Candidate Surname: _____

Candidate Forename(s): _____

Candidate Signature: _____

Teacher name: Mr Delport

# A-Level Design Engineering

## Paper 1 – Principals of Design Engineering

## 2020 Provisional UCAS Predicted Grade Exam series

## Exam Date: 5 March 2020
## Time Allowed: 1 hour 30 minutes

**Materials**
For this paper you must have:
- A pen, pencil and ruler
- A calculator

**Instructions**
- Use black ink or black ball-point pen. Draw diagrams in pencil.
- Answer **all** questions.
- You must answer the questions on the answer booklet provided.
- Do rough work on the answer sheets. Cross through any work you do not want to be marked.

**Information**
- The marks for questions are shown in brackets.
- The maximum mark for this paper is **60**.
- You may ask for more answer paper. Number any such pages and ensure they include your name and the name of the subject on each additional page.

Do not turn the page until you are instructed to do so.

**1** (a) (i) Name the metal-joining process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, the filler metal having a lower melting point than the adjoining metal.

Brazing, Soldering

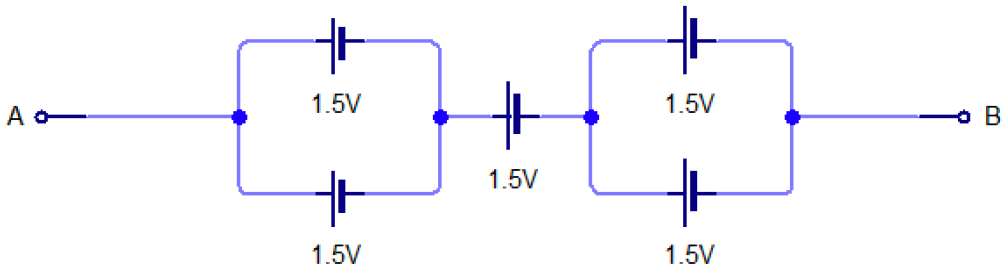
[1 mark]

(ii) Name a suitable component for protecting a circuit from a reverse voltage.

Diode, LED [1 mark]

(iii) Name a component which enables a low voltage circuit to switch on a high voltage or high current circuit. Relay, Transistor [1 mark]

(b) Calculate the total Potential Difference between points A and B. [2 marks]

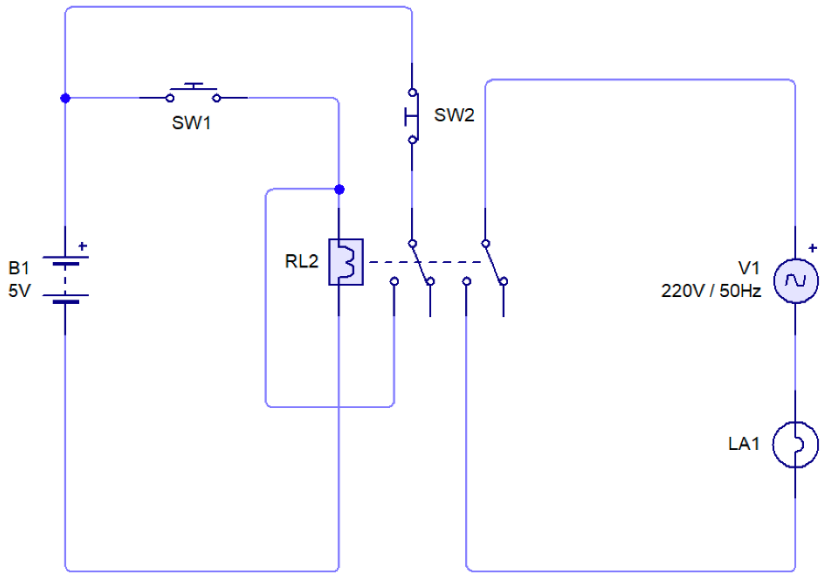



4.5V

**2** Draw a relay circuit that will operate in the following sequence:

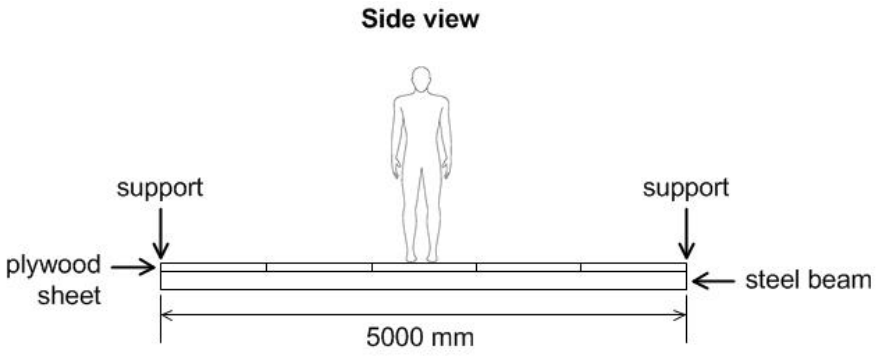
- an PTM switch is momentarily operated from a 5V supply.
- a 220 volt light bulb comes on and remains on
- a second PTB switch is momentarily operated
- the system resets and the light bulb goes off.

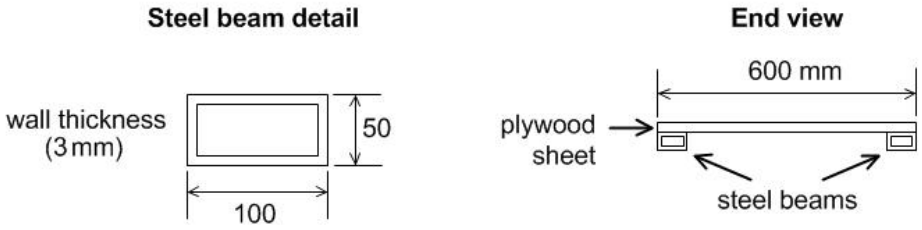
[4 marks]



**3** You may use any of the data at the below and at the top of the next page to help you answer question 3.

An engineer has drawn up an initial design for a sturdy tree-house. The start point of this is to create a platform, shown below. A person of **a mass of 80 kg** is shown standing at the mid-point. Only the unsupported part of the platform across the **5.0m** gap is shown.




**Turn over**

The platform structure consists of two parallel rectangular box section beams made from mild steel. The floor of the platform is made from sheets of 12 mm plywood laid across the beams. It is suspected that there are several problems with this design.

Material Properties Data

| **Beam profile** | **Available stock sizes (mm)** | **Maximum length (m)** | **Mass per metre length (kg $m^{-1}$)** |
|---|---|---|---|
| Flat bar | 50 × 8<br>75 × 6 | 6<br>6 | 3.2<br>3.6 |
| Rectangular box | 50 × 50 (wall thickness 3)<br>100 × 50 (wall thickness 3)<br>200 × 100 (wall thickness 8) | 6<br>6<br>2 | 4.5<br>6.8<br>35.9 |
| I beam | 127 × 76 (wall thickness 13)<br>178 × 102 (wall thickness 19) | 8<br>8 | 13.0<br>19.0 |

| **Material** | **Young's Modulus (GPa)** | **Density (kg $m^{-3}$)** |
|---|---|---|
| Mild steel | 200 | 7800 |
| Aluminium | 69 | 2700 |

| **Plywood Thickness** | **Mass per $m^2$ (kg $m^{-2}$)** |
|---|---|
| 12mm | 7.3 |
| 18mm | 11.0 |

(a) Calculate the total mass of the treehouse platform shown in the diagram above, plus the person, in kg. [3 marks]

Mass of steel beams = 2 x length × mass per unit length
= 2 × 5 × 6.8 = 68 kg (1)

Mass of 12 mm Plywood = area of plywood x mass per unit area
= 5 × 0.6 × 7.3 = 21.9 kg (22 kg) (1)

Total mass = mass of steel beams + mass of plywood sheets + mass of person
= 68* + 21.9* + 80 = 169.9 kg (170 kg) (1)

(b) To analyse the structural integrity of the platform, a design engineer is considering one of the steel box section beams across the 5.0 m gap. The total weight of the platform plus the person is effectively concentrated entirely at the mid-point of the platform. **Each beam supports half of the total weight.**

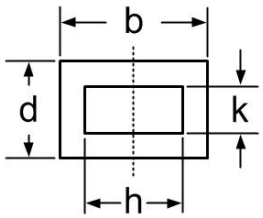
Use the formula below, and data above to show that the deflection of a single beam under the loading conditions described above will be greater than 25 mm.

$$\delta = \frac{FL^3}{48EI}$$

δ is the deflection at the centre of the beam (m)
F is the total force acting at the centre (N)
L is the length of beam between the supports (m)
E is Young's modulus for the beam material (Pa)
I is the second moment of area of the beam

$I$ is calculated by the formula:

$$I = \frac{bd^3 - hk^3}{12}$$




You must clearly explain any assumptions you make and clearly show and explain each stage of your calculations. [3 marks]

Total weight of bridge = mass x gravitational field strength (* means allow ECF)
= 169.9 × 9.8 = 1665 N

Each beam carries half of this total weight
1665* ÷ 2 = 832.5 N (1)

$I = (bd^3\text{-}hk^3) / 12$
$= ((0.1 \times 0.05^3) – (0.094 \times 0.044^3)) \div 12$
$= 3.74 \times 10^{-7}$ (1)

Using the deflection formula:
$d = FL^3 / 48EI$
$= (832.5^* \times 5^3) / (48 \times 200x10^{9*} \times 3.74 \times 10^{-7*})$
= 0.028 m = 28 mm (1)

**4** With the aid of annotated sketches, describe a suitable test that could be carried out to compare the linear expansion of a range of metals for a 100° Celsius rise in temperature.

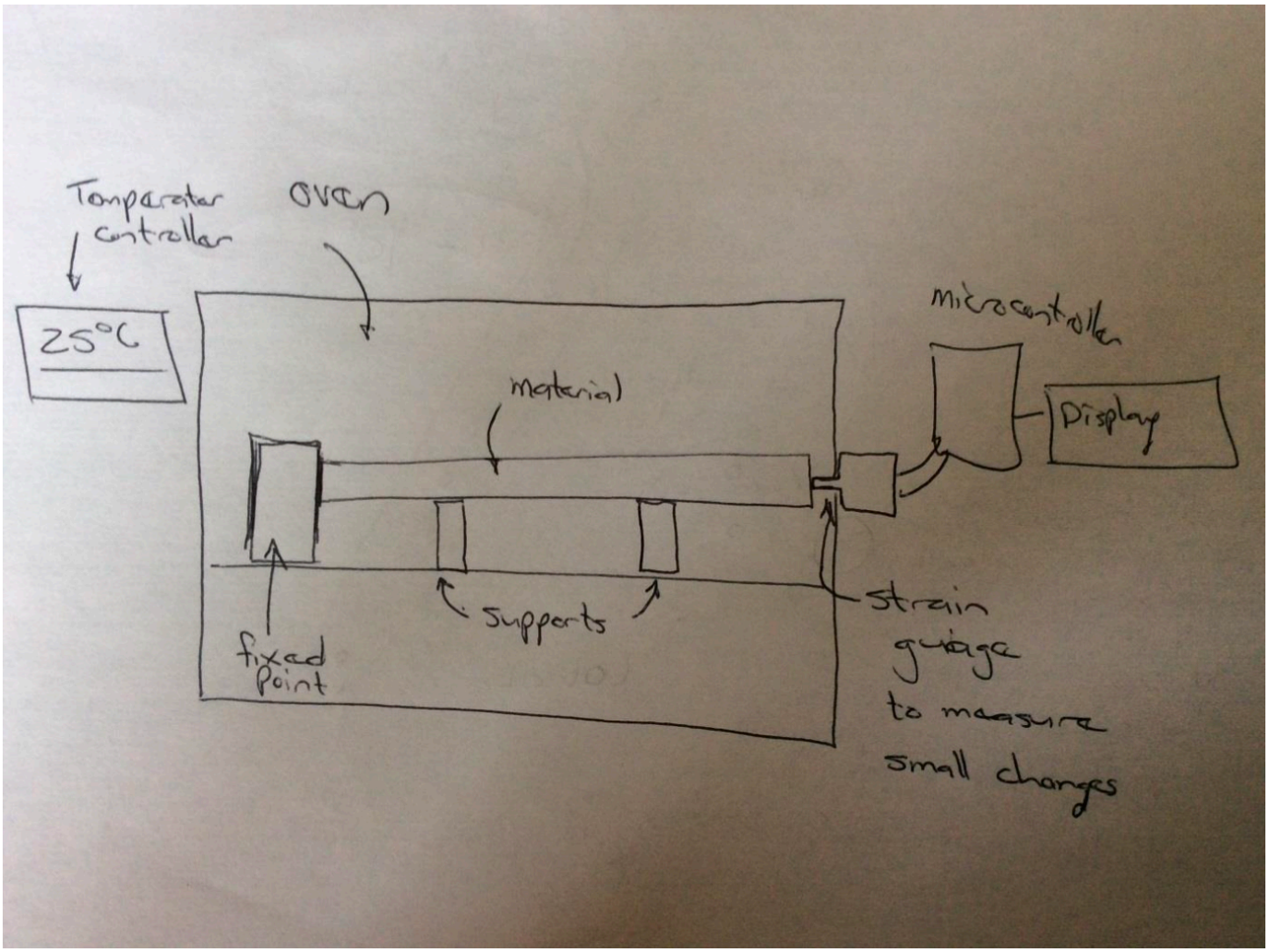
Your answer should indicate:

- the approximate size of the sample
- the method of producing the required temperature change
- the data that needs to be collected
- the method of collecting the data
- how the data is analysed.

[8 marks]

A range of different metals will need to be tested. As many as possible, but at least 10 to get a good average reading.

The materials will need to start in a controlled temperature environment, such as an oven at a specific temperature, for example 25 degrees Celsius. The materials will need to be cut to a specific length and the base temperature. For example 300mm at 25 degrees Celsius.
This would need to be carefully controlled to ensure the start point is accurate.



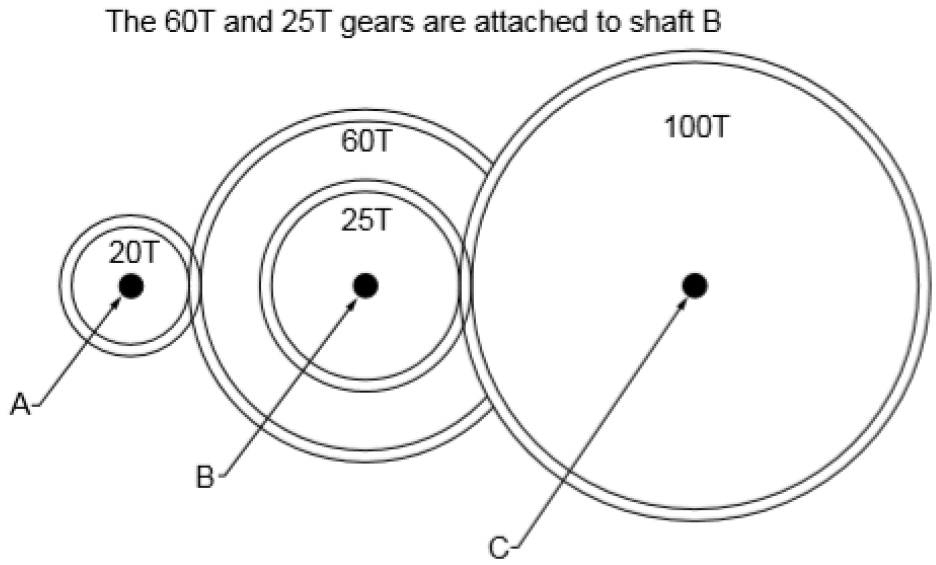

The test piece could be put in the oven and set up a 25 degrees. At the end of the material we could connect a strain gauge to measure very small movements which could be read by a microcontroller. The temperature controller can then be used to increase the temperature by 100 degrees to 125 degrees.
This data could then be analysed to see by how much each material expands per 100 degrees. This could be listed in a table as a guide.

**5** Describe a system that would have a clockwise rotary input of 300 rpm and produce an output of 5 rpm counter-clockwise. Use annotated sketches to support your answer.

[4 marks]

Input and Outputs referenced and rotating in opposite directions 1 mark
Suitable system to invert rotation and transmit motion 1 mark
System reduces speed of rotation 1 mark
System produces 60:1 reduction 1 mark

**6** The diagram below shows a compound gear system.




If shaft A rotates at 360 rpm, calculate the speed of rotation of shaft B and shaft C.

[2 X 2 marks]

Shaft B gear ratio is 20:60, which is 2:6, or 1:3. If shaft A is rotating at 360rpm, then B will rotate at 360/3 = 120rpm.

Shaft C gear ratio is 25:100, or 1:4. If shaft B is rotating at 120rpm, then shaft C will rotate at 120/4 = 30rpm.

**Turn over**

**7** Produce a design for a complete automatic level crossing system that fulfils the following requirements:

- sense when a train is approaching and illuminate an amber light to warn motorists
- after 5 seconds two red lights flash alternately at 1 Hz to stop the motorists
- after 10 seconds a barrier closes to block the road
- when the train is fully clear of the level crossing the barrier should open
- when the barrier is fully open all the lights should go off.

Your diagrams should show clearly where and how the various parts of the system are positioned and mounted with the control and interaction between the sub-systems explained.

Marks will be awarded for:

- the system that senses the approaching train [3 marks]
- the control system [6 marks]
- barrier and drive systems [4 marks]
- assembly and integration of the sub-systems [4 marks]
- selection of materials, components and mountings. [4 marks]

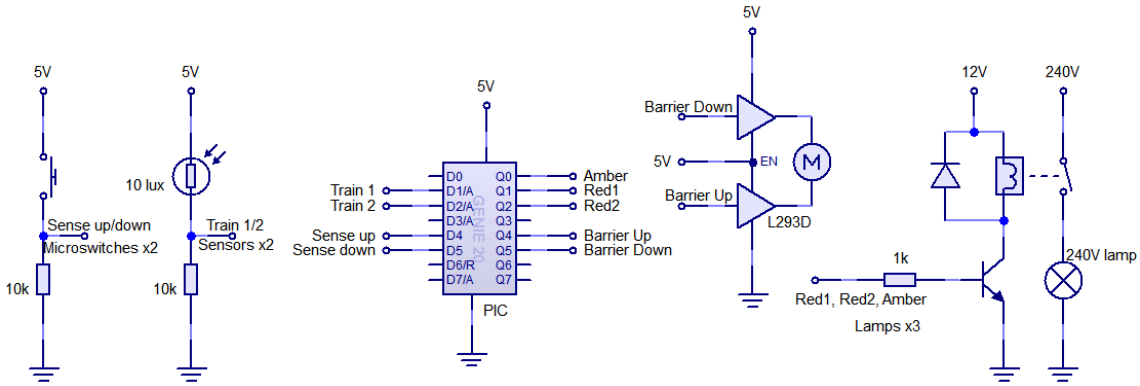
Your diagrams should clearly show where and how the various parts of the system are positioned and mounted with the control and interaction between the sub-systems explained.

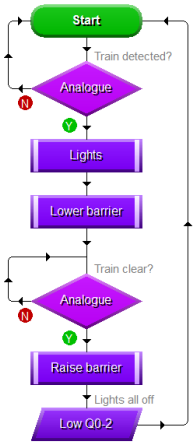
Marks will be awarded for:

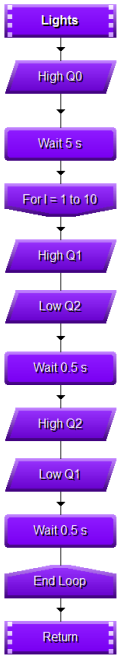
- the system that senses the approaching train Positioning of two sensors (1) Provision of inputs to main control (1) [2 marks]
- the control system Inputs from sensors clearly shown and suitable (1) Time delay system for amber (1) Time delay system for Flashing Red and barrier close (1) Latching system (1) Reset system (1) Switching off all lights and opening barrier (1) [6 marks]
- barrier and drive systems Sketch of barrier capable of opening/closing (1) Prime mover with reversing system (1) Drive system from prime mover to barrier (1) Limitation of barrier movement (1) [4 marks]
- assembly and integration of the sub-systems Inputs interfaced to control (1) Lights interfaced to control (1) Barrier interfaced to control (1) Complete system (1) [4 marks]
- selection of materials, components and mountings. Majority of materials identified and suitable for environment (1) All lights suitably mounted (1) Barrier components mounted and suitable (1) Majority of control components identified and suitable (1) [4 marks]

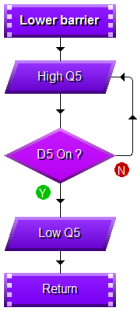
Design a full system for a railway crossing. [20]

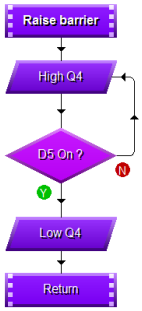
I've combined the different sub-systems from the previous questions into a single PIC circuit. I've added an additional train sensor to the opposite side of the track to sense when the train has cleared the crossing.



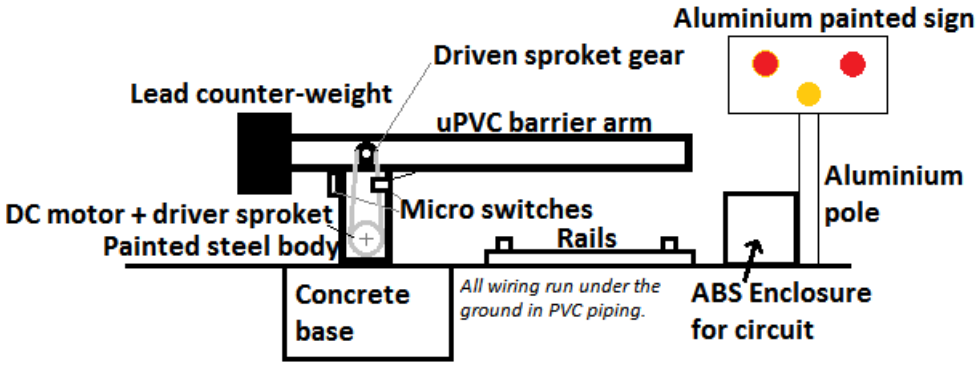



For the code, I have broken it up into sub-routines to make it more readable. The 'Lights' sub-routine shows the amber and red flashing lights. The other two handle driving the barrier motor to lower and raise the barrier until the barrier arm comes into contact with the micro switches mounted on the main body of the barrier.




The barrier will use a large DC motor with a low-ratio gearbox to ensure there is enough torque available to raise and lower the barrier. I'd use a spline in the barrier arm to ensure it doesn't slip, and M6 threaded bar with Nyloc nuts to fasten everything together for future maintenance. By using hollow uPVC, the weight of the barrier is reduced. The lead counter-weight will balance the arm, reducing the load on the motor.

**8** A UK company is considering moving the manufacturing its products to China. Explain the benefits for the company of manufacturing products in China. [4 marks]

*E.g.*
A cheaper product price as wages are lower
Lower standard of H&S practices so easier to produce goods
An available workforce at short notice
A way into trade with the East

**9** A large crane has a steel lifting cable of diameter 36 mm. The steel used has a Young's modulus of 200 GPa. When the crane is used to lift 20 kN, the un-stretched cable length is 25.0m. Calculate the extension of the cable. [4 marks]

$Y_M$ = Stress / Strain
Stress = F / A
Strain = $\Delta L$ / L

$Y_M = 200 \times 10^9$
Stress = $20{,}000 / \pi 0.018^2 = 20000 / 0.00101787602$ Pa = $1.96 \times 10^7$ Pa

So… Strain = Stress / YM = $1.96 \times 10^7 / 200 \times 10^9 = 0.0098 \times 10^{-2}$
$\Delta L$ = Strain x Length
$\Delta L = 0.0098 \times 10^{-2} \times 25 =$ **0.00245m = $2.45 \times 10^{-3}$ = 2.45mm**

…or…

$Y_m = FL / (a\Delta L)$

Re-arrange to $\Delta L = FL / aY_m$ $= 20000 \times 25 / \pi 0.018^2 \times 200 \times 10^9$
$= 5 \times 10^5 / 0.204 \times 10^9$
$= 5 / 0.204 \times 10^4$
$= \mathbf{0.00245m} = \mathbf{2.45 \times 10^{-3}\ m} = \mathbf{2.45mm}$

| | | |
|---|---|---|
| Cite formulae / calculate cross-sectional area | [1] | |
| Calculate Stress | [1] | (Allow for ECF) |
| Re-arrange YM formula | [1] | |
| Calculate $\Delta L$ | [1] | (Allow for ECF) |

**END OF QUESTIONS**