ENGINEERING TRIPOS PART IA

Thursday 5th June 2008 9 to 12

Paper 2

STRUCTURES AND MATERIALS

*Answer **all** questions.*

*The **approximate** number of marks allocated to each part of a question is indicated in the right margin.*

Answers to questions in each section should be tied together and handed in separately.

There is ONE attachment to be made to your answer sheet for section B. A Materials Selection Chart is provided for question 11 section B, which is to be handed in with your answer.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

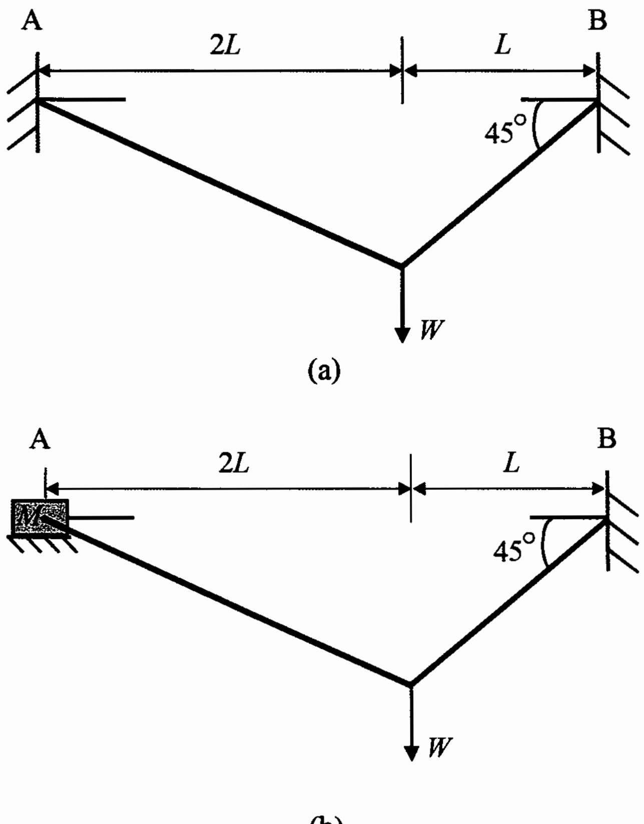
You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

SECTION A

1 **(short)** An inextensible cable is loaded between two supports as shown in Fig. 1(a).

(a) Find the support reactions. [4]

(b) The left hand support is now replaced with a block on a plane as shown in Fig. 1(b). The coefficient of friction between the block and the plane is 0.3. Assuming there is an even pressure distribution under the block, find the minimum mass, *M*, of the block required in order to ensure that the block will not slide. [6]



(b)

Fig. 1

2 (long) In the following, all members have axial stiffness EA and the self-weight can be neglected.

(a) A pin-jointed truss is shown in Fig. 2(a). The truss is loaded with two vertical point loads W. Find the vertical displacement of B for the loading shown. [18]

(b) A symmetric three-pinned arch structure is shown in Fig. 2(b) where a is an arbitrary length. Find the support reactions. [4]

(c) The arch is now connected to the pin-jointed truss as shown in Fig. 2(c). Find the vertical displacement of B for the loading shown. [8]

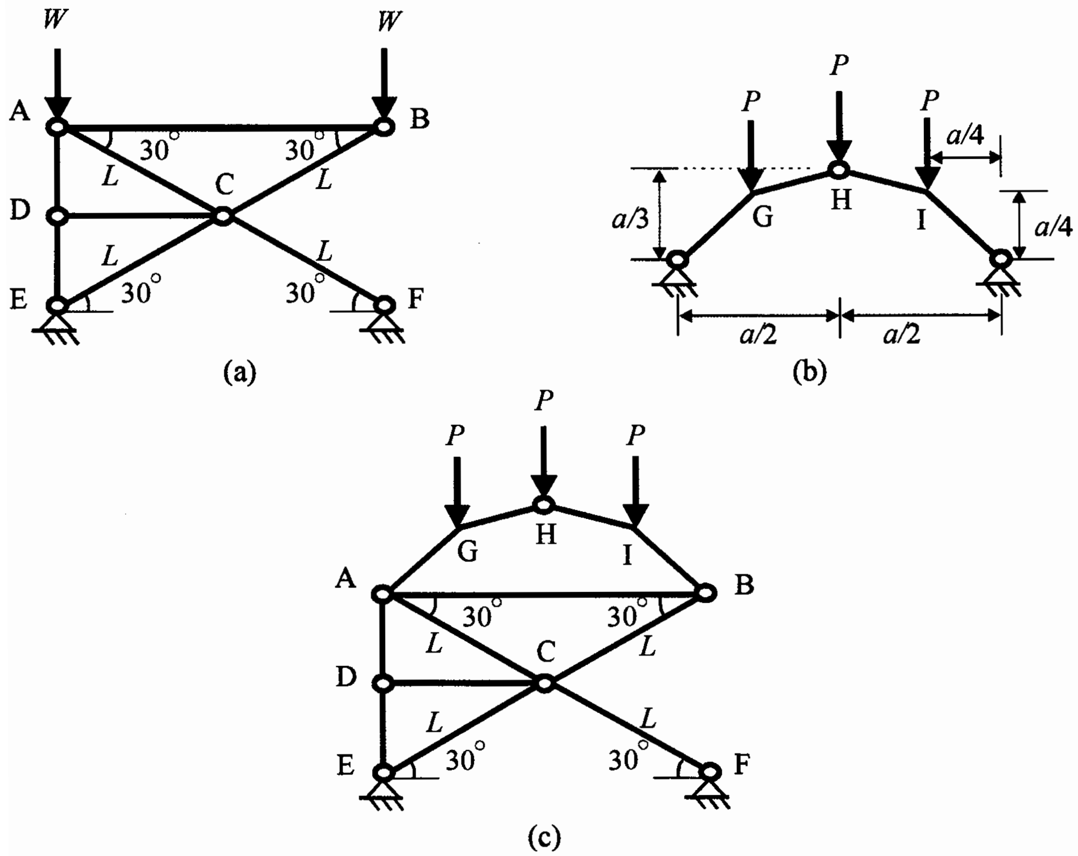


Fig. 2

(TURN OVER

3 **(short)** An inverted, uniform, rigid L-shaped structure is pinned at one end and connected to a cable as shown in Fig. 3. The structure is tilted at an angle where ABC forms an equilateral triangle. The structure is made of two lengths of rod welded together, one with length L and the other $L/2$ where $L = 5$ m. The weight of a length L of rod is $W = 30$ Kn. A linear triangular load varying from a value of 0 kNm^{-1} at C to 10 kNm^{-1} at D is applied in a direction perpendicular to CD, as shown.

Find the tension in the cable. [10]

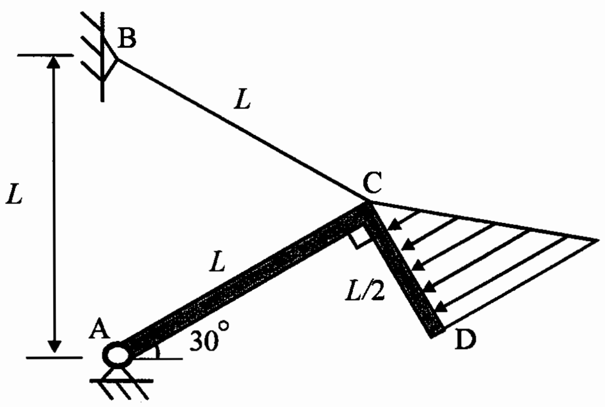


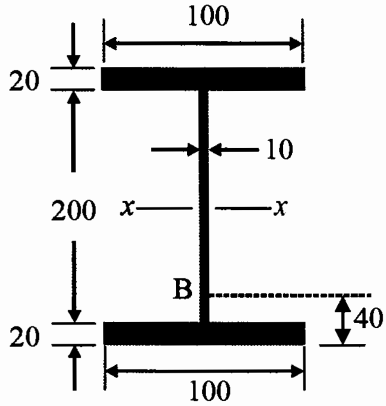
Fig. 3

4 **(short)** The cross-section of a beam is shown in Fig. 4. The cross-section is subjected to a vertical shear force of 15 kN and a bending moment of 20 kNm about the *x-x* axis. Linear elastic behaviour can be assumed.

At the location B, which is 40 mm from the base of the beam, determine:

(a) the magnitude of the longitudinal stress and [4]

(b) the magnitude of the shear stress. [6]



all dimensions are in mms

Fig. 4

(TURN OVER

5 (long) The linear elastic structure shown in Fig. 5 has a total load W distributed between B and C. There are point loads of $W/2$ at A, W at D and $3W/2$ at E. The members have stiffness EI and negligible self-weight.

(a) Find the support reactions at B and C. [7]

(b) Sketch the shear force diagram and bending moment diagrams for the structure, marking salient values. [14]

(c) Find the vertical displacement at A. [9]

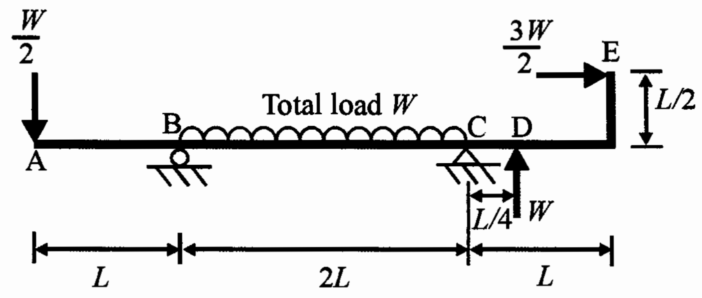


Fig. 5

6 **(short)**

(a) A vertical universal steel column UC356×368×177, which is initially straight and has no imperfections, has a height of 10 m. The ends of the column are restrained against horizontal displacement and rotation and the column is loaded axially. Calculate the buckling load of the column. [4]

(b) An elastic pin-ended strut of length L and stiffness EI is shown in Fig. 6. The supports at A and B allow in-plane rotation but no displacement in the y-direction. In addition, the support at A allows movement in the x-direction. The strut is initially straight and then loaded with an axial force P at an eccentricity of e. Find the governing differential buckling equation (but do not solve). [6]

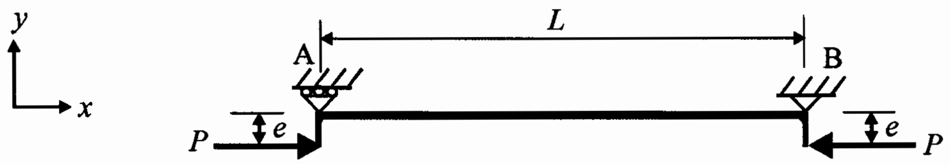


Fig. 6

(TURN OVER

SECTION B

7 **(short)** Give brief answers to the following:

(a) Why are metals generally soft and ceramics hard? [2]

(b) Why are ceramics stronger in compression than in tension? [2]

(c) Sketch a curve of Young's modulus vs temperature between $0.1T_m$ (K) and $0.9T_m$ (K), where T_m is the melting point of the polymer:

(i) a semi-crystalline thermoplastic;
(ii) a thermo-setting resin. [2]

(d) Account for changes in stiffness of both polymers as the temperature increases from very low to high temperature. [4]

8 **(short)**

(a) Sketch the nominal tensile stress-nominal tensile strain curve for annealed mild steel obtained at room temperature. [2]

(b) Indicate with an arrow the yield stress, ultimate tensile stress, and the fracture stress. [2]

(c) Account for the shape of the stress-strain curve between the yield stress and the ultimate tensile stress. [2]

(d) Indicate the point on the curve for the onset of "*necking*". [1]

(e) Explain briefly the phenomenon of "*necking*". [3]

9 (**short**)

(a) Briefly describe 2 specific situations where galvanic corrosion can occur. [3]

(b) Indicate ways of eliminating or reducing the severity of galvanic attack. [3]

(c) A ship's hull is protected from corrosion by connecting it to a zinc anode that initially weighs 136 kg. The average corrosion current is 2A. Estimate how often the anode should be replaced. [4]

The valency of zinc is 2. The atomic mass of zinc is 65.4 $gmol^{-1}$. Avogadro's number is 6.022×10^{23} atoms per mol and the charge on an electron is 1.602×10^{-19} C.

10 (**short**) From a number of identical tensile tests on silicon carbide test-pieces, the fracture stress corresponding to a 95% probability of survival was determined as 250 MPa and the Weibull modulus *m* equal to 10. Small compressor blades of volume 10 times greater than a single tensile test-piece were made from the same ceramic and tested in tension to fracture.

The probability of survival P_S of a sample of volume V_O subjected to a tensile stress σ_O is given by the Weibull equation:

$$P_S(V_O) = \exp[-(\sigma/\sigma_O)^m]$$

(a) Determine the fracture stress of a compressor blade corresponding to a survival probability P_S of 95%. [4]

(b) By what means could you:

(i) increase the tensile strength of ceramics; [3]

(ii) raise the confidence level of operation of ceramic components? [3]

(TURN OVER

11 **(long)** A cylindrical-shaped tank for containment of propane gas under pressure is sealed by welding along its length and is closed by welding hemispherical domes at each end. The tank has a wall thickness t = 14 mm and an outside diameter 2R = 1.68 m, and is made from steel having a fracture toughness K_{IC} = 45 MPa.m$^{1/2}$. The tank is designed to withstand a working pressure p = 1.5 MPa, which is limited by a pressure release safety valve to avoid overloading.

(a) Calculate the maximum allowable stress in the wall of the tank. [4]

(b) A steel tank exploded catastrophically by crack propagation along the length of the longitudinal weld. Subsequent examination of the weld revealed a fatigue crack of length a = 10 mm at the point of fast fracture, which had initiated at the internal surface of the weld. Estimate by how much greater was the pressure in the tank at failure compared to the maximum allowable design pressure. [4]

(c) By comparing the pressure in the tank at failure with the maximum allowable design pressure, what conclusion do you draw? [4]

(d) What is meant by *"leak-before-fracture"* with respect to the fail-safe design of a pressure vessel? [5]

(e) Derive an expression for the maximum allowable pressure that defines the condition of fail-safe design in terms of the fracture toughness, K_{IC}, and yield stress, σ_y, of the material, and the radius, R, of the vessel. [6]

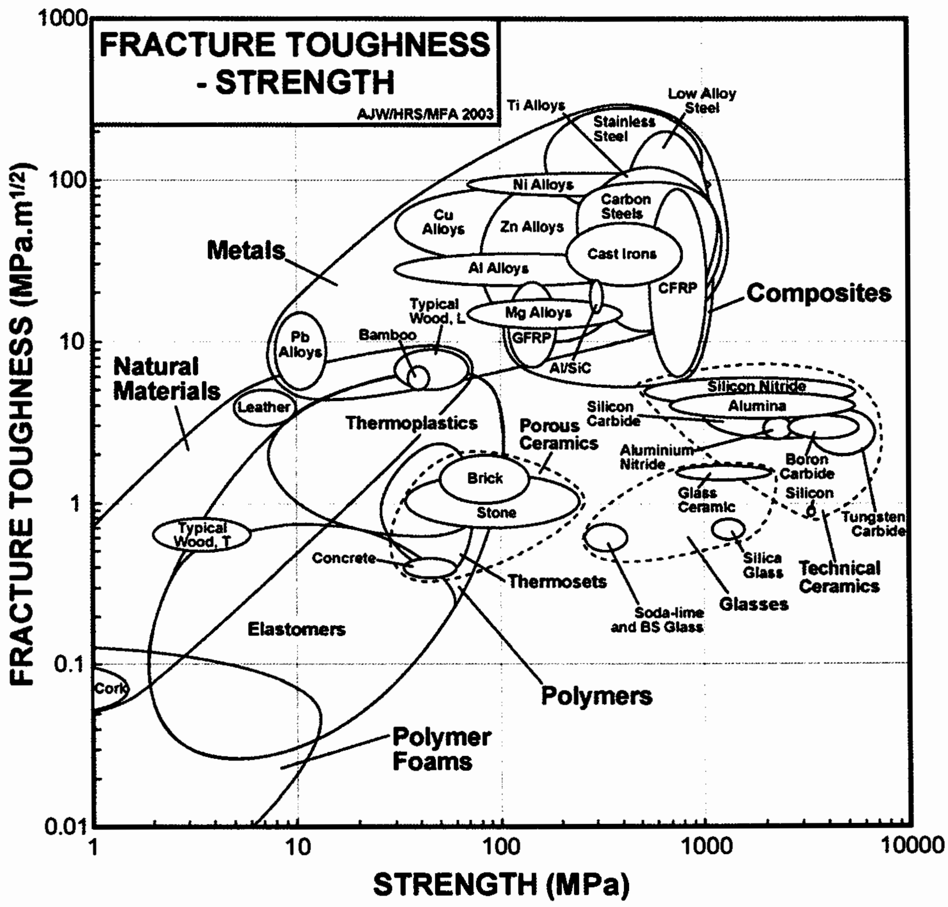
(f) Propose a merit index M_1 for the material from which a vessel can be made to withstand pressure most safely. [3]

CONT NEXT PAGE

11 **(long)** cont.

(g) A fracture toughness–yield strength chart below displays a number of engineering materials from which to select the best material for the fail-safe design of a pressure vessel. On a separate copy of this chart (to be handed in with your answer) draw lines of merit index M_I to identify a suitable search region. Take into account a secondary requirement of a lower yield strength of 200 MPa in order to narrow down your search.

Make a preliminary selection of the best materials. [4]



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12 (**long**)

(a) Explain the 3 principal mechanisms by which metals are strengthened. [6]

(b) Account briefly for strengthening mechanisms responsible for the following increases in yield stress:

(i) Pure annealed aluminium alloyed with Mn and Mg increases the yield stress of Al from 50 MPa to 200 MPa. [3]

(ii) Pure copper alloyed with 40%Zn and cast increases the yield stress of Cu from 35 MPa to105 MPa. [3]

(iii) Pure iron alloyed with 0.4%C, quenched from high temperature and tempered, increases the yield stress of an annealed medium carbon steel from 140 MPa to 550 MPa. [3]

(c) For each of the 3 principal strengthening mechanisms, give an example of other important engineering alloys which exploit these mechanisms. [5]

(d) The tensile yield strength, σ_y, of pure aluminium is 30 MPa. Estimate the enhancement in yield strength of aluminium that contains 5% by volume of $CuAl_2$ particles of 80 nm diameter in a slip plane within the aluminium. The shear modulus, G, of aluminium is 26 GPa and its burgers vector, b, is 3×10^{-10} m. [6]

(e) Account for any changes in yield strength of the Al-Cu alloy if:

(i) dispersion of particles is non-uniform; [2]

(ii) particle size increases with time at elevated temperature. [2]

END OF PAPER

Question 12(d) – corrected 02/05/11