UNIVERSITY OF GHANA

BSC. ENGINEERING
SECOND SEMESTER EXAMINATIONS: 2015/2016

DEPARTMENT OF BIOMEDICAL ENGINEERING
BMEN 308: DESIGN OF MECHANICAL SYSTEMS (3 CREDITS)

INSTRUCTIONS:
ATTEMPT ALL QUESTIONS
ALL QUESTIONS SHOULD BE ANSWERED IN THE BOOKLET PROVIDED
EACH MAJOR QUESTION SHOULD START ON A NEW PAGE
CALCULATIONS SHOULD BE DETAILED AND SYSTEMATIC. MARKS ARE ALLOCATED TO STEPS
RELEVANT FORMULAE ARE PROVIDED AT THE END OF THE QUESTION SETS

TIME ALLOWED: THREE (3) HOURS

An aged care centre approaches you as a biomedical engineer to design a device for checking the weight of the aged who are unable to stand on their own. After going through the engineering design process, you come up with the mechanical system shown in Figure 1. The device is to be used in a controlled environment with easily determined loads and to cut down on cost, you also choose a material frequently used in this application.

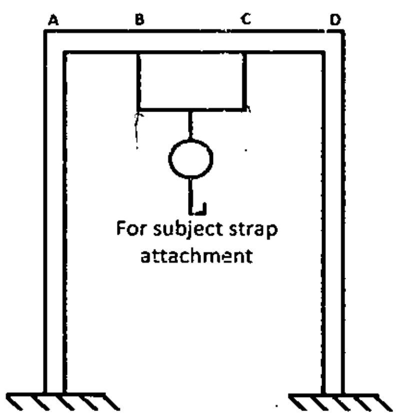

Figure 1. Proposed design for a weighing device to be used in an aged care centre. Length of AD = 150 cm, BC = 80 cm and AB = CD.

1. As an engineer, the code of conduct entreats you to hold paramount the safety of the public in carrying out your work.
    a. List any three (3) of the guidelines stipulated by the National Safety Council to ensure safety in the design of equipment.

(6 marks)

b. Based on the function of the device and knowledge that it would be subjected to static and/or dynamic loads:
    i. State and briefly explain any 3 effects that you may observe as the device fails. Indicate which part of the design may experience each effect (must be relevant to this particular design).

(9 marks)

    ii. State one material property you would consider for each of the failure modes you identified above.

(6 marks)

c. From the strength-life diagram, one is able to determine the endurance limit for a given material. Explain endurance limit.

(4 marks)

d. Would you choose a low (1.25-2.5) or high (>3) factor of safety for the design? Briefly explain why.

(5 marks)

2. The average mass of a 60-year old male is known to be about 80 kg. Assume section ABCD has negligible mass.
    a. Determine the reaction forces at point A, B, C and D.

(4 marks)

    b. Isolating section ABCD and the reaction forces at those points,
        i. Draw the shear force diagram for the section.

(3 marks)

        ii. Draw the bending moment diagram for the section.

(3 marks)

        iii. Is any part of the section undergoing pure bending? Indicate which part, if yes.

(3 marks)

    c. The section ABCD is a circular beam of diameter 8 cm made of material with elastic modulus 4 GPa. If simple bending takes place between points B and C,
        i. Calculate the curvature that would be observed for a maximum bending stress of 180 MPa.

(4 marks)

        ii. Calculate the associated bending moment.

(3 marks)

3. Analysis of your design showed that the mechanism for attachment is inappropriate. You decide to replace it by a 2-member component which you model as the bar and spring shown in Figure 2 (Area of bar = 16 cm^2, spring constant = 40 Nm^{-1}). The bar has an elastic modulus of 4 GPa and length of 10 cm. Using the Displacement/Stiffness method of Finite Element Analysis (FEA),
    a. Determine the elemental stiffness matrix for each member.

(8 marks)

    b. Determine the global stiffness matrix for the whole component.

(4 marks)

c. Calculate the nodal displacements if the component is subjected to a maximum tensile load of 1500 N at the free end of the spring with the bar having a fixed end.

(6 marks)

d. Calculate the elemental strain and stress for the bar element.

(7 marks)

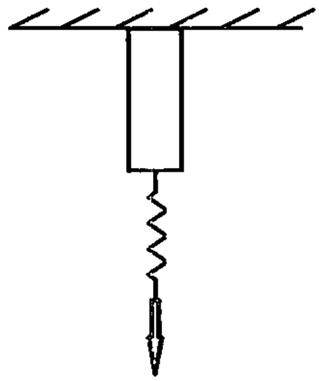

Figure 2. A 2-member component for patient attachment. [Area of bar = 16cm², spring constant = 40 Nm⁻¹]

4. Considering only the bar member in Figure 2 under a uniaxial force (F_y) of 1500 N,
   a. Determine the principal normal stresses (σ_1, σ_2 and σ_3) and principal shear stresses (τ_{12}, τ_{13} and τ_{23}) using Mohr's circle.

   (15 marks)

   b. Given that the material of the bar has a yield strength of 3 GPa and your selected factor of safety is 2,
      i. Will your bar fail under the maximum principal stress theory? Answer should be justified with calculation.

      (5 marks)

      ii. Will your bar fail under the maximum shear stress theory? Answer should be justified with calculation.

      (5 marks)

Useful formulae *(all letters have their usual contextual meanings)*:

$$g = 10ms^{-2}$$

$$(I = \frac{\pi d^4}{64})$$

$$\sigma = \frac{M}{I}y$$

$$\epsilon = \frac{y}{R}$$

$$Curvature = \frac{1}{R}$$

$$E = \frac{\sigma}{\epsilon}$$

$$M = \frac{E}{R}I$$

$$\tau_{13} = \frac{|\sigma_1 - \sigma_3|}{2}$$

$$\tau_{12} = \frac{|\sigma_1 - \sigma_2|}{2}$$

$$\tau_{23} = \frac{|\sigma_2 - \sigma_3|}{2}$$

$$\sigma^3 - C_2\sigma^2 - C_1\sigma - C_0 = 0$$

$$C_2 = \sigma_x + \sigma_y + \sigma_z$$

$$C_1 = \sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_x\sigma_z - \tau_{xy}^2 - \tau_{yz}^2 - \tau_{xz}^2$$

$$C_0 = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{yz}\tau_{xz} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{xz}^2 - \sigma_z\tau_{xy}^2$$

$$\sigma_1 \leq \frac{S_u}{F_d}$$

$$\tau_{max} = \frac{|\sigma_1 - \sigma_3|}{2}$$

$$\tau_{yield} = \frac{S_y}{2}$$

$$\tau_{max} \leq \frac{\tau_{yield}}{F_d}$$

$$\sigma_e = \frac{\sqrt{2}}{2}[(\sigma_2 - \sigma_1)^2 + (\sigma_3 - \sigma_1)^2 + (\sigma_3 - \sigma_2)^2]^{\frac{1}{2}}$$

$$\sigma_e = \sqrt{\frac{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{xy}^2+\tau_{yz}^2+\tau_{xz}^2)}{2}}$$