UNIVERSITY OF GHANA

BSC. ENGINEERING
SECOND SEMESTER EXAMINATIONS: 2016/2017

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

INSTRUCTIONS:
ATTEMPT ALL QUESTIONS
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 orthopaedic centre in Ghana has contracted a Biomedical Engineer to design a rehabilitative device in the form of parallel bars to aid the work of their physiotherapists. The device is to be used mainly by adult patients who visit the centre. By modifying existing designs, the engineer ends up with the product shown below in Figure 1. It consists of a ground attachment and two horizontal cylindrical bars. The horizontal bars are supported vertically from the ground attachment by two smaller cylindrical bars of different diameter on each side as shown. It is also made of stainless steel of elastic modulus 192 GPa for all the parts.

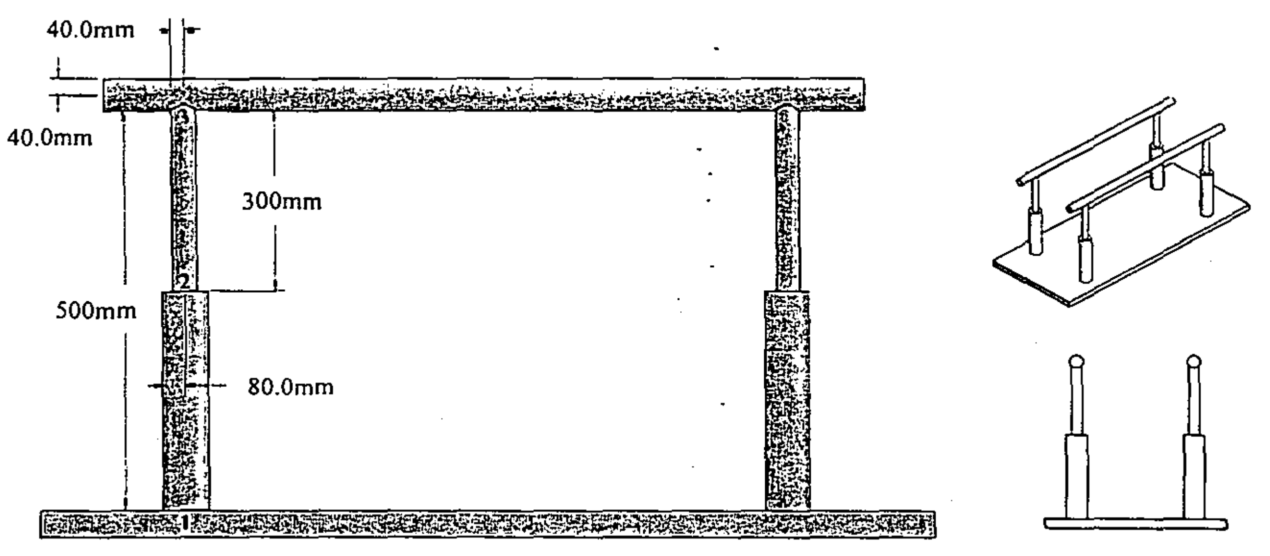

Figure 1. A designed parallel bar to be used by patients at an orthopaedic centre

1. The main point from the needs assessment was that all the adult patients should be able to use the product.
   a. State one question you would ask the client to further clarify the above statement.

   (2 marks)

   b. State and briefly explain two (2) requirements that would enable the engineer to meet the above stated need.

   (6 marks)

   c. For each requirement in 1(b), state two (2) relevant engineering characteristics the engineer would consider for the design in Figure 1.

   (4 marks)

   d. Briefly explain one approach you would use to determine the target value for any of the engineering characteristics stated in 1(c).

   (5 marks)

   e. Based on your knowledge of how the device would be used,
      i. State any two (2) mechanisms by which the device could fail.

      (4 marks)

      ii. Indicate one part of the device which could fail by each mechanism stated.

      (4 marks)

2. The engineer decides to analyse the effect of an externally applied load on one of the supports between the horizontal bar and ground attachment. The analysis is to ensure that the device does not cause further injury to patients during use by deforming by more than 20 mm under a vertical compressive load of 1000 N applied at node 3 of the support mechanism. The ground attachment is constrained to the ground. Refer to Figure 1 for dimensions.
   a. State three considerations or provisions the engineer can make to ensure the safety of the product.

   (6 marks)

   b. Determine the elemental stiffness matrix for each member in the support mechanism.

   (8 marks)

   c. Determine the global stiffness matrix for the whole support mechanism.

   (4 marks)

   d. Calculate the nodal displacements (nodes 1, 2 and 3) of the support mechanism.

   (6 marks)

   e. Determine if the support will meet the requirement of not deforming by >20mm.

   (6 marks)

3. To further support any patient who uses the parallel bars, the engineer comes up with a suspension mechanism which can be attached to a torso strap. The suspension mechanism is as shown in Figure 2 below. It consists of two rectangular bars arranged in a triple riveted single lap joint. [thickness of bar = 2 cm, cross-sectional area of bar = 10 cm^2, length of bar = 20 cm, diameter of rivet = 1 cm, allowable tensile stress of bar material = 690 MPa, allowable shear stress of rivet material = 320 MPa, allowable crushing stress of rivet = 640 MPa, allowable crushing stress of bar material = 600 MPa, pitch of rivets = 3 cm]

   a. State and illustrate with sketches three (3) ways in which the joint could fail. ***(9 marks)***

   b. Determine the efficiency of the joint in the suspension mechanism. ***(13 marks)***

   c. Based on your answers in (a) and (b), how is the joint most likely to fail? ***(3 marks)***

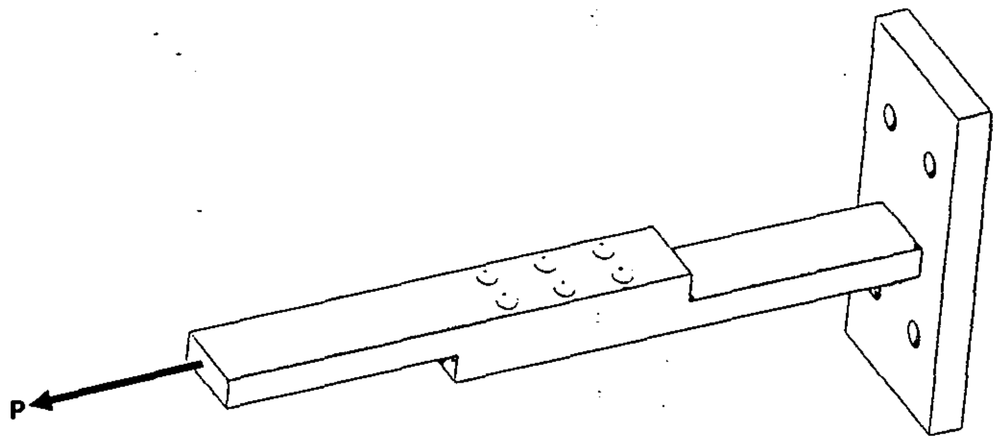

Figure 2. Suspension mechanism for additional patient support

4. You have been accepted as an intern in the engineer's firm. To evaluate your practical knowledge and skills, you are asked to build a prototype of the suspension mechanism in Figure 2. A large slab of metal and the dimensions of the prototype are provided. Sequentially outline the steps you would take in the workshop to realise the prototype. Indicate the tools you would use as well as two (2) safety precautions you would take. ***(20 marks)***

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$L = nA_r\tau_d$$

$$L = nA_b\sigma_c$$

$$A_b = td$$

$$L = A_p\sigma_t$$

$$A_p = (p - d)t$$

$$\eta = \frac{least\ safe\ load}{p\ t\ \sigma_t}$$