1 (a) The Young modulus is defined as the ratio of *tensile stress* to *tensile strain*. Explain what is meant by each of the terms in italics.

tensile stress ____

____

____

tensile strain ____

____

(3)

(b) A long wire is suspended vertically and a load of 10 N is attached to its lower end. The extension of the wire is measured accurately. In order to obtain a value for the Young modulus of the material of the wire, two more quantities must be measured. State what these are and in each case indicate how an accurate measurement might be made.

quantity 1 ____

method of measurement ____

____

quantity 2 ____

method of measurement ____

____

(4)

(c) Sketch below a graph showing how stress and strain are related for a ductile substance and label important features.

(2)

(Total 9 marks)

2 As part of a quality check, a manufacturer of fishing line subjects a sample to a tensile test. The sample of line is 2.0 m long and is of constant circular cross-section of diameter 0.50 mm. Hooke's law is obeyed up to the point when the line has been extended by 52mm at a tensile stress of 1.8×10^8 Pa.
The maximum load the line can support before breaking is 45 N at an extension of 88 mm.

(a) Calculate

(i) the value of the Young modulus,

____

____

____

(ii) the breaking stress (assuming the cross-sectional area remains constant),

____

____

____

(iii) the breaking strain.

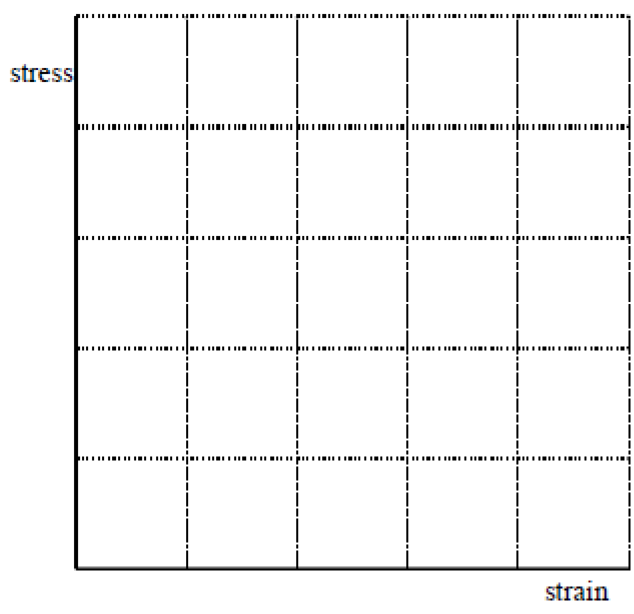
____

(5)

(b) Sketch a graph on the axes below to show how you expect the tensile stress to vary with strain. Mark the value of stress and corresponding strain at

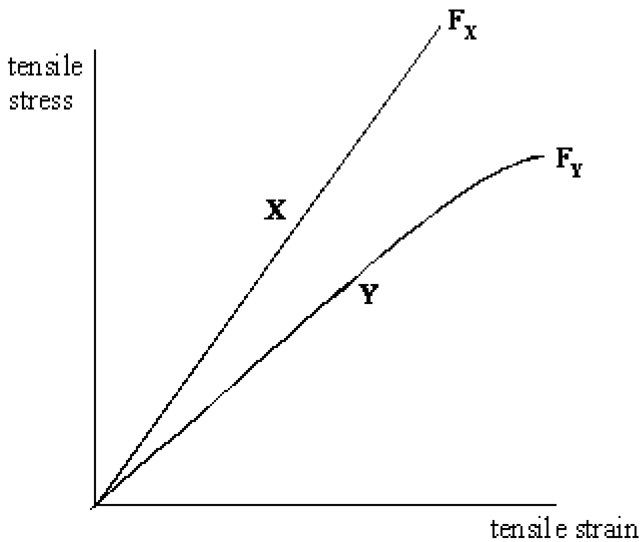
(i) the limit of Hooke's law,

(ii) the breaking point.



(4)
(Total 9 marks)

3 (a) The graph shows the variation of *tensile stress* with *tensile strain* for two wires **X** and **Y**, having the same dimensions, but made of different materials. The materials fracture at the points $\mathbf{F}_X$ and $\mathbf{F}_Y$ respectively.



You may be awarded marks for the quality of written communication provided in your answer to the following questions.

State, with a reason for each, which material, **X** or **Y**,

(i) obeys Hooke's law up to the point of fracture,

(ii) is the weaker material,

(iii) is ductile,

(iv) has the greater elastic strain energy for a given tensile stress.

(8)

(b) An elastic cord of unstretched length 160 mm has a cross-sectional area of 0.64 mm^2. The cord is stretched to a length of 190 mm. Assume that Hooke's law is obeyed for this range and that the cross-sectional area remains constant.

the Young modulus for the material of the cord = 2.0×10^7 Pa

(i) Calculate the tension in the cord at this extension.

___

___

___

___

___

(ii) Calculate the energy stored in the cord at this extension.

___

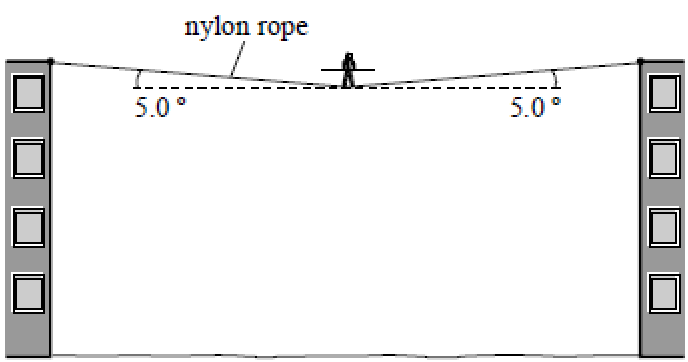
___

___

___

(5)
(Total 13 marks)

4 The figure below shows a person of weight 800 N, crossing the gap between two buildings on a nylon rope.



Before the crossing commenced the rope was horizontal and just taut. When the person is halfway across the rope sags by 5.0°.

(a) Explain briefly why, however taut the rope is, the rope must sag when the person is on it.

___

___

___

(1)

(b) By calculation or scale drawing, determine the tension in the rope when the person is half way across.

(3)

(c) The nylon rope has an ultimate tensile stress of 7.0×10^7 Pa. Calculate the minimum diameter of the rope that could be used.

(3)

(Total 7 marks)

5 (a) State what is meant by the *yield stress* of a material.

___

___

___

___

(3)

(b) A steel piano wire has a diameter of 1.8×10^{-3} m and a length of 1.55 m. When tightened to emit a note of the required frequency it extends by 1.3×10^{-3} m. The Young modulus of the steel is 2.1×10^{11} Pa.

(i) Calculate the force exerted on the frame of the piano by this wire.

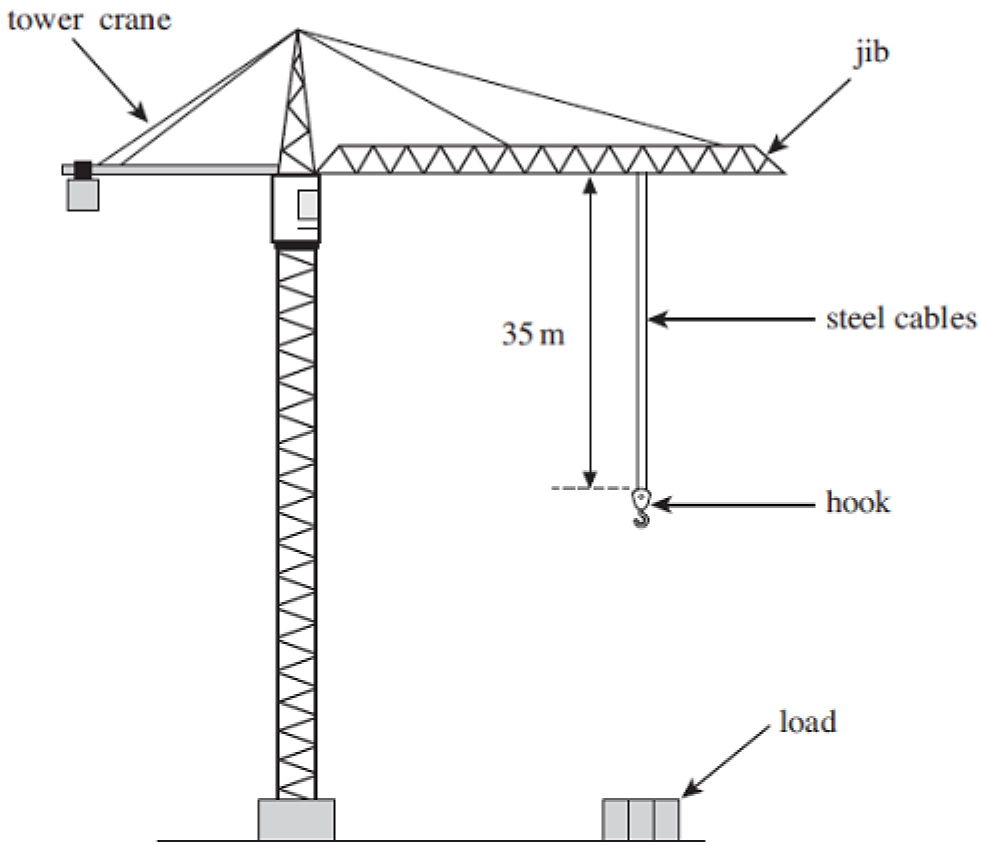
(3)

(ii) Calculate the strain energy stored in this stretched wire.

(2)

(Total 8 marks)

6 The diagram below shows a tower crane that has two identical steel cables. The length of each steel cable is 35 m from the jib to the hook.



(a) Each cable has a mass of 4.8 kg per metre. Calculate the weight of a 35 m length of one cable.

weight = ____________________ N

(2)

(b) The cables would break if the crane attempted to lift a load of 1.5×10^6 N or more. Calculate the breaking stress of **one** cable.

cross-sectional area of each cable = 6.2×10^{-4} m^2

breaking stress = ____________________ Pa

(2)

(c) When the crane supports a load **each** cable experiences a stress of 400 MPa. Each cable obeys Hooke's law. Ignore the weight of the cables.

Young modulus of steel = 2.1×10^{11} Pa

(i) Calculate the weight of the load.

weight = ____________________ N

(2)

(ii) The unstretched length of each cable is 35 m.

Calculate the extension of each cable when supporting the load.

extension = ____________________ m

(3)

(iii) Calculate the combined stiffness constant, *k*, for the **two** cables.

stiffness constant = ____________________ Nm^{-1}

(2)

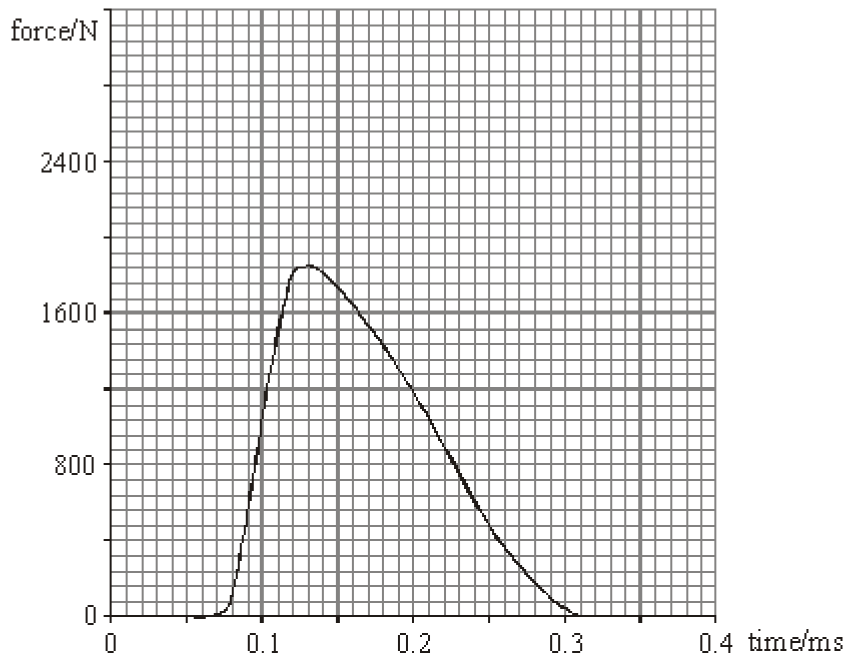
(iv) Calculate the total energy stored in both stretched cables.

energy stored = ____________________ J

(2)

(Total 13 marks)

7 The diagram below shows how the impact force on the heel of a runner's foot varies with time during an impact when the runner is wearing cushioned sports shoes.



(a) Estimate the maximum stress on the cartilage pad in the knee joint as a result of this force acting on the cartilage pad over a contact area of 550 mm^2.

____

____

____

____

____

____

____

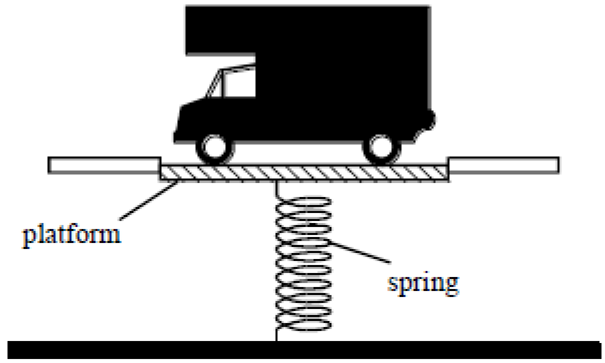
(4)

(b) On the diagram above, sketch the graph of force against time you would expect to see if a sports shoe with less cushioning had been used.

(3)

(Total 7 marks)

8 The diagram below shows a lorry of mass 1.2×10^3 kg parked on a platform used to weigh vehicles. The lorry compresses the spring that supports the platform by 0.030 m.



Calculate the energy stored in the spring.

gravitational field strength g = 9.8 N kg^{-1}

Energy stored = ____________________

(Total 3 marks)

9 (a) (i) Define the Young modulus for a material.

____

____

(ii) Explain what is meant by the *elastic limit* for a wire.

____

____

(2)

(b) A wire supported at its upper end, hangs vertically. The table shows readings obtained when stretching the wire by suspending masses from its lower end.

load / N	0	2.0	4.0	6.0	7.0	8.0	9.0	10.0	10.5
extension / mm	0	1.2	2.4	3.6	4.2	4.9	5.7	7.0	8.0

(i) Plot a graph of load against extension.

(One sheet of graph paper should be provided)

(ii) Indicate on your graph the region where Hooke's law is obeyed.

(iii) The unstretched length of the wire is 1.6 m and the area of cross-section 8.0×10^{-8} m^2. Calculate the value of the Young modulus of the material.

(8)

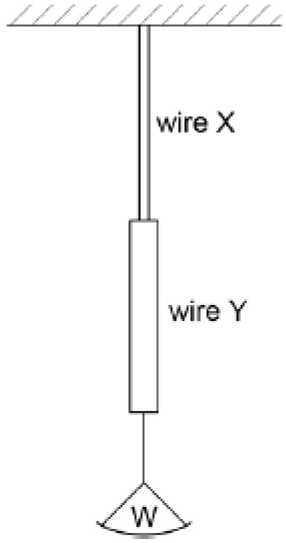
(c) (i) By considering the work done in stretching a wire, show that the energy stored is given by $\frac{1}{2}Fe$, where F is the force producing an extension e.

(ii) Calculate the energy stored in the wire in part (b) when the extension is 4.0 mm.

(4)

(Total 14 marks)

10 Two vertical copper wires X and Y of equal length are joined as shown. Y has a greater diameter than X. A weight W is hung from the lower end of Y.



Which of the following is correct?

A The strain in X is the same as that in Y. ☐

B The stress in Y is greater than that in X. ☐

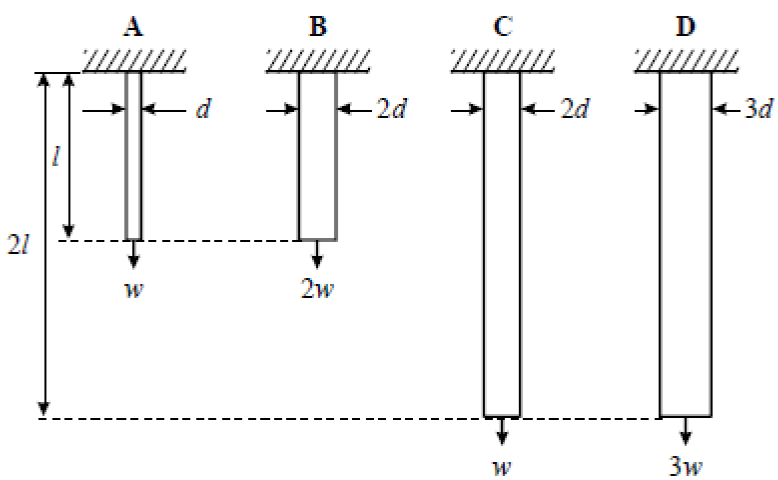
C The tension in Y is the same as that in X. ☐

D The elastic energy stored in X is less than that stored in Y. ☐

(Total 1 mark)

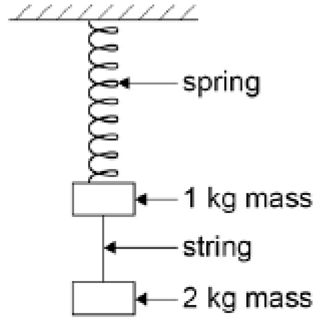
11 The four bars **A**, **B**, **C** and **D** have diameters, lengths and loads as shown. They are all made of the same material.

Which bar has the greatest extension?



(Total 1 mark)

12 Two masses hang at rest from a spring, as shown in the diagram. The string separating the masses is burned through.



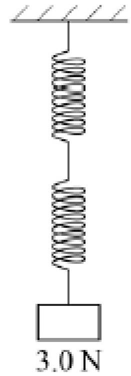
Which of the following gives the accelerations of the two masses as the string breaks?

acceleration of free fall = g

	acceleration of 1 kg mass upwards in m s^{-2}	acceleration of 2 kg mass downwards in m s^{-2}	
A	3 g	1 g	☐
B	2 g	2 g	☐
C	2 g	1 g	☐
D	1 g	1 g	☐

(Total 1 mark)

13 A load of 3.0 N is attached to a spring of negligible mass and spring constant 15 N m^{-1}.

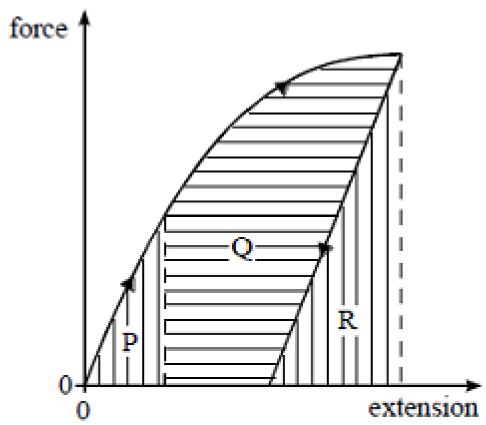


What is the energy stored in the spring?

A	0.3 J	☐
B	0.6 J	☐
C	0.9 J	☐
D	1.2 J	☐

(Total 1 mark)

14 The force on a sample of a material is gradually increased and then decreased. The graph of force against extension is shown in the diagram.



The increase in thermal energy in the sample is represented by area

A R

B $P + Q$

C $P + Q + R$

D $P + Q - R$

(Total 1 mark)

Mark schemes

1

(a) tensile stress = $\dfrac{\text{(tensile) force}}{\text{cross - sectional area}}$ **(1)**

tensile strain = $\dfrac{\text{extension}}{\text{original length}}$ **(1)**

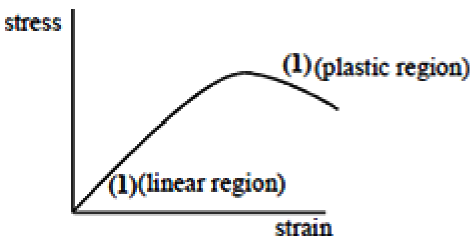
mention of tensile **and** original **(1)**

(3)

(b) diameter of wire **(1)**
in several *places* [or repeated] **(1)**
using a micrometer **(1)**
(original) length of wire **(1)**
using a metre rule (or tape measure) **(1)**

(max 4)

(c)



(2)

[9]

2

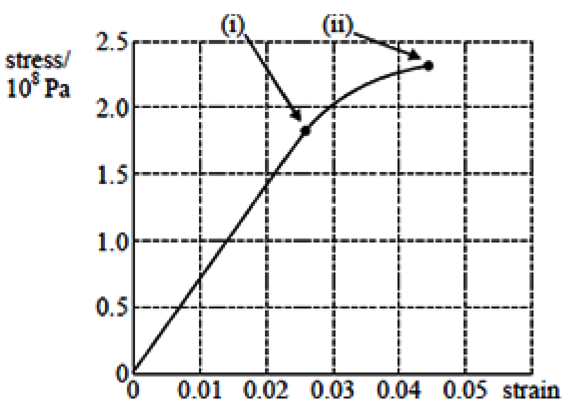
(a) (i) strain = 0.026 **(1)**
$E = 6.92 \times 10^9$ Pa **(1)**

(ii) $A = 1.96 \times 10^{-7}$ (m^2) **(1)**
stress = 230×10^8 Pa **(1)**

(iii) breaking strain = 0.044 **(1)**

5

(b)



shape overall **(1)**

(i) straight line **(1)**
0 to (0.026, 1.8) **(1)**

(ii) curve **(1)**
to (0.044, 2.3) **(1)**

max 4

[9]

3 (a) (i) X **(1)**
stress (force) $\propto$ strain (extension) for the whole length **(1)**

(ii) Y **(1)**
has lower breaking stress (or force/unit area is less) **(1)**

(iii) Y **(1)**
exhibits plastic behaviour **(1)**

(iv) Y **(1)**
for given stress, Y has greater extension
[or greater area under graph] **(1)**

8
QWC 2

(b) (i) (use of $E = \frac{F}{A} \times \frac{l}{\Delta L}$ gives)

$$F\left(= \frac{EA\Delta L}{l}\right) = \frac{2.0 \times 10^{7} \times 0.64 \times 10^{-6} \times 30 \times 10^{-3}}{160 \times 10^{-3}}$$ **(1)**

(1) for data into correct equation, **(1)** for correct area

= 2.4 N **(1)**

(allow C.E. for incorrect area conversion)

(ii) (use of energy stored = ½*Fe* gives) energy = $\frac{2.4 \times 30 \times 10^{-3}}{2}$ **(1)**

= 36 × 10^{-3} J **(1)**

(allow C.E. for value of *F* from (i))

5

[13]

4 (a) rope has to provide an upward force to balance that of the weight down

B1

(1)

(b) reasonable attempt to resolve vertical forces
T sin 5 or T cos 85 seen in a calculation but **not** T cos 5
or some progress in use of scale diagram

C1

2 T sin 5 = 800 **or** well drawn scale diagram with scale indicated

C1

T = 4590 N (4600N)
or 4500 to 4700 by scale drawing

A1
(3)

(c) UTS = maximum force / area
or force / minimum area

C1

area = 6.6×10^{-5} m^2
or their (b) / 7×10^7

C1

d = 0.0091 m
{$1.35 \times 10^{-40} \times \sqrt{(b)(i)}$}

A1
(3)
[7]

5 (a) The force per unit area

B1

at which the material extends considerably / a lot / plastically /
or strain increases considerably etc
NOT doesn't return to its original shape / permanently deformed

B1

for no (or a small) increase in) force / stress

B1
(3)

(b) (i) strain = 8.4×10^{-4} (1.3×10^{-3} / 1.55 seen) (allow if in $E = FL / A\Delta L$)

B1

or area of cross section = 2.54×10^{-6}
or π $(0.9 \times 10^{-3})^2$
stress = E × strain (explicit or numerically) and
stress = F / A or $E = FL / AL$

C1

force = 440 – 450 N(cao)

A1
(3)

(ii) Energy = ½ $F \Delta l$ or ½ stress × strain × volume

C1

0.29 J ecf for F from (b)(i)

A1
(2)
[8]

6 (a) ($W = mg$)

$= 4.8 \times 35 \times 9.81$ ✓

$=1600$ (1648 N) ✓

Allow g=10 : 1680 (1700 N)

g = 9.8 → 1646 N

max 1 for doubling or halving.

Max 1 for use of grammes

2

(b) (stress = tension / area)

For first mark, forgive absence of or incorrect doubling / halving.

$= (0.5 \times)\ 1.5 \times 10^6 / 6.2 \times 10^{-4}$ OR $= 1.5 \times 10^6 / (2 \times)\ 6.2 \times 10^{-4}$ ✓

$= 1.2 \times 10^9$ (1.21 GPa) ✓

Forgive incorrect prefix if correct answer seen.

2

(c) (i) (weight = stress × area)

max 1 mark for incorrect power of ten in first marking point

$= 400 \times (10^6) \times 6.2 \times 10^{-4}$ (= 248 000 N) ✓

max 1 mark for doubling or halving both stress and area

$(\times 2 =)\quad 5.0 \times 10^5$ (496 000 N) ✓

Forgive incorrect prefix if correct answer seen.Look out for YM ÷ 400k Pa which gives correct answer but scores zero.

2

(ii) $\Delta L = \frac{F\ L}{A\ E}$ **OR** correct substitution into a correct equation (forgive incorrect doubling or halving for this mark only ✓

OR alternative method:

strain = stress / E

then ΔL = L × strain

$= \frac{(\text{Ans 4ci}/2) \times 35}{6.2\times10^{-4} \times 2.1\times 10^{11}}$ **OR** $\frac{\text{Ans 4ci} \times 35}{2 \times 6.2\times10^{-4} \times 2.1\times 10^{11}}$ ✓ ecf from 4ci

If answer to 4ci is used, it must be halved, unless area is doubled, for this mark

$\left(= \frac{(4.96\times10^5/2) \times 35}{6.2\times10^{-4} \times 2.1\times 10^{11}} = \right)\ 6.7\times10^{-2}$ (6.667×10^{-2} m) ✓ ecf from 4ci

Any incorrect doubling or halving is max 1 mark.

Allow 0.07

3

(iii)

$\left(k = \frac{F}{\Delta L} \right)$

$= \frac{2 \times 248\,000}{6.667 \times 10^{-2}}$ OR correct substitution into $F = k\Delta L$ ✓ ecf ci and cii (answer 4c(i) ÷ answer 4c(ii))

Allow halving extension for force on one cable

$= 7.4(4) \times 10^{6}$ ✓(Nm^{-1})

Correct answer gains both marks

2

(iv) $\left(E = \frac{1}{2} F\Delta L \text{ or } E = \frac{1}{2} k\Delta L^{2} \right)$

Correct answer gains both marks

$= ½ \times 496\,000 \times 6.667 \times 10^{-2}$ OR $½ \times 7.4(4) \times 10^{6} \times (6.667 \times 10^{-2})^{2}$ ✓ ecf ci, cii, ciii

$= 1.6(5) \times 10^{4}$ (J)✓

Forgive incorrect prefix if correct answer seen.

Doubling the force gets zero.

2

[13]

7 (a) maximum force (from graph) = 1840 (N) (±100 N) **(1)**

max stress $\left(= \frac{\text{force}}{\text{contact area}} \right) = \frac{1840\,(\text{N})}{550 \times 10^{-6}\,(\text{m}^{2})}$ **(1)**

(for correct denominator) **(1)**

$= 3.3 \times 10^{6}\ \text{N m}^{-2}$ **(1)**

4

(b) using shoes without cushioning:

impact time would be less **(1)**
maximum impact force would be greater **(1)**
area under the curve the same **(1)**

3

[7]

8 use of mg with g = 9.8[use of g 10 – 1]

B1

energy = ½ $F\,l$ = ½ (1200 × 9.8) × 0.03

M1

= 180 J [176] [omission of g will score only 1]

A1

[3]

9 (a) (i) the Young modulus: tensile stress / tensile strain **(1)**

(ii) maximum force or load which can be applied without wire being permanently deformed
[or point beyond which (when stress removed,) material does not regain original length] **(1)**

2

(b) (i) graph: suitable scale **(1)**
correct points **(1) (1)**
best straight line followed by curve **(1)**

(ii) indication of region or range of Hooke's law **(1)**

(iii) (use of $E = \frac{Fl}{Ae}$)

values of F and e within range or correct gradient **(1)**

to give $E = \frac{67}{4 \times 10^{-3}} \times \frac{1.6}{8.0 \times 10^{-8}}$ **(1)**

$= 3.3(5) \times 10^{10}$ Pa **(1)**

8

(c) (i) work done = force × distance **(1)**
= <u>average</u> force × extension (= ½Fe) **(1)**
[or use work done = area under graph
area = ½ base × height]

(ii) energy stored = $\frac{67 \times 4 \times 10^{-3}}{2}$ **(1)**

$= 13.(4) \times 10^{-3}$ J **(1)**

4

[14]

10 C **[1]**

11 A **[1]**

12 C **[1]**

13 A **[1]**

14 B **[1]**

Examiner reports

2 In part (a)(i) there were many good answers with the calculation clearly set out and the answer quoted correctly to 2 significant figures and with the correct unit. Some candidates incorrectly attempted to calculate the stress for a force of 45N while others had difficulty in converting from mm to m in determining the strain. In part (a)(ii) about 25% of the candidates could not calculate correctly the cross-sectional area of the wire since they used the diameter and not the radius, or they failed to convert the radius from mm to m. Most candidates were able to calculate correctly the value for the breaking strain.

The sketch graph in part (b) was often carelessly drawn. Sketch graphs gaining full marks showed a straight line up to the limit of Hooke's law followed by a curved region up until the breaking point. The nature of the curved region of the graph was treated generously in the marking. Most candidates marked correctly their values of stress and corresponding strain on the axes.

3 Examiners were pleased to find that part (a) was answered satisfactorily and that candidates not only chose the correct wire but were very often able to provide the correct reason for doing so. Many candidates gained full marks, while a large number only lost one or two marks.
Part (i) was usually correct, although reasons such as ‘the graph is a straight line’ were not accepted. A ‘constant gradient’ was accepted but few candidates gave this as a reason, most giving the proportionality of the quantities involved. In part (ii) answers such as ‘Y broke before X’ was not accepted. Examiners were looking for a reason in terms of lower breaking stress.

Answers to part (iii) were not so good and candidates who did not know the correct answer attempted an answer in terms of the gradients of the curves or the bending of curve Y as the tensile strain increased. Part (iv) gave the most trouble. Many candidates again tried an explanation in terms of the gradient, but a significant number followed the correct track and gave a reason in terms of the area under such a graph. Unfortunately the majority of these candidates referred to the area under the whole curve, whereas it should have been the area under the curve at a given tensile stress. Surprisingly, many candidates, even when using a given stress, gave the area under X as being greater than that under Y.

The final calculation in part (b) did not cause too much difficulty and, provided the initial equation for the Young modulus was correct, candidates produced a correct answer with correct units. One common error which again arose from not reading the question thoroughly, was using the extended length of the elastic cord as the extension. Converting the cross-sectional area of the cord from mm^2 to m^2 caused some problems, but this error was carried forward after the initial penalty had been imposed. The calculation in part (ii) was also done well by those who knew the expression for the energy stored, or were aware that it was given in the data sheet. Some answers, resulting from a carry forward of an incorrect force in part (i) gave energies amounting to several million joules. This attracted no comment.

5 (a) It was expected that within the answer candidates would show that they understood the meaning of stress. Only a minority of the candidates did this. The idea that small increases in stress would produce large increases in strain was not commonly given. Many simply stated that the material would become plastic.

(b) (i) Most candidates were able to gain 2 or 3 marks for this question. Some made mistakes in arithmetic following use of the correct formula and substitution. Others used the wrong formula for area of cross section, $2\pi r^2$ or $\pi r^2 L$ being seen frequently.

(ii) This was usually well done but a significant proportion of the candidates misread the question and gave the strain rather than the strain energy as the answer. Some made the going hard by using ½ *stress* × *strain* × *volume*. Others simply determined ½ *stress* × *strain* thinking that this was the strain energy.

6 (a) Most were successful but a significant number did not multiply by g, perhaps not understanding the difference between weight and mass.

(b) A common error was to not half the force (or double the area). However, a high percentage did realise that you had to do more than simply substitute the numbers given.

(c) (i) Most correctly calculated the load on one of the cables but many did not realise they needed to double their result to get the complete load.

(ii) A lot of rounding errors were evident. 0.06 recurring was often rounded to 0.06 rather than 0.067. Many used their value for weight but did not halve it. Some candidates therefore lost a mark because even though they got the correct answer, they had not halved that weight and this was a physics error.

(iii) Many did not understand that they should use the weight and the extension previously calculated. Many thought that the total load divided by the extension of one cable would give only half of the total stiffness constant. This is not the case because the extension of each cable is the same.

7 In part (a), most candidates read off the maximum force correctly from the graph and also knew how to use this maximum force to calculate the stress. Some candidates were unable to convert the contact area successfully into m^2. Again, in part (b), most candidates correctly sketched the second curve higher and narrower than the first, although few candidates showed or stated that the area under the second curve was the same as that under the first curve.

8 Errors in this question were usually the omission of g (i.e. using *mass* for *weight*) or the assumption that the energy lost by the lorry is all transferred to the spring (i.e. using $mg\Delta h$). Again, significant figure mistakes were very common.

9 High marks were gained for this question on the Young modulus. The definitions in part (a) were usually correct, although it is worth reminding candidates that when defining the Young modulus it is essential to use tensile stress and tensile strain and not just stress and strain. The description of elastic limit was sometimes vague, but the examiners sensed that the candidates knew what it was, even if their wording was not perfectly clear. It should be emphasised however that the wire can only regain its original length when the load or force is removed. A large number of candidates referred to the wire regaining its original shape rather than length; the shape of a wire does conjure up a different picture to the length of a wire.

The graph in part (b) was usually well drawn, although a significant number of candidates did omit the zero point, which was an important point to plot. Surprisingly in part (iii), although candidates had indicated correctly on the graph the extent of Hooke's law, they used a load of 10N in the calculation. This load extended the wire well beyond the region of Hooke's law. Many candidates not only omitted the units in the calculation, but also used incorrect units, N m^2 being a popular alternative.

In part (c), because the expression for the energy stored was given in the question, showing that the work done in stretching the wire = ½Fe proved to be more difficult than expected. In the calculation in part (ii) the usual error encountered was not converting the 4 mm to metres.