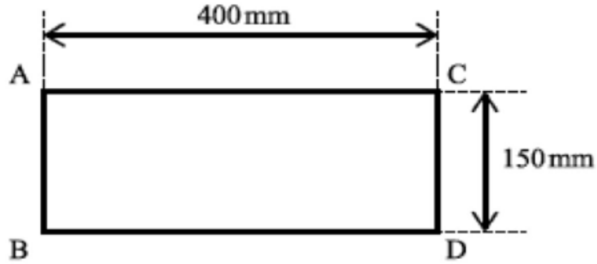

Fig. 4

The plate is freely suspended in a state of equilibrium from corner A. Calculate the angle that side AB makes with the vertical.

This is a candidate style answer.

$$\theta = tan^{-1}\left(\frac{200}{75}\right)$$
= 69.4° (or 110.6°)

[2]

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(c) Fig. 5 shows a cantilever beam with length 15 m attached to a wall. The total weight of the beam is modelled by a vertical downward force of 20 N acting at a point 6 m from the wall. A vertical upward force of 100 N acts at the other end of the beam.

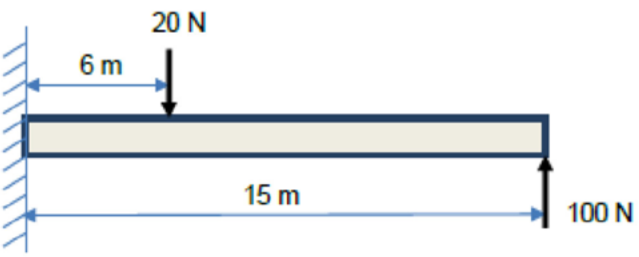


Fig. 5

(i) Calculate the vertical reaction at the wall.

This is a candidate style answer.

80 N (downwards) [1]

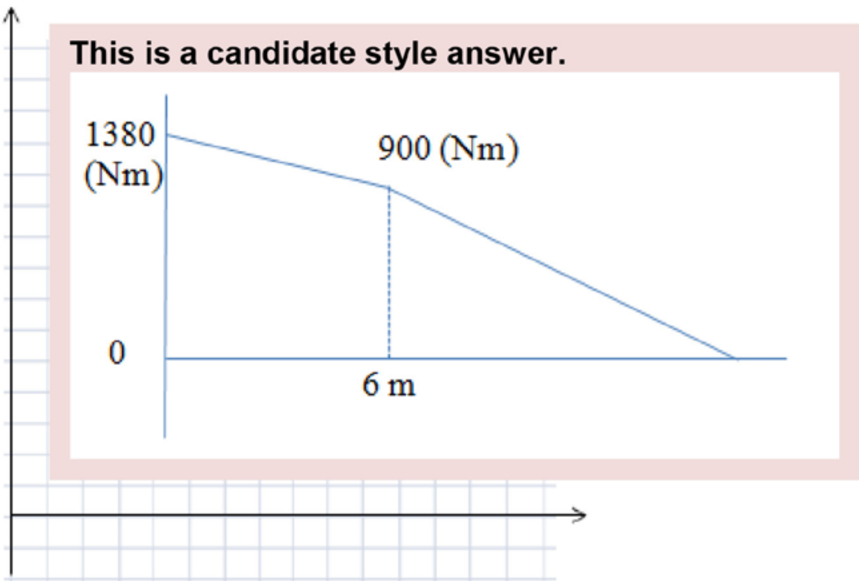
(ii) Calculate the bending moment at the wall.

This is a candidate style answer.

M = 100 ×15 – 20 x 6
= 1380 Nm [2]

(iii) Draw a labelled bending moment diagram for the beam on the grid below.

This is a candidate style answer.



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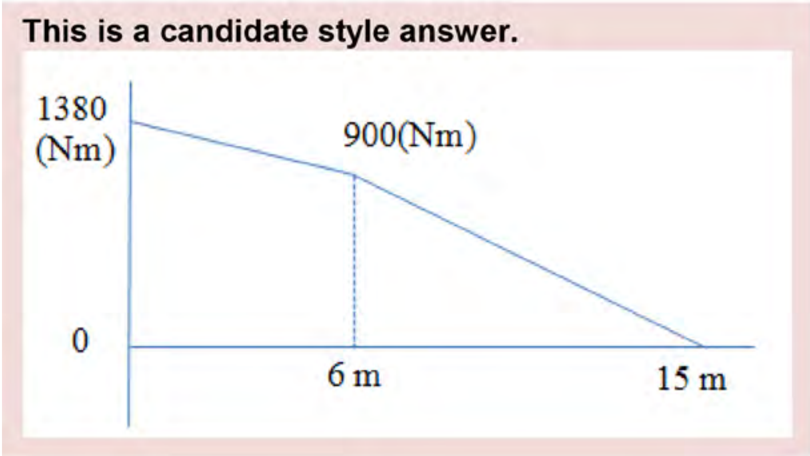
Commentary

Responses to (a) (b) (c) (i) and (c)(ii) are all correct so all score full marks.

In (c) (iii), the diagram is not complete. The diagram below would score full marks.



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Question 5

5 (a) A simple gear train consisting of two spur gears has a velocity ratio of 2.4. The output gear rotates at a speed of 36 rpm.

(i) Calculate the rotation speed of the input gear.

(VR = V_o/V_i : V_i = 36/2.4)
= 15 rpm

[1]

(ii) Calculate the mechanical advantage (MA) of this gear train.

(1 ÷ 2.4)
= 0.42 (0.417)

[1]

(b) Give one advantage and one disadvantage of a flat belt for use in a belt and pulley system.

Advantage

Disadvantage

One mark for one advantage e.g.:

- Simple/easy to install
- Relatively cheap
- Axis of shafts need not be aligned
- No lubrication needed
- Minimal maintenance required

One mark for one disadvantage e.g.:

- Belt can slip
- Belt can stretch
- Angular-velocity ratio may not be constant

[2]

(c) A belt and pulley system has an input pulley and an output pulley. The diameter of the output pulley is 40 cm. When the input pulley turns through an angle of $\frac{\pi}{6}$ radians a point on its circumference moves through an arc of length 7.85 cm. Calculate the velocity ratio of this belt and pulley system.

Arc length = $r\theta$ so r = 7.85÷ (π/6) = 15 cm
Diameter = $2r$ = 30 cm
VR = input diameter ÷ output diameter
= 30/40
= 0.75

[3]

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Question 4

(d) Fig. 6, below, shows an image of a wheelbarrow. The labels A, B and C indicate key features of the wheelbarrow in the context of a **lever**.

(i) State the class of lever associated with this wheelbarrow.

Class 2 **[1]**

(ii) Complete the labels for A, B and C on the diagram which should name the key features of a lever to which they relate.

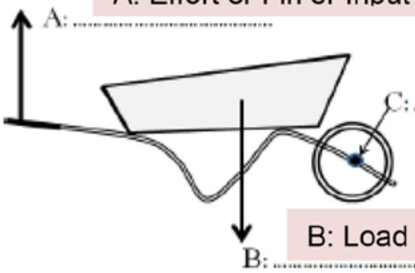

Fig. 6

[2]

Mark scheme guidance

5 a) ii)

Note that 0.41 is a rounding error (see 9 above)
Accept 1/2.4 seen

5 b)

Accept any alternative correct response.

5 c)

Allow ecf of incorrect radius.
Synoptic mark from Unit 1:LO4

5 d) ii)

Award 1 mark if 2 of 3 correct.
Allow pivot for C

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Question 6

6 Fig. 7 shows a cyclist travelling down a slope on a smooth road inclined at 6° to the horizontal. The combined mass of the cyclist and bike is 80 kg.

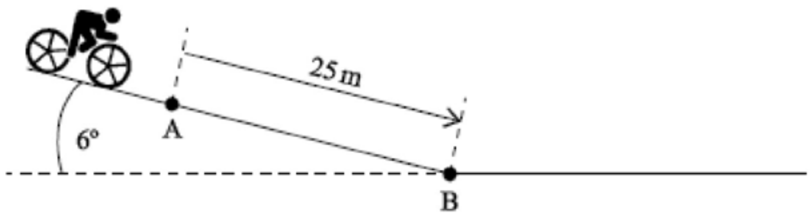

Fig. 7

(i) At point A along the slope the cyclist has a speed of 2.7 m s^{-1}. Calculate the combined kinetic energy of the cyclist and bike at this point.

$(E = \frac{1}{2}mv^2 = \frac{80}{2} \times 2.7^2)$
$= 291.6$ (J)

[1]

(ii) The cyclist then travels a distance of 25 m along the slope to point B. Calculate the change in gravitational potential energy between points A and B.

(P.E $= mgh =$) $80 \times 9.8 \times 25\sin 6$
$\approx$ 2049 J

[2]

(iii) Between points A and B the cyclist is rolling along the slope under the influence of gravity only with no other forces affecting motion. Calculate the speed of the bike when it reaches the bottom of the slope at point B.

Increase in K.E = answer to 6ii

Final K.E = 291.6 + 2049 = 2340 J
$2340 = \frac{1}{2}mv^2$
$v = 7.64$ (m s^{-1})

[3]

(iv) At the bottom of the slope at point B the road changes to a rough horizontal surface where the coefficient of friction, μ, between the bike and the road is 0.15. Calculate the maximum frictional force acting on the bike.

$R = mg = 80 \times 9.8 = 784$

$(F_{max} = \mu R = 784 \times 0.15) = 117.6$ (N)

[2]

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(v) At the bottom of the slope the cyclist uses the pedals for the next 50m to maintain a constant speed as calculated in part **(iii)**. Calculate the work done by the cyclist over this distance.

Work = force × distance where force =117.6 × 50
(constant speed means equilibrium)
5880 J

[2]

Mark scheme guidance

6 i)

Synoptic mark from Unit 2:LO2

6 ii)

Accept answers between 2038 and 2051. Ignore sign.
Unit must be seen for second mark in either i or ii

6 iii)

Seen or implied

Calculation of final K.E. ecf part i) and part ii).

Allow ECF from parts ii) and iii) only. Accept answers between 7.63 and 7.65 m s–1.

Allow alternative method using N2L and SUVAT, C1 for correct acceleration and C1 for correct use of suvat

6 iv)

Calculation of reaction force. May be implied in later working.

6 v)

ECF answer to part iv).

Unit required

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