National Qualifications 2019

X723/77/11 Engineering Science

FRIDAY, 17 MAY
1:00 PM – 3:00 PM

Total marks — 60

Reference may be made to the Advanced Higher Engineering Science Data Booklet.

SECTION 1 — 30 marks

Attempt ALL questions.

SECTION 2 — 30 marks

Attempt ALL questions.

Write your answers clearly in the answer booklet provided. In the answer booklet, you must clearly identify the question number you are attempting.

For questions 2 (a), 5 (a) and 7 (a), write your answers clearly in the worksheets provided in booklet X723/77/21.

Show all working and units where appropriate.

The number of significant figures expressed in a final answer should be equivalent to the least significant data value given in the question. Answers that have two more figures or one less figure than this will be accepted.

Use **blue** or **black** ink. Sketches, diagrams and graphs may be drawn in pencil.

Before leaving the examination room you must give your answer booklet **and** worksheets to the Invigilator; if you do not, you may lose all the marks for this paper.

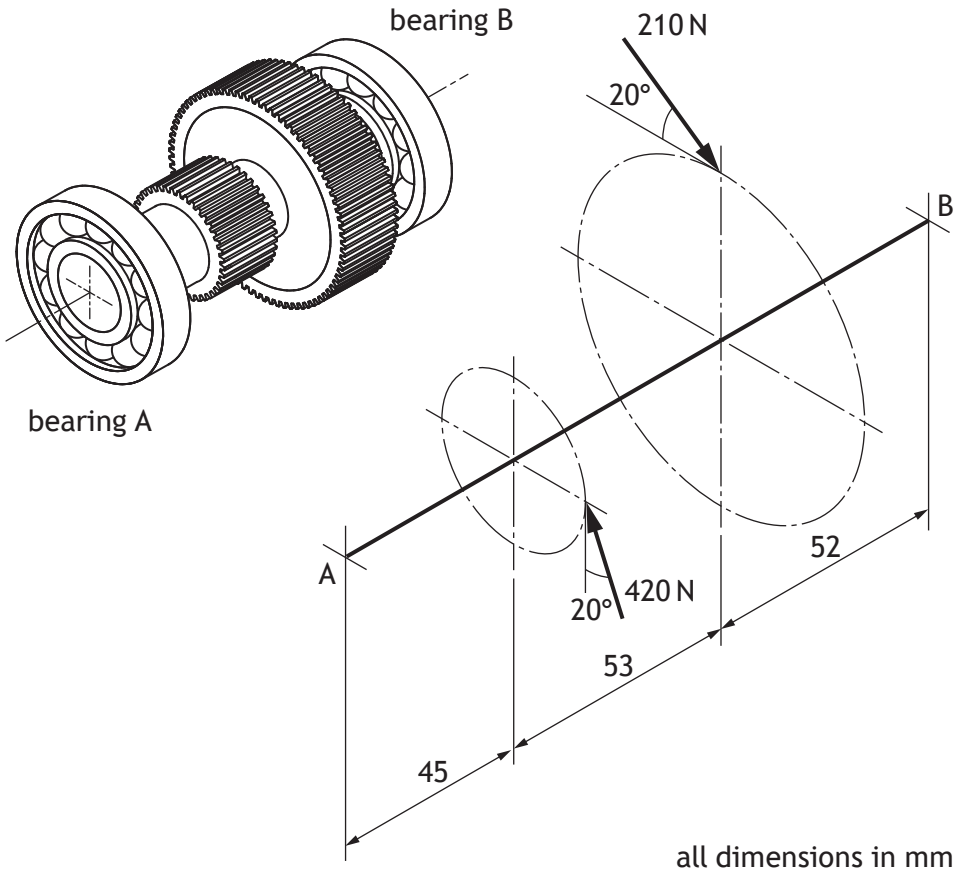
X7237711

MARKS

SECTION 1 — 30 marks

Attempt ALL questions

1. A shaft within a gearbox is shown. The forces that act on the two spur gears when running at constant speed are 210 N and 420 N. The pressure angle for both gears is 20°.



all dimensions in mm
gear pressure angle is accurate to 0·1°

Calculate the magnitude and the direction of the reaction at bearing A. **5**

MARKS

2. A project manager divided a short project into eight stages, A–H, identified the precedents for each stage and the planned duration of each stage. The information is detailed in the precedence table below.

Stage	Precedents	Duration (weeks)
A	–	2
B	–	4
C	A	3
D	B,C	4
E	B	5
F	A,B	6
G	E	2
H	D,F,G	7

(a) Use the precedence table and **worksheet for question 2 (a)** to

(i) complete a Gantt chart for stages D–H of the project, showing the timing of each stage without floats **1**

(ii) determine the float available for project stage F **1**

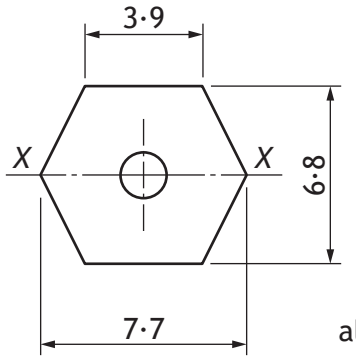
(iii) identify the critical path for the project. **1**

(b) Describe the difference between a direct cost and an indirect cost for a large-scale engineering project you are familiar with. Make reference to an example of each type of cost in relation to the project. **2**

[Turn over

MARKS

3. The wooden body of a pencil has a cross-section of dimensions shown, with a centrally located circular hole of diameter 1·5 mm.



all dimensions in mm

The second moment of area of a right-angled triangle about its base is given by the formula

$$I_{base} = \frac{bh^3}{12}$$

where b and h are base and height dimensions respectively.

Calculate the second moment of area of the cross-section about axis $X-X$, as shown above. **4**

[Turn over for next question

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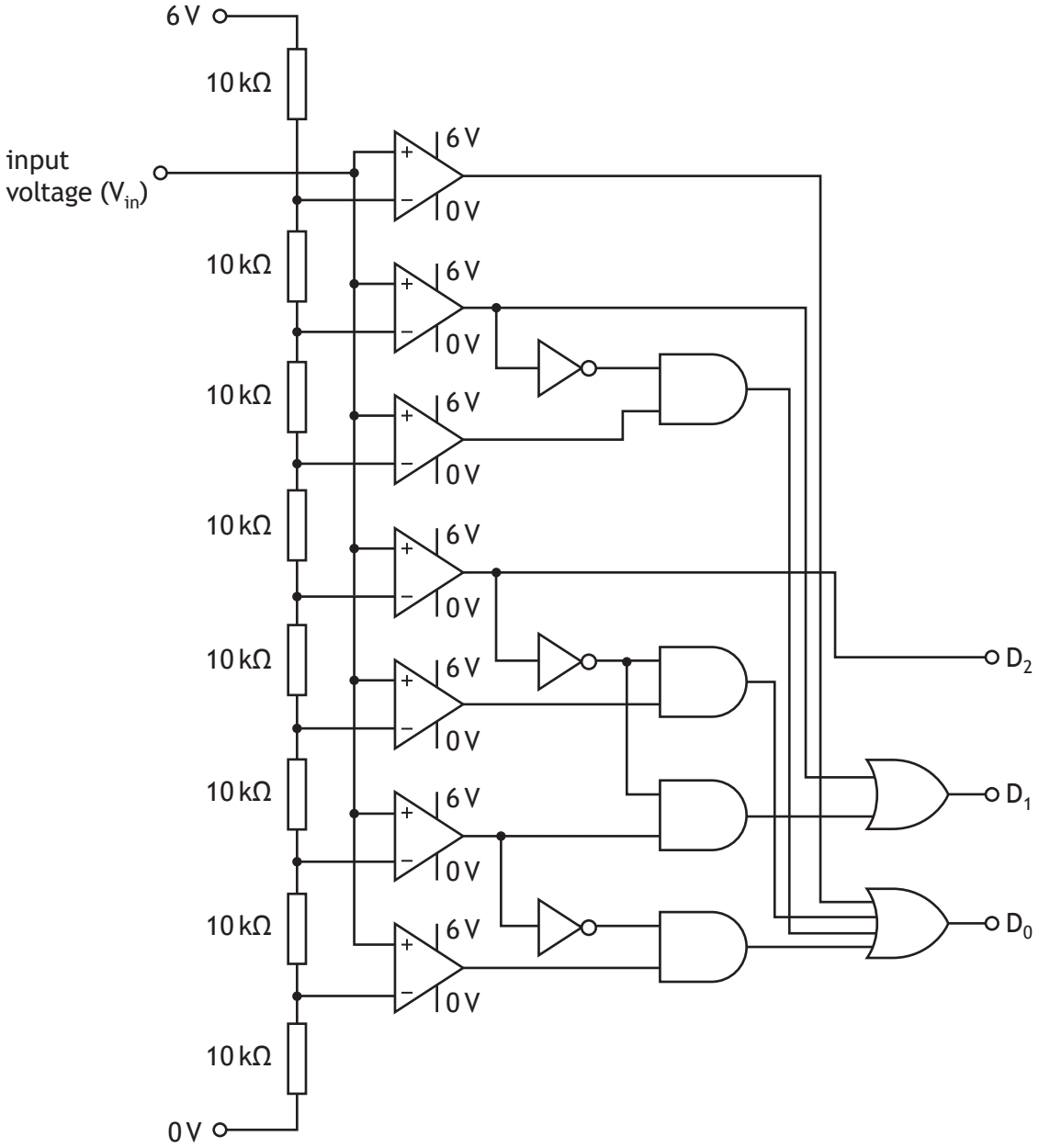
4. The circuit below represents a 3-bit flash analogue to digital (A–D) converter. The input voltage, V_{in}, can vary between 0 V and 6 V.

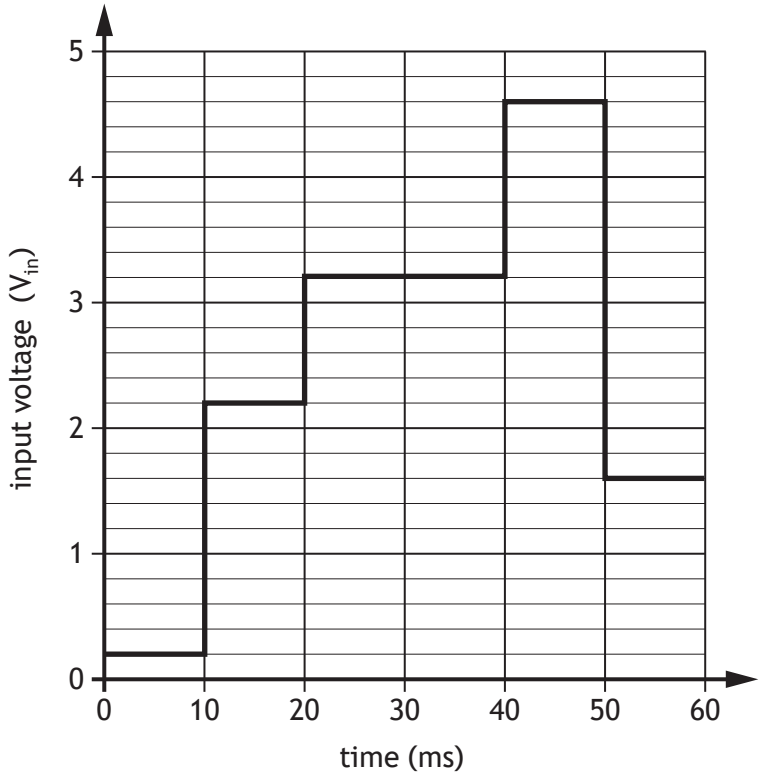
A comparator output is a logic HIGH value when the input voltage is greater than the voltage on its inverting input terminal.



Note: D_0 is the least significant bit

4. (continued)

Input voltage signals processed by the A–D converter are shown in the graph below.

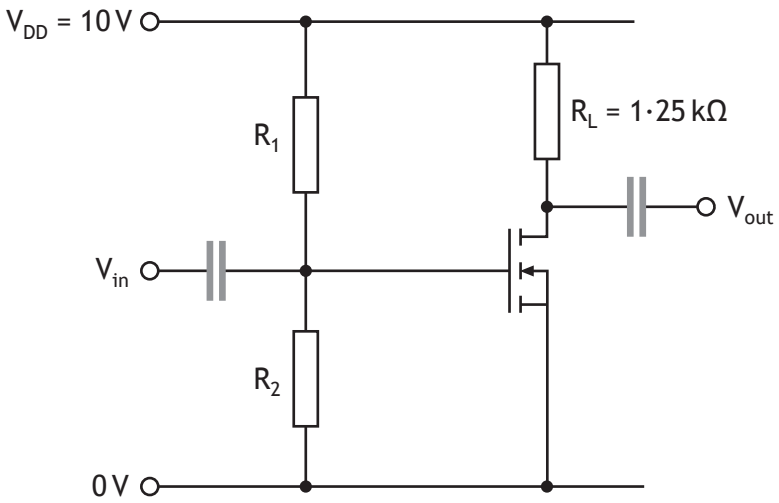


(a) Calculate the 3-bit digital output just after the voltage step change at 40 ms. **3**

(b) Calculate the range of analogue input voltages which would produce the 3-bit digital output 101. **2**

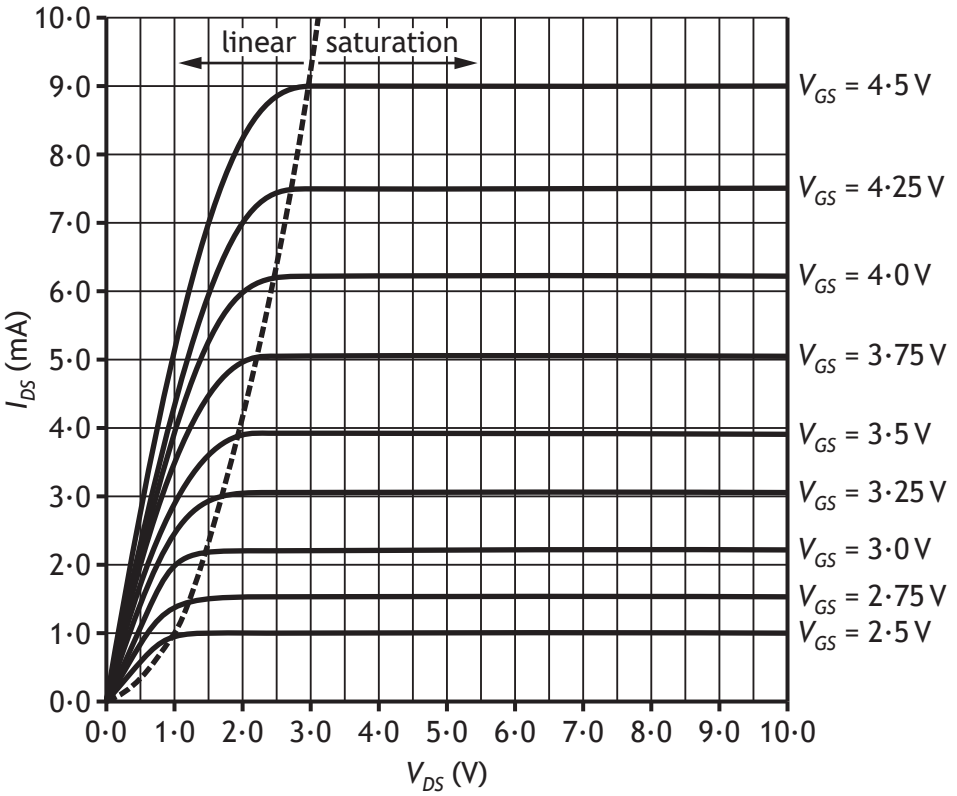
[Turn over

5. A MOSFET amplifier circuit is being designed based on the circuit diagram below.



For component calculations, ignore the greyed-out capacitors.

The performance characteristic curves for the MOSFET are shown below and on **worksheet for question 5 (a)**. The MOSFET threshold voltage is 1·5 V.



The MOSFET must be biased in the **saturation** region.

MARKS

5. (continued)

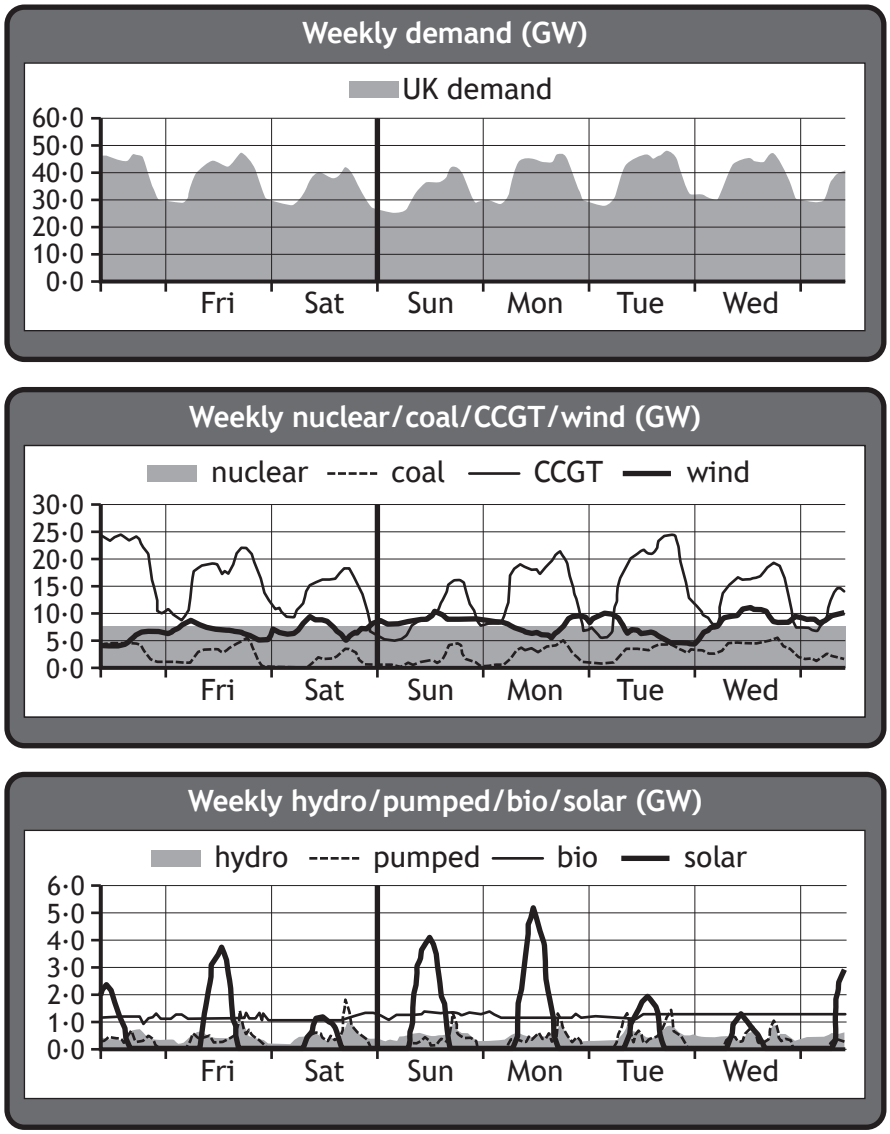
(a) Draw the load line on **worksheet for question 5 (a)**. **2**

The MOSFET is biased so that V_{GS} = 3·25 V at the operating point. A design rule is also used: when R_1 and R_2 are connected in parallel, their effective resistance is 525 kΩ.

(b) Calculate suitable values for R_1 and R_2. **3**

[Turn over

6. The electricity demand in the UK is met from a variety of sources. The snapshot diagram below shows demand and production during a typical week in the winter.



GW = gigawatts CCGT = combined cycle gas turbines

bio = biomass pumped = pumped storage hydro electric

Capacity is a measure of the power that can be provided at any point in time.

(a) Explain, with reference to the data supplied, how the grid meets both base and peak demand over time and how the unpredictable capacity from certain production types is compensated. **3**

A single-phase step-down transformer operating on the grid has an input power rating of 110 kVA and decreases the 11000 V AC input voltage to 415 V AC at its output. The primary and secondary windings of the transformer have resistances of 0·440 Ω and 0·00438 Ω respectively. The core loss is 1·75 kW.

(b) Calculate the resistive power loss in each of the two windings when the overall efficiency of the transformer is 98·1%. **3**

[Turn over for SECTION 2

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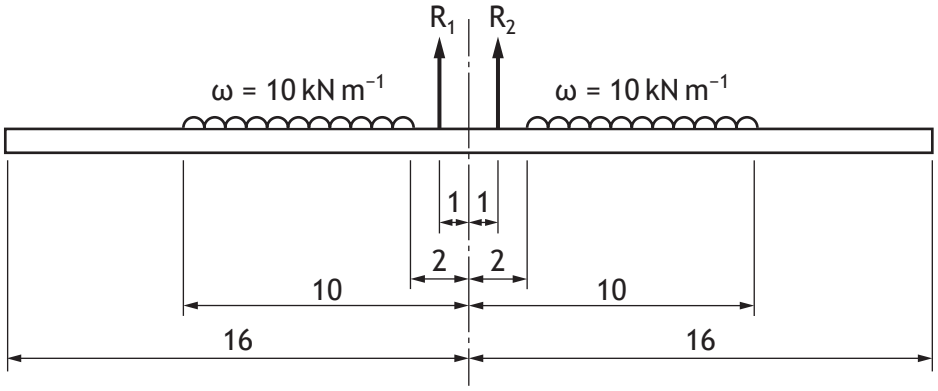
SECTION 2 — 30 marks

Attempt ALL questions

7. The Forth Road Bridge and its replacement, the Queensferry Crossing, are both suspension bridges. The main deck of each bridge is supported by cables suspended from towers. However, the bridges differ in that the cables attached to the main deck are in different locations with respect to the width of the deck.

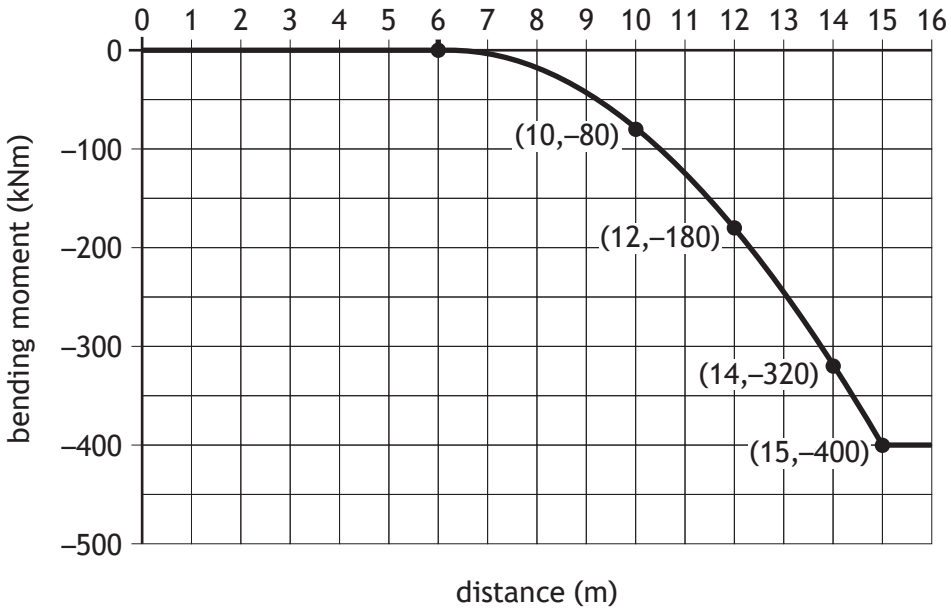
To investigate the effect of the different suspension points, a student creates a simple model of each of the arrangements. The model of the Queensferry Crossing is shown below.



model of Queensferry Crossing

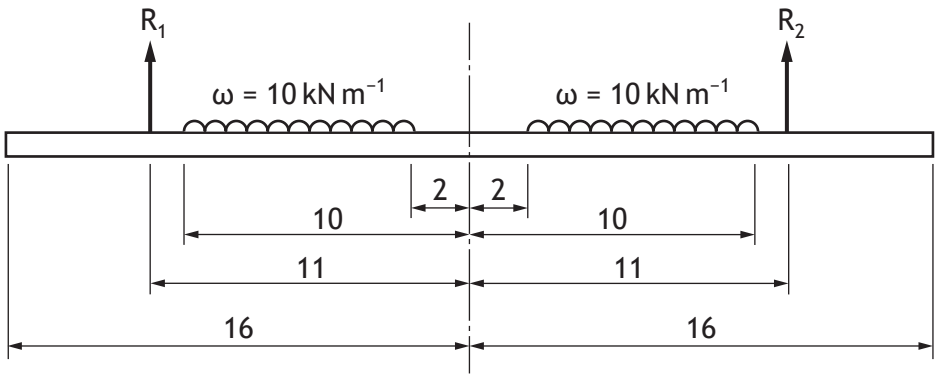
all dimensions are in metres (m)

The student then draws a bending moment diagram from the left-hand end to the centreline of the model, as shown below.



7. (continued)

The student also creates a model of the Forth Road Bridge, as shown below.



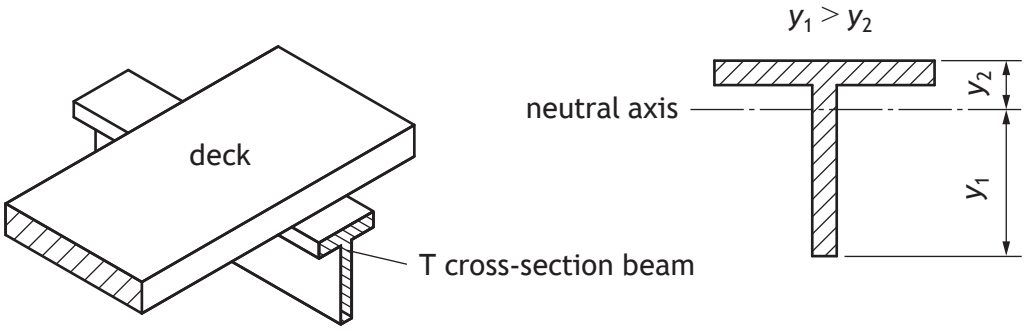
model of Forth Road Bridge

all dimensions are in metres (m)

(a) Draw the bending moment diagram for the left-hand half of the model of the Forth Road Bridge on **worksheet for question 7 (a)**. Indicate the value of the bending moment at key points from the left-hand end, similar to those on the bending moment diagram for the Queensferry Crossing. **6**

(b) Explain how the information from these bending moment diagrams would inform a bridge designer as to the selection of a suitable structural beam for the deck. **2**

T cross-sections are used to minimise material use in structural beams when the material is stronger in compression than in tension. They are used in the orientation shown below.

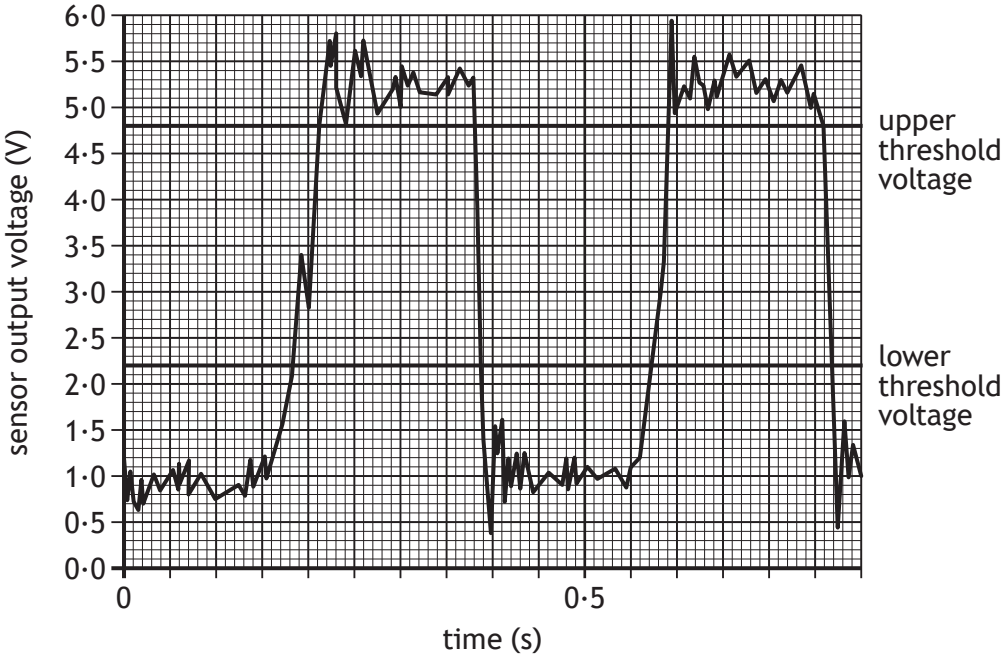


(c) State which of the two bridge models would be better supported by a T cross-section beam and justify your selection. **2**

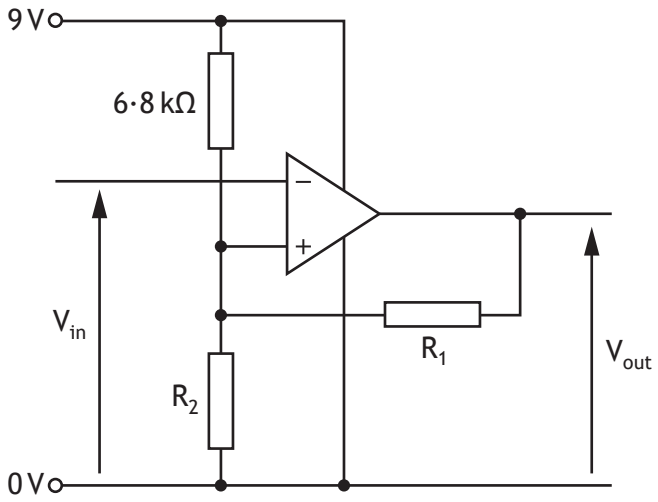
[Turn over

7. (continued)

The bridge uses a number of strain gauges which were fixed inside the structure as it was being constructed. An electronic engineer uses a Schmitt trigger to process the signals produced by the strain gauge circuits. A graph of the signal from one sensor is shown below. Selected threshold voltages for the Schmitt trigger circuit are also shown.



The Schmitt trigger circuit is shown below.



The op-amp output saturates at 7·7 V and 0 V.

(d) Calculate, using nodal analysis, the required values for R_1 and R_2. **5**

[Turn over for next question

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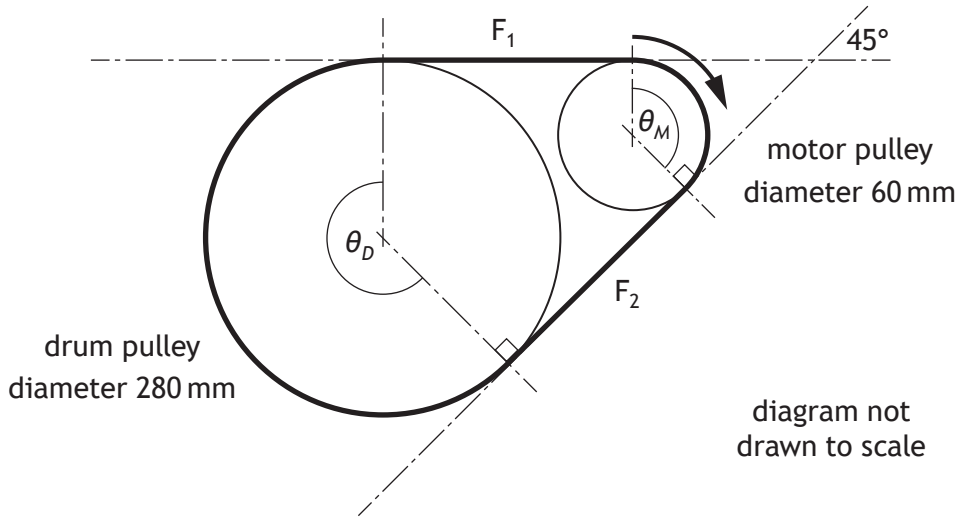
MARKS

8. The drum of a washing machine is driven by an electric motor using a pulley and belt arrangement as shown. Under load, the tension in the part of the belt denoted as F_1 is greater than the tension in the part of the belt denoted as F_2.

The maximum ratio of the tensions F_1 and F_2 is governed by the equation shown where there is a dependency on the coefficient of friction, μ, and the angle of contact, θ, between a belt and a pulley. The angle θ is measured in radians.

$$\frac{F_1}{F_2} = e^{\mu\theta}$$



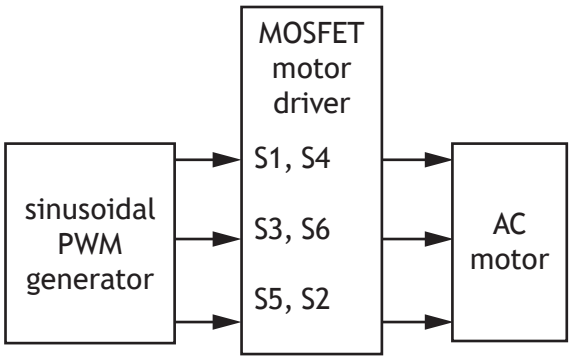
(a) Calculate the maximum power that can be transmitted for a coefficient of friction, μ, of 0·8 if F_1 is 470 N and the angular input velocity is 1200 rpm at the motor. **4**

Note, 360° is equal to 2π radians.

8. (continued)

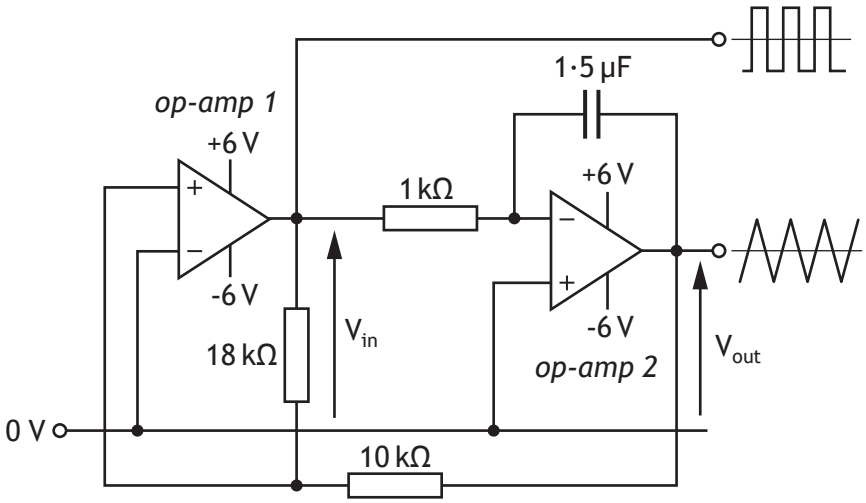
MARKS

The washing machine motor is controlled using sinusoidal pulse-width modulation (PWM) signals. A block diagram of the system is shown below.

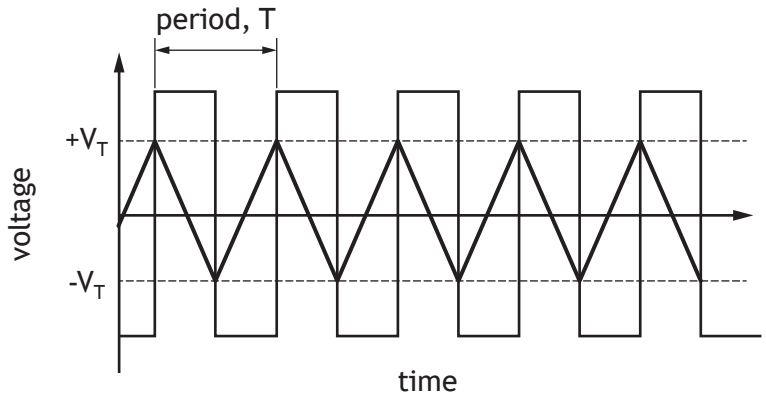


A triangular wave generator is a required part of the sinusoidal PWM generator. A circuit diagram for a triangular wave generator is shown below.

The op-amps used in the design saturate at ±5·2 V.



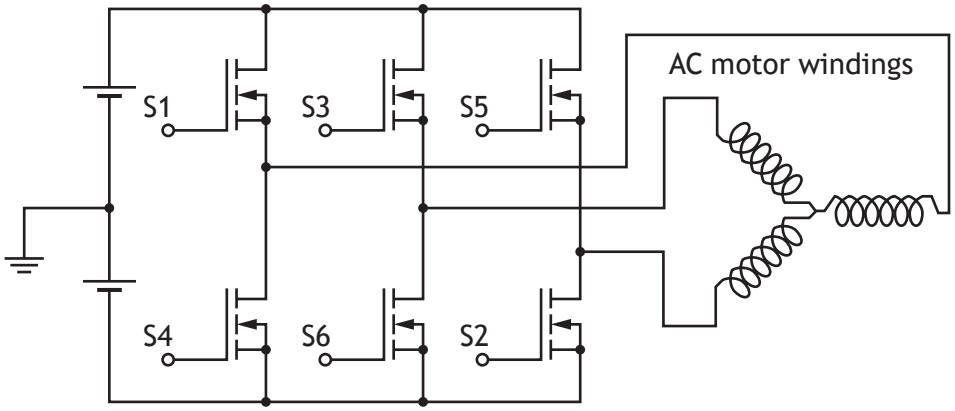
Typical output waveforms are shown below (not to scale).



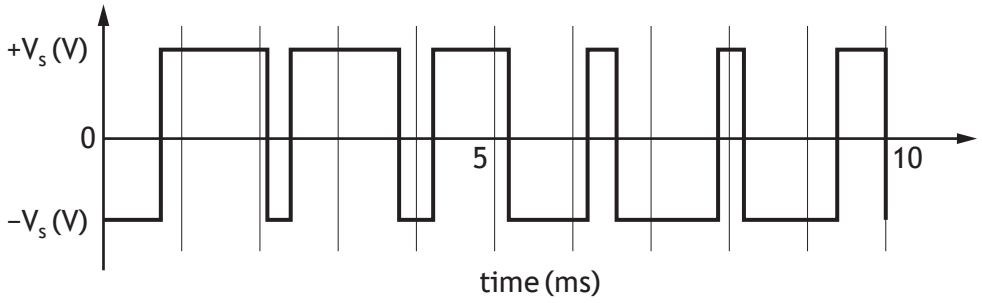
(b) Calculate $+V_T$, $-V_T$ and the period of the triangular wave. **5**

8. (continued)

The PWM signal is processed by a MOSFET-based driver circuit as shown below.

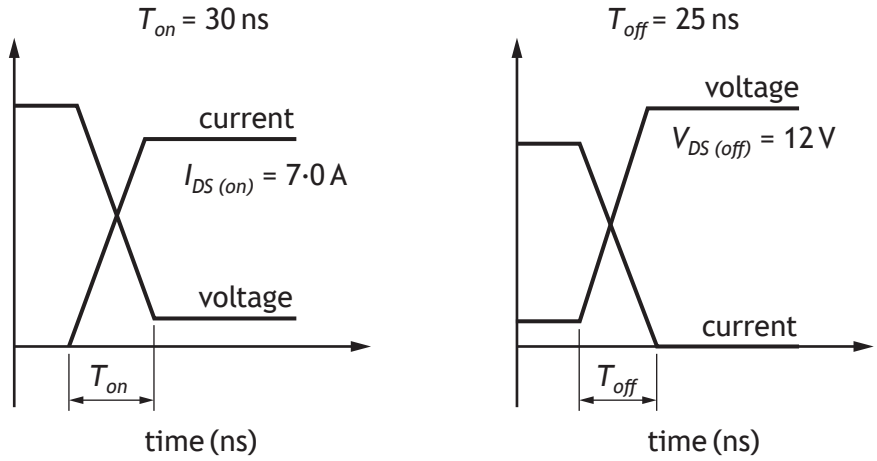


The graph below shows the input voltage to a MOSFET **over one cycle.**



The MOSFET dissipates power when conducting and when **switching on and off.**

The graphs below show a magnified view of the V_{DS} and I_{DS} when a MOSFET **switches on and off.**



8. (continued)

When each MOSFET **switches on and off** it experiences a switching energy loss given by the formula below.

$$E_{Switching} = \frac{1}{2} V_{DS(off)} \left(T_{on} I_{DS(on)} + T_{off} I_{DS(on)} \right)$$

The switching power is calculated using the formula

$$P_{Switching} = E_{Switching} \times n \times f$$

where

n = number of switches per cycle, and

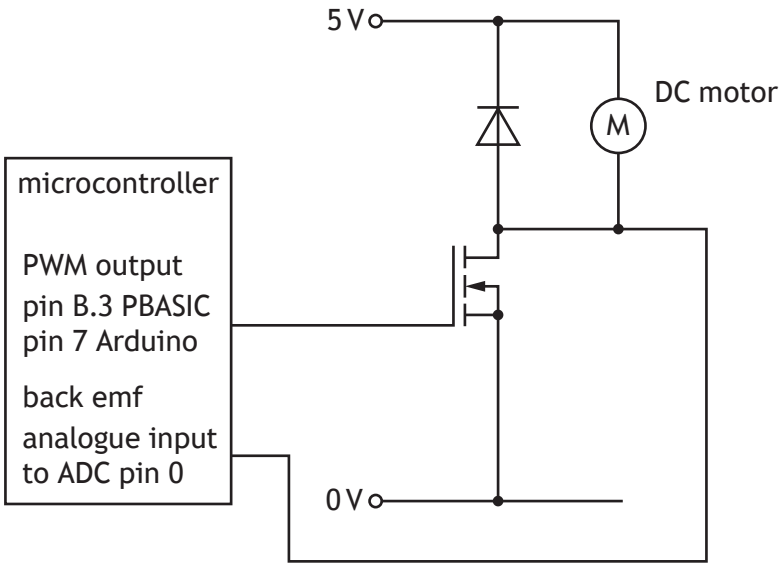
f = cycle frequency.

(c) Calculate the MOSFET switching power loss for one MOSFET. **4**

[Turn over

8. (continued)

A student builds a model of the washing machine using a DC motor. A microcontroller is used to generate a PWM signal to control the motor speed. The speed of the motor is measured using the following system.



Back emf is proportional to the angular velocity of the motor.

A voltage of 5 V at the ADC input would give a reading of 1023.

8. (continued) **MARKS**

The following sub-procedure was written to calculate the back emf.

ARDUINO

```
void speed_bemf()
{
 sum_of_bemf = 0;  //reset sum_of_bemf
 analogWrite(7, duty);  //PWM to motor
 delay(10);
 digitalWrite(7, LOW);  //stop PWM
for(int x=1; x<=10; x++)
 {
  inst_bemf = analogRead(A0);
  inst_bemf = 1023 – inst_bemf;
  sum_of_bemf = sum_of_bemf +
                                  inst_bemf;
 }
 bemf= sum_of_bemf / 10;

Serial.println(bemf);  // value to serial
                                  monitor
}
```

PBASIC

```
speed_bemf:

sum_of_bemf = 0    'reset sum_of_bemf
pwmout B.3, 255, duty    'PWM to motor
pause 10
pwmout B.3, 255, 0    'stop PWM
for x = 1 to 10

  readadc10 C.0, inst_bemf
  inst_bemf = 1023 – inst_bemf
  sum_of_bemf = sum_of_bemf +
                                  inst_bemf

next x
bemf = sum_of_bemf / 10

debug bemf  'value to serial monitor

return
```

(d) Describe, making reference to the back emf, the function of the shaded section of the program. The following information is provided for reference. **2**

ARDUINO	**PBASIC**
Command analogWrite() **Description** Writes a PWM signal to a pin until the next call to analogueWrite() or digitalWrite() on the same pin. **Syntax** analogWrite(pin, value) **Parameters** pin: a variable/constant which is the pin to write to value: the duty cycle between 0 (off) and 255 (fully on)	**Command** pwmout **Description** Writes a continuous PWM signal to a pin until another pwmout command is sent to the pin. **Syntax** pwmout pin, period, mark **Parameters** pin: a variable/constant which is the pin to write to period: set to 255 for this application mark: the duty cycle between 0 (off) and 255 (fully on)
Variable *duty*: integer with value between 0 – 255, used to set desired speed. Assigned in another part of the program. *inst_bemf*: integer with value –32,768 to 32,767 *sum_of_bemf*: integer with value –32,768 to 32,767 *bemf*: integer with value –32,768 to 32,767	**Variable** *duty*: value between 0 – 255, used to set desired speed. Assigned in another part of the program. *inst_bemf*: word integer with value 0 – 65535 *sum_of_bemf*: word integer with value 0 – 65535 *bemf*: word integer with value 0 – 65535

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FOR OFFICIAL USE

National Qualifications 2019

Mark

X723/77/21

Engineering Science Worksheets

FRIDAY, 17 MAY

1:00 PM – 3:00 PM

X7237721

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Number of seat

Date of birth

Day

Month

Year

Scottish candidate number

Worksheets for questions 2 (a), 5 (a) and 7 (a).

Write your answers clearly in the spaces provided in this booklet.

Use **blue** or **black** ink. Sketches, diagrams and graphs may be drawn in pencil.

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Worksheet for question 2 (a)

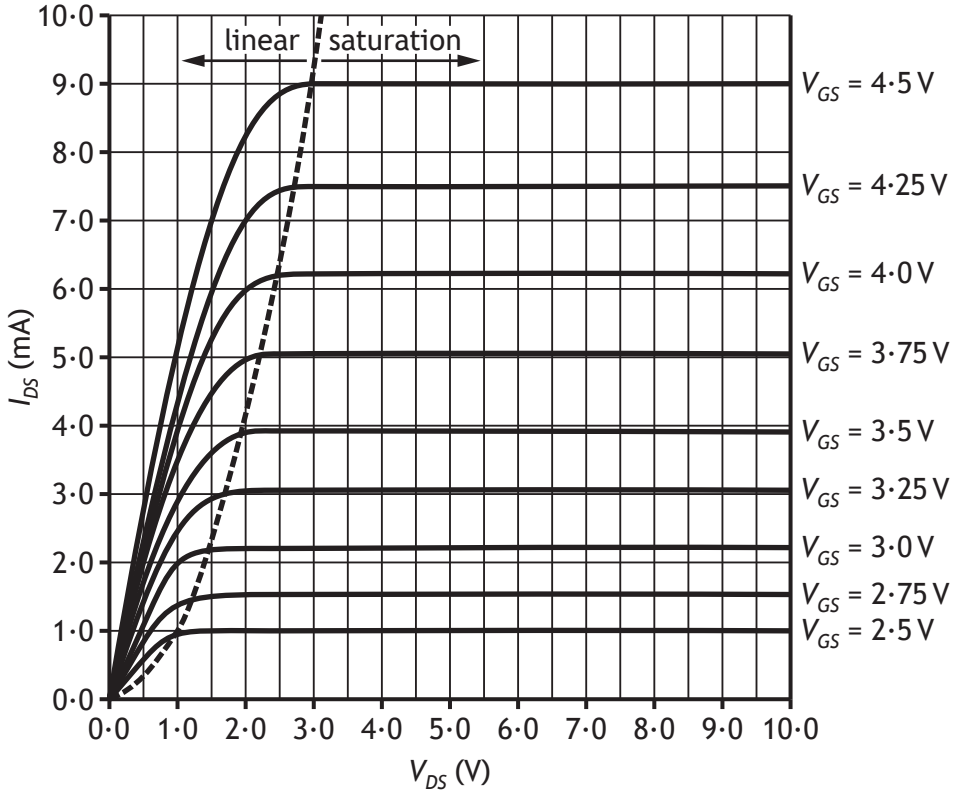
Stage	Precedents	Duration (Weeks)
A	–	2
B	–	4
C	A	3
D	B,C	4
E	B	5
F	A,B	6
G	E	2
H	D,F,G	7

	Week																	
Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A																		
B																		
C																		
D																		
E																		
F																		
G																		
H																		

2. (a) (ii) Float for project stage F

2. (a) (iii) Critical path

Worksheet for question 5 (a)



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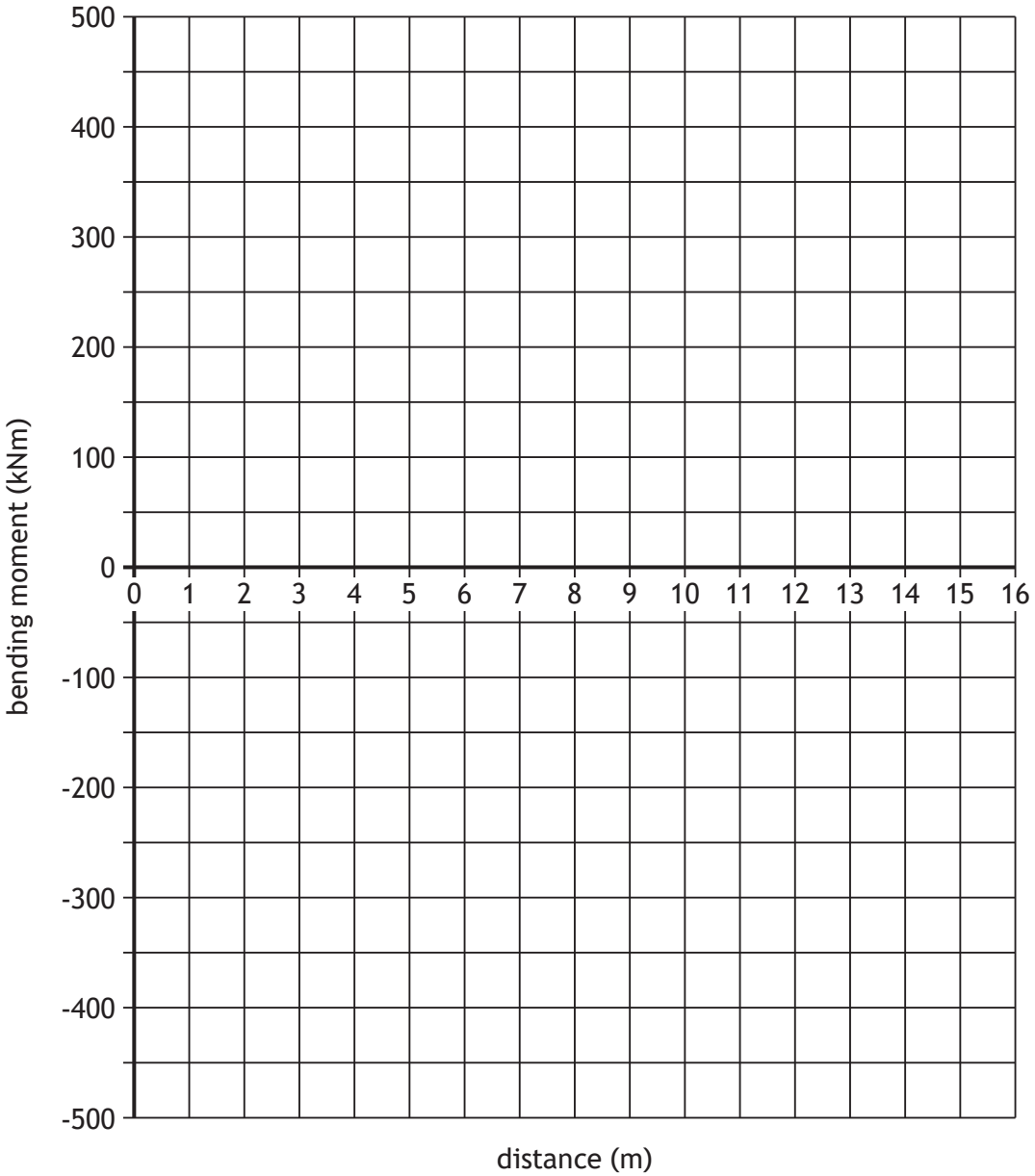
Worksheet for question 7 (a)

Bending moment diagram for the Forth Road Bridge.



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National Qualifications

Mark

X723/77/01

Engineering Science
Answer booklet

X7237701

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Number of seat

Date of birth

Day | Month | Year

Scottish candidate number

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For marker's use	
Question	Marks