

THE UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING  
POST GRADUATE  
2020/2021 ACADEMIC YEAR

CEE 5211 DESIGN IN REINFORCED AND PRE-STRESSED CONCRETE(BS 8110)

CEE 5311 WATER MANAGEMENT AND HYDRAULIC STRUCTURES

CEE 6111 CONSTRUCTION CONTRACT AND ADMINISTRATION

CEE 6772 PROJECT RISK AND QUALITY MANAGEMENT

EEE 5240 DYNAMIC SYSTEMS AND CONTROL ENGINEERING

MEC 5051 MACHINE DESIGN II PAPER 1

MEC 5455 ALTERNATIVE ENERGY SOURCES

MEC 5465 REFRIGERATION AND AIRCONDITIONING

MEC 5551 ENVIRONMENTAL ENGINEERING

MEC 5855 AUTOMOBILE ENGINEERING

**THE UNIVERSITY OF ZAMBIA**  
**SCHOOL OF ENGINEERING**  
**CIVIL AND ENVIRONMENTAL ENGINEERING DEPARTMENT**  
**UNIVERSITY EXAMINATION**  
**2020-2021 ACADEMIC YEAR**  
**CEE 5211**

**DESIGN IN REINFORCED AND PRE-STRESSED CONCRETE (BS 8110).**

**TIME: THREE HOURS**

**INSTRUCTIONS TO CANDIDATE**

- (a) Candidates must ensure that their ID numbers are clearly written on each answer booklet used and that the number of answered questions is entered in the space provided on the front of the booklet.
- (b) Answer **ALL FIVE** questions.
- (c) Marks on each question are as indicated.
- (d) Mathematical gadgets and drawing instruments are allowed.

**MAXIMUM SUM OF MARKS: 100**

**(OPEN BOOK)**

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Study the attached architectural drawing which are just showing pictures of the structure and study the “Beam Layout Plan” which has measurements clearly indicated and answer the following questions:-

**QUESTION ONE**

Determine the design load on the slab, if the dead load on the slab, from roofing and walls is  $14\text{ kN/m}^2$  on the slab area and thickness of slab is  $200\text{ mm}$ , imposed load is  $1.5\text{ kN/m}^2$  and density of concrete is  $24\text{ kN/m}^3$ . **(10 marks)**

**QUESTION TWO**

- (a). Using design load in question one, design the steel reinforcement in the slab using moments only, taking effective depth to be  $160\text{ mm}$ , cover to reinforcement is  $25\text{ mm}$ . Given the characteristic strength of concrete to  $f_{cu}=30\text{ N/mm}^2$  and that of steel  $f_y=500\text{ N/mm}^2$  **(10 marks)**
- (b). Using the slab panel used in slab design, make a structural drawing of the slab entering only two of main steel reinforcement bars in **tension**, into the bar bending schedule. **(10 marks)**

### QUESTION THREE

(a). Design the reinforced concrete beams 1 using fixed moments. Given the characteristic strength of concrete to be  $f_{cu}=30\text{N/mm}^2$  and that of steel  $f_y=500\text{N/mm}^2$ , take effective depth  $d=360\text{mm}$  and cover to reinforcement as  $25\text{mm}$ . The beams are  $400\times 200\text{mm}$ , as cross-section measurements. **(10 marks)**

(b). Make a structural drawing of beam 1 and enter the steel reinforcement into the bar bending schedule use nominal links R8. **(10 marks)**

### QUESTION FOUR

(a). Design the reinforced concrete Column C1 of sizes  $300\times 300\text{mm}$ , height of column is  $3\text{m}$  and cover to main reinforcement  $25\text{mm}$ . Moment from beam 1 to be taken from question 3 above, then take  $d'=275\text{mm}$ ,  $h'=275\text{mm}$ .  $f_{cu}=30\text{N/mm}^2$  and  $f_y=500\text{N/mm}^2$ . **(30 marks)**

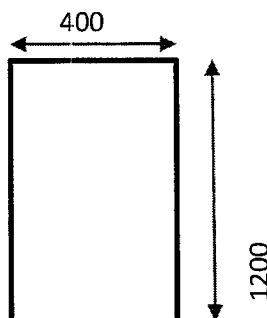
(b). Make a structural drawing of the column and enter the steel reinforcement into the bar bending schedule make nominal links R8. **(10 marks)**

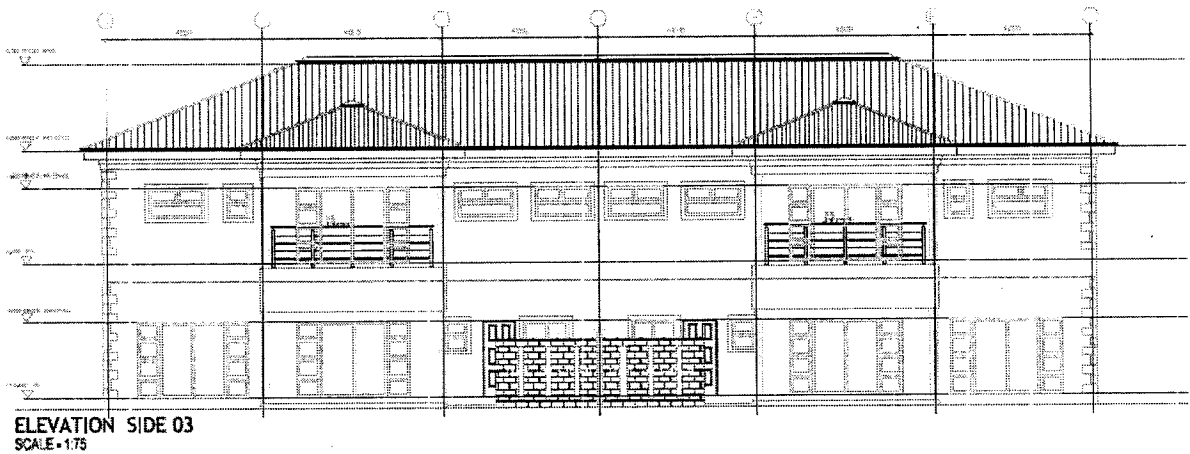
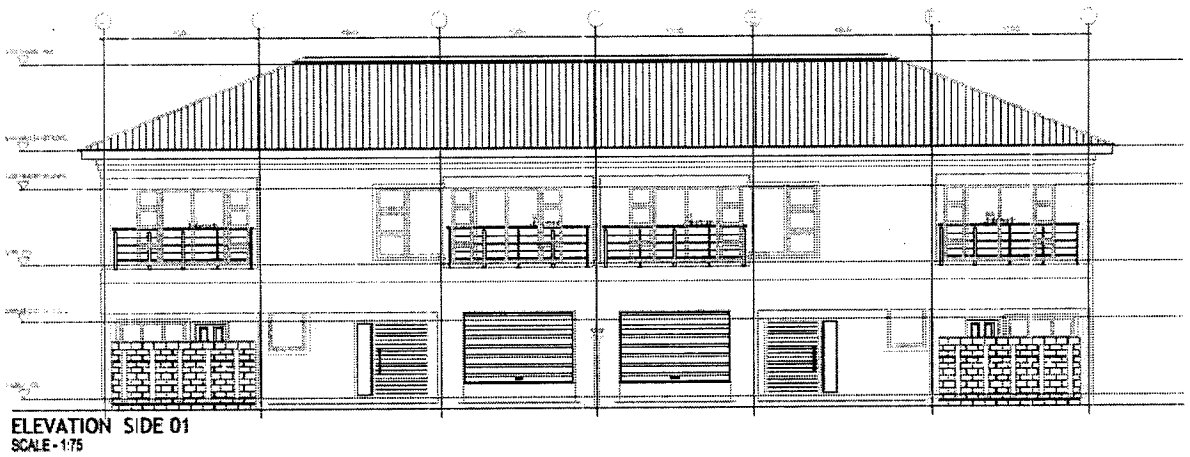
### QUESTION FIVE (Pre-Stress Concrete Design)

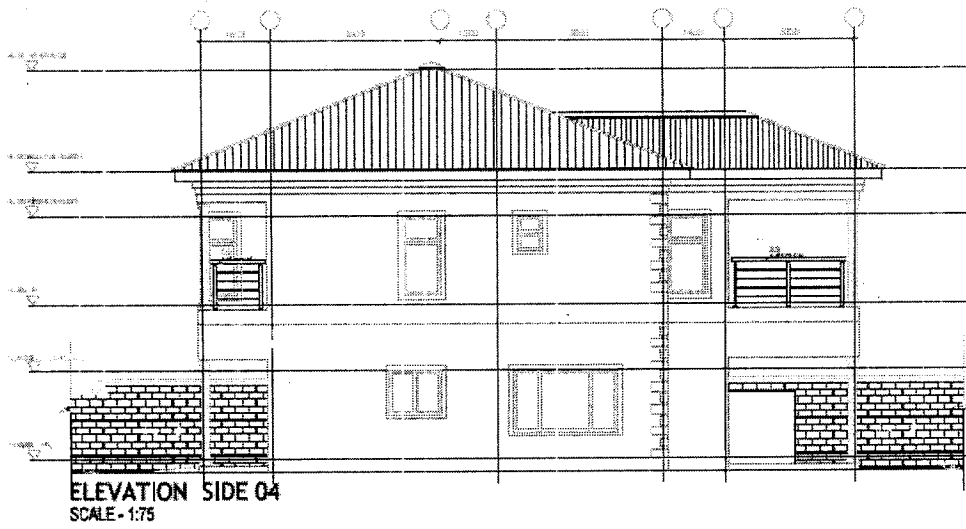
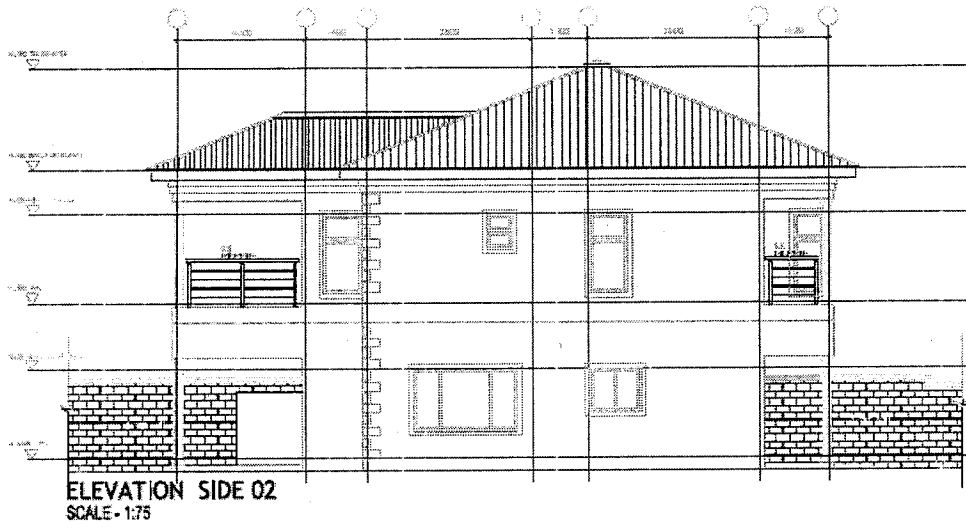
A simply supported pre-tensioned concrete beam has dimensions as shown and spans  $15\text{m}$ . It has an initial pre-stress force of  $1100\text{kN}$  applied to it and it carries a uniformly distributed imposed load of  $12\text{ kN/m}$ . Determine the extreme fibre stresses at mid-span

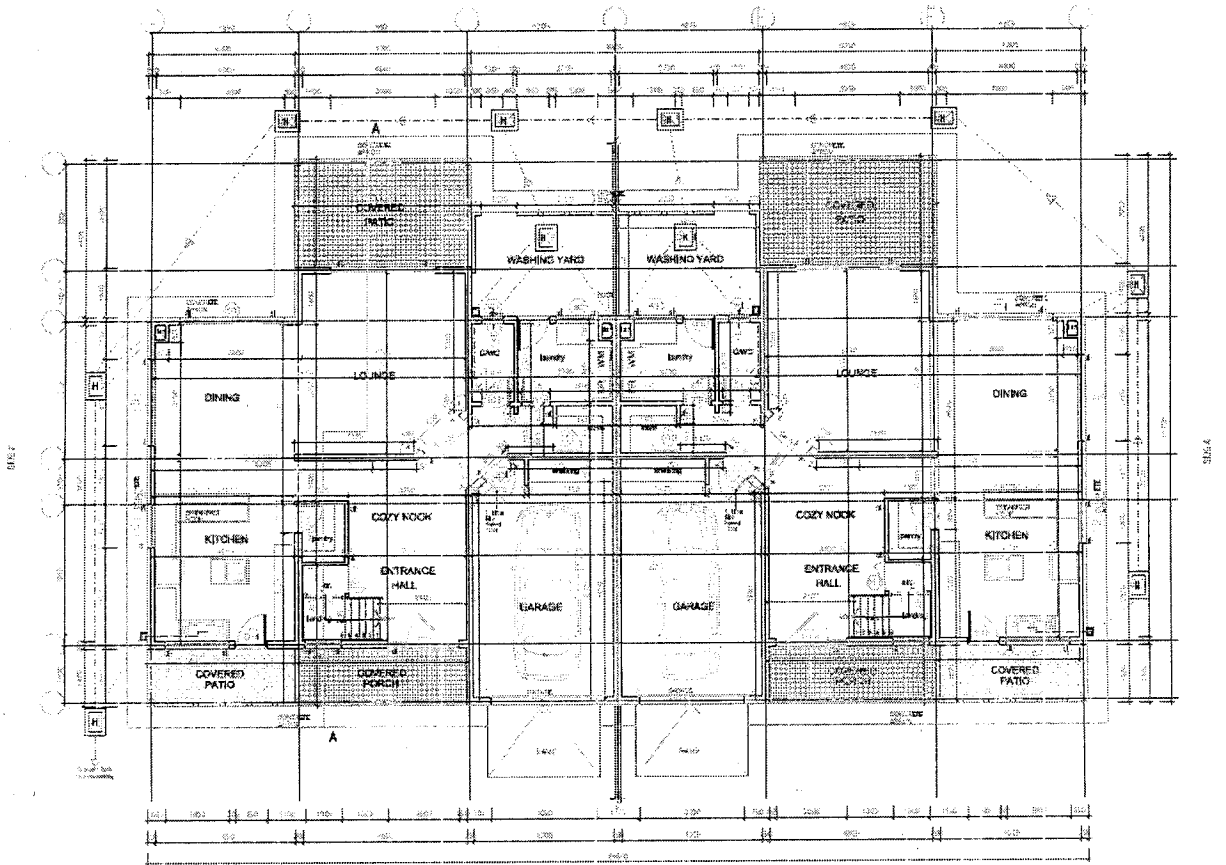
(a). under the self-weight of the beam, if the short- term losses are  $10\%$  and eccentricity is  $325\text{mm}$  below the beam centroid. **(10 marks)**

(b). under service load, when the pre-stress force has been reduced by a further  $10\%$ . **(10 marks).**

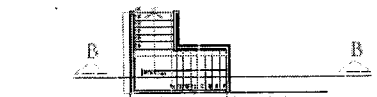
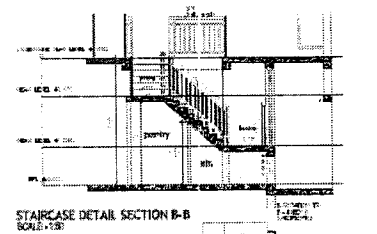
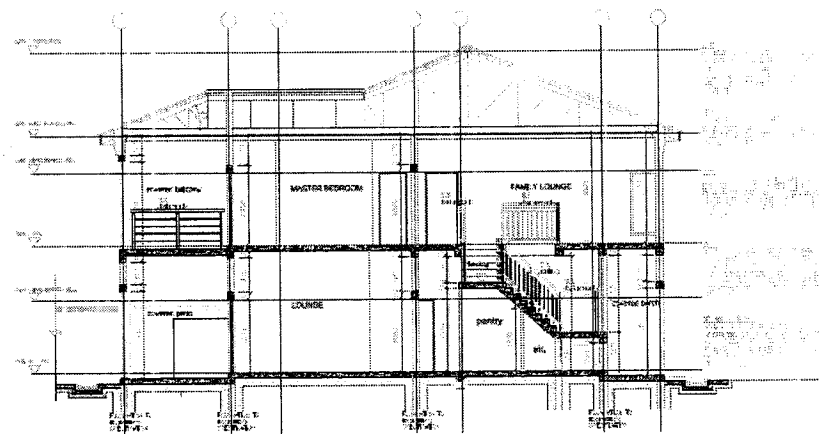
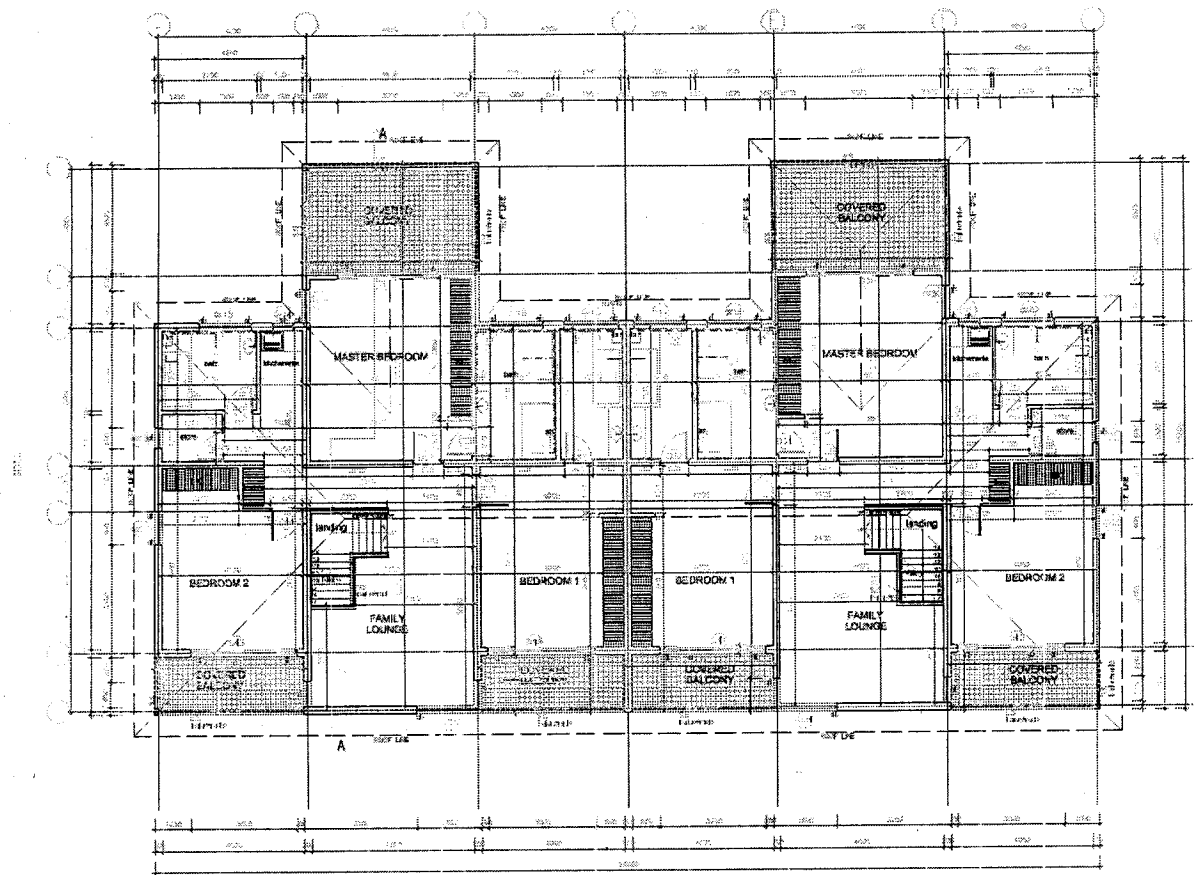


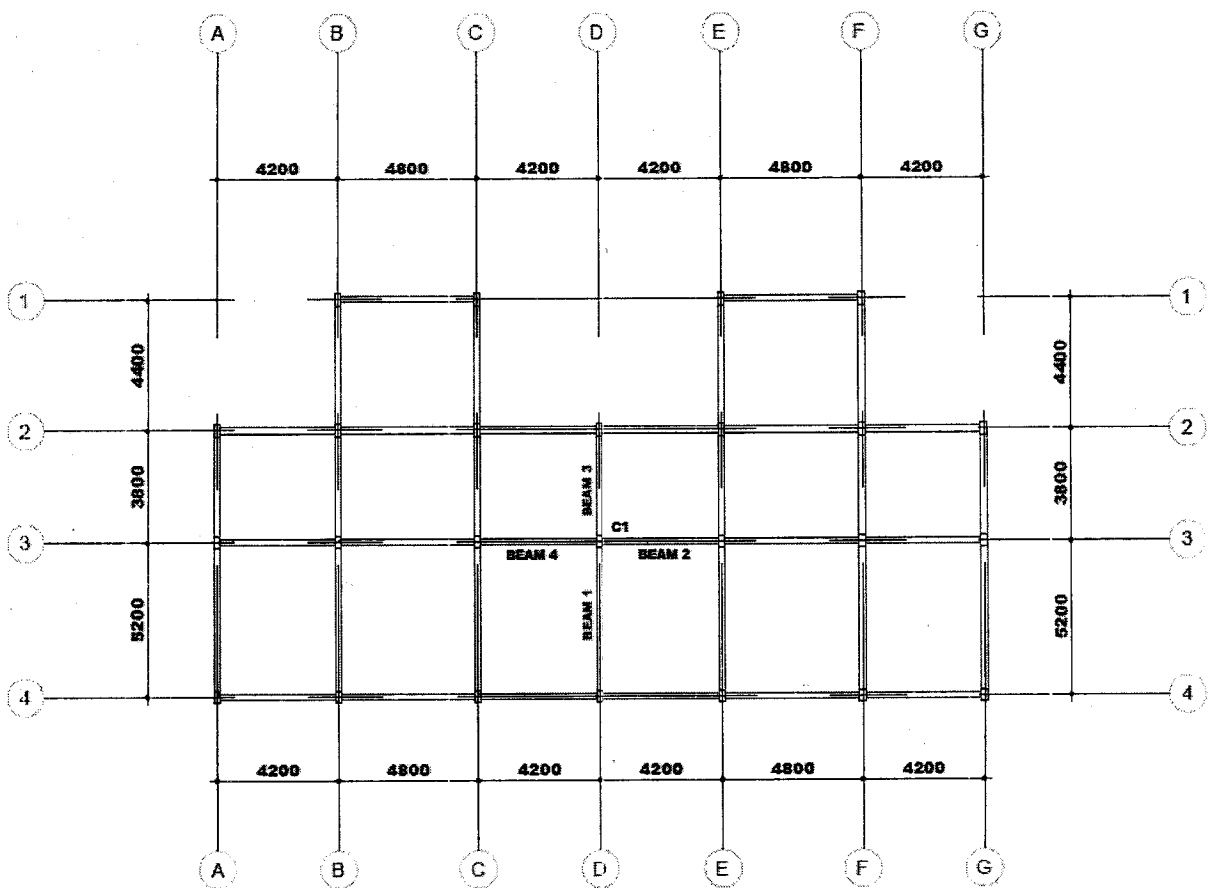




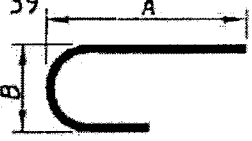
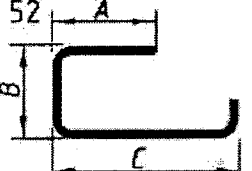
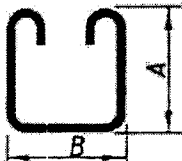
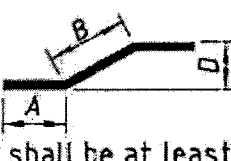
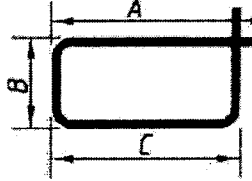
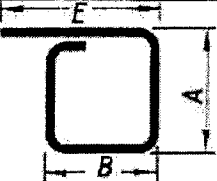
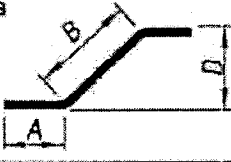
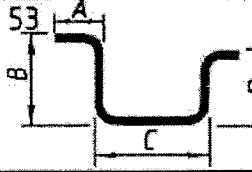
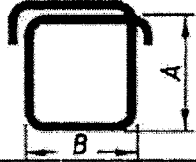
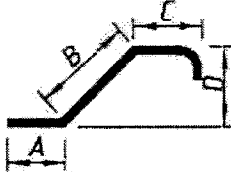
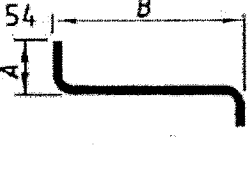
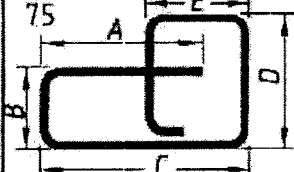
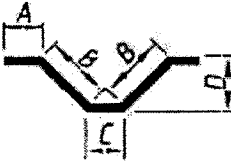
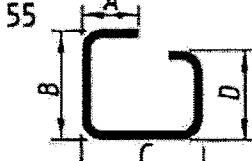
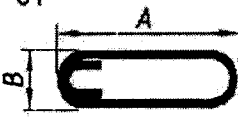
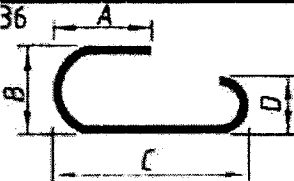
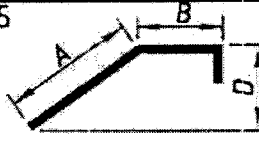
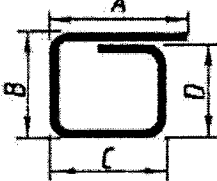
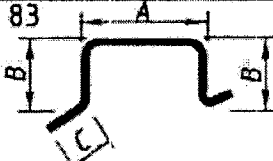
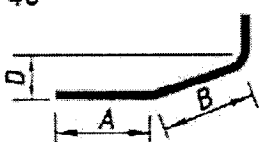
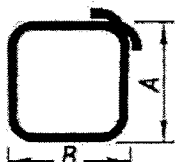
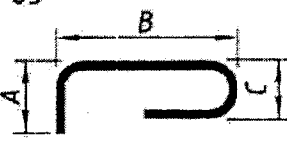
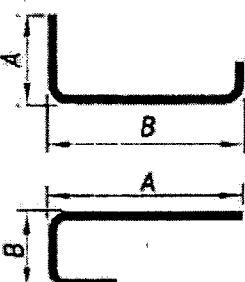
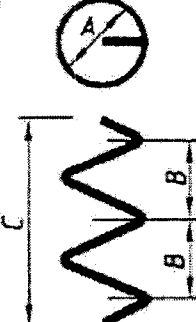
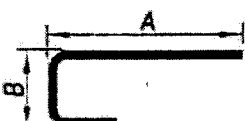


GROUND FLOOR PLAN  
 PLINTH : 329.51 sqm  
 SCALE 1:50





**COLUMN AND BEAM LAYOUT PLAN**  
**SCALE: 1 : 100**

| 1                                                                                         | 2                                                                                                                        | 3                                                                                         | 4                                                                                           |
|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| 20<br>   | 39<br>                                  | 52<br>   | 72<br>   |
| 32<br>   | 41<br><br><i>D shall be at least 2a</i> |          | 73<br>   |
| 33<br>   | 2a<br>                                  | 53<br>   | 74<br>   |
| 34<br>   | 42<br>                                  | 54<br>   | 75<br>   |
| 35<br>  | 43<br>                                 | 55<br>  | 81<br>  |
| 36<br> | 45<br>                                |        | 83<br> |
| 37<br> | 48<br>                                | 60<br> | 85<br> |
| 38<br> | 49<br>                                | 62<br> | 86<br> |
|        | 51<br>                                | 65<br> |                                                                                             |

## BAR BENDING SCHEDULE

[illegible]

This schedule complies with the requirements of BS4466

**THE UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING  
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**2021 ACADEMIC YEAR  
FINAL EXAMINATIONS**

**CEE 5311 - WATER MANAGEMENT AND HYDRAULIC STRUCTURES**

**INSTRUCTIONS**

- Attempt any FIVE questions.
- All questions carry equal marks (20%). Marks for sub-questions are indicated at the end of each sub-question.
- If you fail to answer part of a question, assume a value and use it in the subsequent calculations
- Make sure the computer number is clearly indicated on all the booklets together with the questions attempted.

**TIME: THREE (3) HOURS**

**CLOSED BOOK EXAM**

**Question 1**

- ) How does one determine the actual pump operating head? (2 marks)
- ) What is the best way (s) to assure safety of a dam? (6 marks)
- ) How are tensile forces avoided in dams? (2 marks)
- ) Briefly explain whether as variability of the flow increases in a river, the required reservoir capacity increases. (2 marks)
- ) Mention all the phases that are usually involved in the planning and management of a major water resource project. (2 marks)
- ) What advantage(s) is obtained by the fact that Manning's roughness in a distorted model must always be larger than in nature. (3 marks)
- ) Briefly explain the importance of an Environmental Impact Assessment. (3 marks)

**Question 2**

- ) During inspection of a dam, it is found that there is excess seepage at or just downstream of the toe of the dam. What actions should be taken? (4 marks)
- ) What is the advantage (s) of selecting a pump such that the operating point is close to the best operating point? (3 marks)
- ) How can one compute pore pressure in an earth dam? (2 marks)
- ) When considering minimum pool level in a reservoir, will there be any difference for a water supply project and a hydropower one? Briefly explain. (3 marks)
- ) In structural analysis, how is the arch dam visualized. (3 marks)
- ) Mention three practical limitations of modeling. (3 marks)
- ) When analysing compatibility of multi-purpose uses, why is flood mitigation the least compatible of all uses? (2 marks)

**Question 3**

- ) When does the Froude number play a dominating role in hydraulic modeling? (3 marks)
- ) A spillway model is to be built to a scale of 1:25 across a flume which is 60 cm wide. The prototype is 11.25m high and the maximum head expected is 1.5m.
  - i) What height of model should be used? (5 marks)
  - ii) What head on the model should be used? (5 marks)
  - iii) If the flow over the model at 60cm head is  $0.02\text{m}^3/\text{s}$ , what flow per meter of prototype may be expected? (7 marks)

#### Question 4

If the quantity of water to be delivered by the pump varies, the flow may be regulated by throttling with a valve on the discharge line.

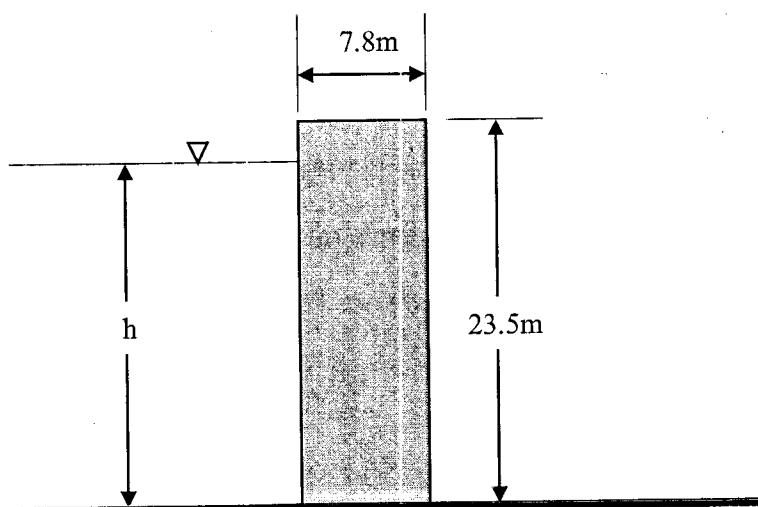
- Why is this not preferred? (3 marks)
- Give the preferred way and justify your solution. (5 marks)

A given turbine runs at a maximum efficiency of 87% when discharging  $5.66 \text{ m}^3/\text{s}$  at 150 rpm under net head of 24.3m. If this same turbine is operated under a net head of 12.2m,

- derive similarity laws for speed, flow rate and brake power using  $n \propto \sqrt{h}/D$  and  $Q \propto \sqrt{h}D^2$  (6 marks)
- compute the speed (2 marks)
- compute the flow rate (2 marks)
- compute the brake horsepower (2 marks)

#### Question 5

Determine the critical height  $h$  of the water level before the concrete dam starts to tip over due to water pressure acting on its face. Assume water also seeps under the base of the dam. The specific weights of concrete and water are  $23.5 \text{ kN/m}^3$  and  $9.81 \text{ kN/m}^3$ , respectively. (20 marks)



#### Question 6

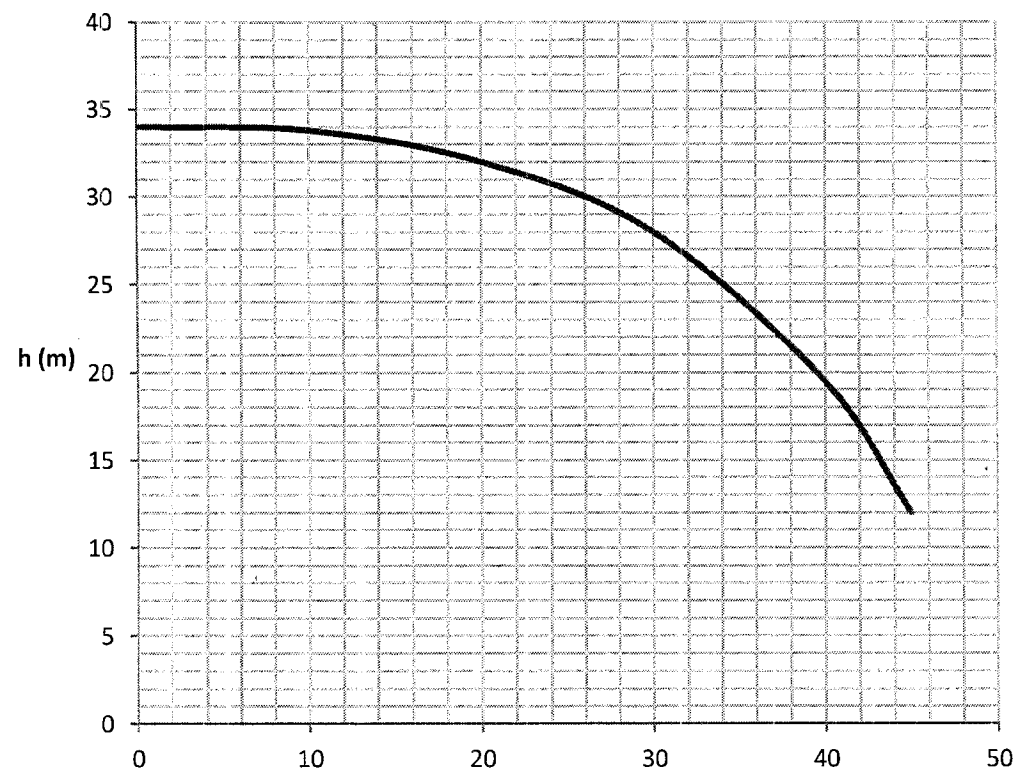
- Mention two functions of spillways. (4 marks)
- Why are outlet works provided in dams? (2 marks)
- Mention a good practice for sluiceways passing through earth or rock-fill dams. (2 marks)
- The water supply for part of Lusaka is pumped from boreholes to a distribution reservoir. The estimated hourly water requirements for the maximum day are indicated below. If the pumps are to operate only between 13:00 and 18:00 hours at a uniform rate, what reservoir capacity is required? (12 marks)

| Hour  | Demand<br>$\text{m}^3$ |
|-------|------------------------|
| 01:00 | 720                    |
| 02:00 | 650                    |
| 03:00 | 565                    |
| 04:00 | 530                    |

|       |      |
|-------|------|
| 06:00 | 500  |
| 07:00 | 560  |
| 08:00 | 690  |
| 09:00 | 775  |
| 10:00 | 850  |
| 11:00 | 870  |
| 12:00 | 900  |
| 13:00 | 910  |
| 14:00 | 935  |
| 15:00 | 935  |
| 16:00 | 920  |
| 17:00 | 925  |
| 18:00 | 940  |
| 19:00 | 940  |
| 20:00 | 970  |
| 21:00 | 985  |
| 22:00 | 1000 |
| 23:00 | 950  |
| 24:00 | 890  |

### Question 7

The pump whose characteristic curve is shown below when operating at 1450 rpm is used to pump water from reservoir A to reservoir B through a 45-cm-diameter pipe ( $f=0.032$ ) 150m long. Neglecting minor losses, Find the flow rate when the water surface elevation of reservoir B is 6m higher than that in reservoir A. Assume  $f$  does not change with flow rate. **(20 marks)**



INTS

$$r = \frac{P}{A} \pm \frac{Mc}{I}$$

$$= \frac{bh^3}{12}$$

$$Re = \frac{\rho v L}{\mu}$$

$$Fr = \frac{v}{\sqrt{gL}}$$

$$\tau_s = c + \sigma \tan \phi$$

$$\tau = \frac{W \cos \theta}{\Delta L} - u_w$$

$$= \frac{u_1}{\sqrt{2gh}}$$

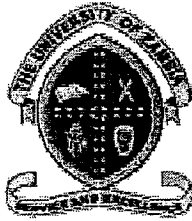
$$\rho = \frac{2\pi N}{60}$$

$$q = K \frac{\partial h}{\partial x}$$

$$= \frac{NPSH}{h} = \frac{P_{atm}/\gamma + P_s/\gamma + V_s^2/2g - P_v/\gamma}{h}$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g}$$

$$\frac{V_1^2}{2g} + \frac{P_1}{\rho g} + z_1 + h_p = \frac{V_2^2}{2g} + \frac{P_2}{\rho g} + z_2 + h_t + h_l$$



**THE UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING**

**MASTER OF ENGINEERING CONSTRUCTION MANAGEMENT**

**SESSIONAL EXAMINATION**

**14:00 – 17:00 HOURS – DECEMBER 13, 2021**

**CEE 6111: CONSTRUCTION CONTRACT AND ADMINISTRATION**

**Instructions to Candidates**

1. This paper consists of Seven (7) **PRACTICAL** Questions.
2. Each question carries 20 Marks and Candidates are expected to attempt any Five (5) Questions in whichever order.
3. The answer for each question should begin on a new sheet
4. Candidates are free to express themselves in their responses as the questions are all real work situation cases.
5. The time allowed is three hours.
6. Make sure the student number is clearly indicated on all booklets together with the questions attempted.
7. Where specific information is not given, make and state your assumptions
8. Marks will be lost for illegible, untidy and unorganised presentation
9. The examination is strictly closed book

## Question One

- 1.1 One of the most common disputes under construction contracts is where the Contractor and the Engineer differ on whether a particular instruction is or is not a variation. Explain the actions the contractor is likely to take when:
- 1.1.1 He considers an instruction constitutes a variation. (3 Marks).
- 1.1.2 The Engineer refuses to pay for the perceived variation. (2 Marks).
- 1.1.3 Explain the content of the Sub Clause 20.1 (Contractors Claim Procedure) which the contractor must follow. (5 Marks)
- 1.2 When the Employer includes a condition in contract limiting the Engineer's authority to instruct a variation. Then the Engineer issues an instruction, believing it to be a simple instruction and not a Variation. The conditions of contract in the meantime contains a Sub clause 13.1, expressly forbidding the contractor from carrying out a variation without a variation order. Then the contractor carries out the works as instructed by the Engineer.
- 1.2.1 What would be the contractor's argument for a claim? (5 Marks)
- 1.2.2 What would be the Client's argument to decline the payment of the claim? (5 Marks)

**[Total: 20 Marks]**

## Question Two

- 2.1 Explain the following:
- 2.1.1 Correspondence; (5 Marks)
- 2.1.2 Written notices; (5 Marks)
- 2.1.3 Site instructions. (5 Marks)
- 2.2 List atleast 8 documents that will form part of the contract for construction. (5 Marks)

**[Total: 20 Marks]**

### Question Three

- 3.1 Under contractual clauses, materials and goods have to be provided only 'so far as procurable'. It will be noticed, however, that the contractor's obligation under the same conditions of contract is to provide what is specified in the contract documents. What happens if the contractor cannot obtain materials? (10 Marks)
- 3.2 If an Engineer approves a contractor's programme, can the contractor subsequently change the programme without the Engineer's knowledge and, if so, can the Engineer demand an update? (5 Marks)
- 3.3 Does the contractor have a contractual duty to draw attention to an error on the Engineer's drawing? – Explain (5 Marks)

**[Total: 20 Marks]**

### Question Four

- 4.1 Several General conditions of Contract contain clauses that address instructions related to "Variations and the valuation of such instructions". Then there are other clauses which state that "the engineer and the contractor must endeavour to agree a price before the contractor carries out an instruction". Further clauses though set out the Engineer's power to determine the value of work if no agreement can be reached.
- 4.1.1 Can the contractor insist on agreement on price before carrying out the work? (5 Marks)
- 4.1.2 Can the Engineer claim extra fees for looking at claims? Explain. (5 Marks)
- 4.1.3 Is the contractor obliged to stick to a low rate in the bill of quantities if the amount of work is substantially increased? Explain. (5 Marks)
- 4.2 The contractor put in a very high rate for an item of which there were only 3no. in the bills of quantities and it was subsequently found necessary to instruct over 200no. of these items. Would the quantity surveyor / Engineer be in order to reduce the unit rate? Explain. (5 Marks)

**[Total: 20 Marks]**

## Question Five

In the JBCC and the Blue book (General Conditions of Contract for Civil Engineers), three types of sub-contractors are mentioned. The (1) nominated sub-contractor, (2) selected subcontractor and (3) domestic subcontractor.

- 5.1 If the contractor is in financial trouble, can the employer pay the sub-contractors directly? Explain what would happen in each case of the subcontractors.

(5+5+5 = 15 Marks)

- 5.2 Is the employer entitled to hold retention against future defects after the end of the rectification period? Explain.

(5 Marks)

**[Total: 20 Marks]**

## Question Six

In *Balfour Beatty Construction Ltd vs The Mayor and Burgesses of the London Borough of Lambeth*, 136 there were references to the use of programs for estimating extensions of time. As part of its submission to the adjudicator, the contractor referred to the 'most widely recognised and used' delay analysis methods:

- i. Time Impact Analysis (or 'time slice' or 'snapshot' analysis). This method is used to map out the impacts of particular delays at the point in time at which they occur permitting the discrete effects of individual events to be determined.
- ii. Window analysis. For this method the programme is divided into consecutive time 'windows' where the delay occurring in each window is analysed and attributed to the events occurring in that window.
- iii. Collapsed as-built. This method is used so as to permit the effect of events to be 'subtracted' from the as-built programme to determine what would have occurred but for those events.
- iv. Impacted plan where the original programme is taken as the basis of the delay calculation, and delay faults are added into the programme to determine when the work should have finished as a result of those delays.
- v. Global assessment. This is not a proper or acceptable method to analyse delay.

The need to take into account revisions to the programme was recognised in the Balfour Beatty case where the court said that, for the contractor to challenge an extension of time:

*... the foundation must be the original programme (if capable of justification and substantiation to show its validity and reliability as a contractual starting point) and its success will similarly depend on the soundness of its revisions on the*

*occurrence of every event, so as to be able to provide a satisfactory and convincing demonstration of cause and effect.*

- 6.1 You are the Engineer /Architect / Quantity Surveyor: Explain what would satisfy the Adjudicator on the best method for extensions of time consideration.

(10 Marks)

- 6.2 Choose any Condition of Contract you are familiar with in responding to this question. If the Engineer / Architect does not receive all the delay information required until a week before the date for completion, must the extension of time still be granted before the completion date? Explain.

(10 Marks)

**[Total: 20 Marks]**

### **Question Seven**

- 7.1 The contractor is running over time. The employer wishes to terminate, but the architect has over-certified. Explain how this situation should be handled professionally taking all possibilities into consideration.

(10 Marks)

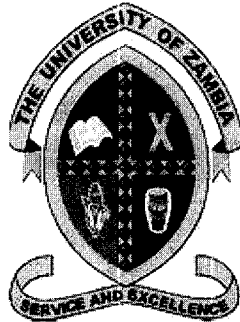
- 7.2 Is there any time limit for the employer to terminate after the Engineer / architect / Project Manager has issued a default notice?

(5 Marks)

- 7.3 The employer has terminated, but the contractor refuses to leave site, saying that it is entitled to stay until paid in full. As an Engineer /Architect /Project Manager, advise the client how his contractual obligation in this matter.

(5 Marks)

**[Total: 20 Marks]**



**THE UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING**

**MEng – PROJECT MANAGEMENT  
PROJECT RISK AND QUALITY MANAGEMENT  
CEE 6772 – EXAMINATION**

**FRIDAY 17<sup>TH</sup> DECEMBER 2021 - 14:00 - 17:00 HRS**

**TIME ALLOWED IS THREE (3) HOURS**

**INSTRUCTIONS TO CANDIDATES:**

1. Check that you have the CORRECT examination paper in front of you
2. There are THREE (3) sections to this examination. CHECK for instructions under each Section
3. Begin each question on a NEW PAGE
4. Except for calculators, NO books, files, or mechanical/electronic aids are permitted
5. There shall be no ANY form of communication between students during the examination

**DO NOT TURN THIS PAGE UNTIL YOU ARE TOLD TO DO SO**

**SECTION A – Answer All Questions**

**[20 Marks]**

1. Which of the following statements is true about operational risks?
  - a. Operational risk relates to board and management performance with regard to ethics, community stewardship, and company reputation
  - b. Operational risk result from errors in strategy, such as choosing a technology that can't be made to work
  - c. Operational risk includes risks from poor implementation and process problems such as procurement, production, and distribution
  - d. Operational risk include competition, foreign exchange, commodity markets, and interest rate risk, as well as liquidity and credit risks.
2. There are many factors both internally and externally that can affect an organization's risk appetite. Which of the following is not an external factor?
  - a. Market maturity
  - b. Financial stability
  - c. Competition
  - d. Technological breakthroughs
3. Which of the following is not a function for an individual having responsibility for a project reserve?
  - a. Review and approve the reserve estimates and their underlying assumptions
  - b. Approve the transfer of reserve amounts
  - c. Monitor the status of the reserves and their rate of usage; develop project cost control reports to aid in this analysis.
  - d. Participate in estimating the time which may be required to complete the total project or a specific segment of the project.
4. Control measures are the things you put in place to reduce risk and prevent harm. Control measures may include; except?
  - a. Treatments
  - b. Limitations
  - c. Methods
  - d. Arrangements
5. Joseph M. Juran ranks near Deming in the contributions he has made to quality and the recognition he has received as a result. Juran is best known for the following contributions to the quality philosophy; except?
  - a. Quality Cycles
  - b. Trilogy

- c. Pareto Principle
  - d. Basic steps to progress
6. Which of the following is not a major process of project quality management?
- a. Quality management planning
  - b. Quality assurance
  - c. Quality control
  - d. Continual improvement
7. Which of the following is not a key element of leadership for quality?
- a. Obsession with quality
  - b. Rewarding performing team members
  - c. Looking for faults in systems
  - d. Emphasizing on peak performance
8. Inhibitors to statistical process control include?
- a. Capability in statistics, misdirected responsibility, low production rates
  - b. Capability in statistics, internal focus, low production rates
  - c. Capability in statistics, misdirected responsibility, internal focus
  - d. Internal focus, misdirected responsibility, low production rates
9. Which is true about war-gaming?
- a. helps companies assess major changes in one or two specific variables whose effects would be major and immediate, although the exact timing is not forecastable
  - b. is suited for long-range analysis, typically five to 10 years out
  - c. assesses a firm's vulnerability to disruptive technologies or changes in competitors' strategies
  - d. is a systematic process for defining the plausible boundaries of future states of the world
10. Quality planning involves developing the products, systems, and processes needed to meet or exceed customer expectations. The following steps are required, except?
- a. Compare performance with goals
  - b. Determine who the customers are
  - c. Identify customers' needs
  - d. Develop products with features that respond to customer needs.

**SECTION B – *There is one (1) Compulsory Question*****[20 Marks]**

Consider the following case and answer the questions that follow;

| Reasons                       | No. of observations |
|-------------------------------|---------------------|
| Don't know about the product  | 15                  |
| Don't drink in winters        | 111                 |
| Unavailable in area           | 65                  |
| Don't trust the product       | 12                  |
| Unhealthy                     | 85                  |
| Taste not good                | 10                  |
| Unattractive packaging        | 20                  |
| Price too high                | 45                  |
| supply chain conundrum        | 5                   |
| No sufficient unique value    | 3                   |
| Product is inferior to others | 4                   |

**QUESTIONS (*Section B - Please Answer ALL*):**

1. What is the value of the Pareto Principle for a project manager? [4]
2. What is the cumulative count percentage for each reason in the case provided? [3]
3. Demonstrate the relative significance within each group of results? [3]
4. Establish the priority list for improvement actions? [4]
5. Discuss the applications of the Pareto Principle in quality control? [6]

**SECTION C – *There are Six (6) Optional Questions (Answer any 4)***

**[60 Marks]**

**QUESTION 1. [15 Marks]**

- A. What are the three dimensions of an effective project risk management? [3]
- B. Discuss the steps involved in the preparation phase for Statistical Process Control? [6]
- C. Detail the types and causes of reputational risk? [6]

**QUESTION 2. [15 Marks]**

- A. What are the objectives of reserve analysis? [3]
- B. Discuss the approaches that a quality manager can use to carry out his/her responsibility? [9]
- C. List the three categories of risks for creating an effective risk-management system? [3]

**QUESTION 3. [15 Marks]**

- A. List Deming's seven deadly diseases? [7]
- B. Discuss the quality characteristics that relate to the attributes, measures and methods attached to a particular project? [8]

**QUESTION 4. [15 Marks]**

- A. What are the various response strategies that can be applied to address overall project risk? [10]
- B. Discuss the leadership techniques that leaders can use to inspire others to commit to organization's vision, mission, and goals? [5]

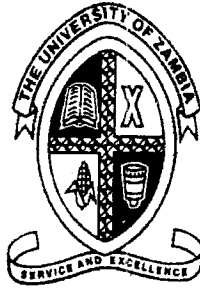
**QUESTION 5. [15 Marks]**

- A. Explain the importance of cultivating a risk culture in an organization? [4]
- B. Discuss the rationale for benchmarking? [7]
- C. Distinguish the four types of Quality-related costs? [4]

**QUESTION 6. [15 Marks]**

- A. Explain the benefits of enterprise risk management (ERM)? [4]
- B. List the elements of an organization's quality culture? [5]
- C. Discuss the effects of cognitive biases when managing risk? [6]

\_\_\_\_\_THE END\_\_\_\_\_



# THE UNIVERSITY OF ZAMBIA

## SCHOOL OF ENGINEERING

Department of Electrical and Electronic Engineering

### **EEE 5240: Dynamic Systems and Control Engineering**

FINAL EXAM – NOVEMBER 2021

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**TIME** : Three (3) hours

**INSTRUCTIONS** : Answer at least two (2) from **Section A** and at least two (2) from **Section B** plus one (1) from either section. Use **SEPARATE ANSWER BOOKLETS** for each section.

**ADDITIONAL INFORMATION** : *All Questions Carry Equal Marks (i.e. 20 marks)*

---

## Section A (Answer at least two (2) questions)

### Question 1

1. Find a linear expression to the function

$$y(r, \theta) = 3r \sin \theta + r^2 \theta + 2$$

valid near the operating point  $(r, \theta) = (1, \pi/2)$

[6 marks]

2. Off-road vehicles experience many disturbance inputs as they traverse over rough roads. An active suspension system can be controlled by a sensor that looks "ahead" at the road conditions. An example of a simple suspension system that can accommodate the bumps is shown in Fig. Q2-1

(i) Draw the signal flow graph "SFG" corresponding to the block diagram.

[2 marks]

(ii) Find the appropriate gain  $K_1$  so that the vehicle does not bounce when the desired deflection is  $R(s) = 0$  and the disturbance is  $T_d(s)$ .

[6 marks]

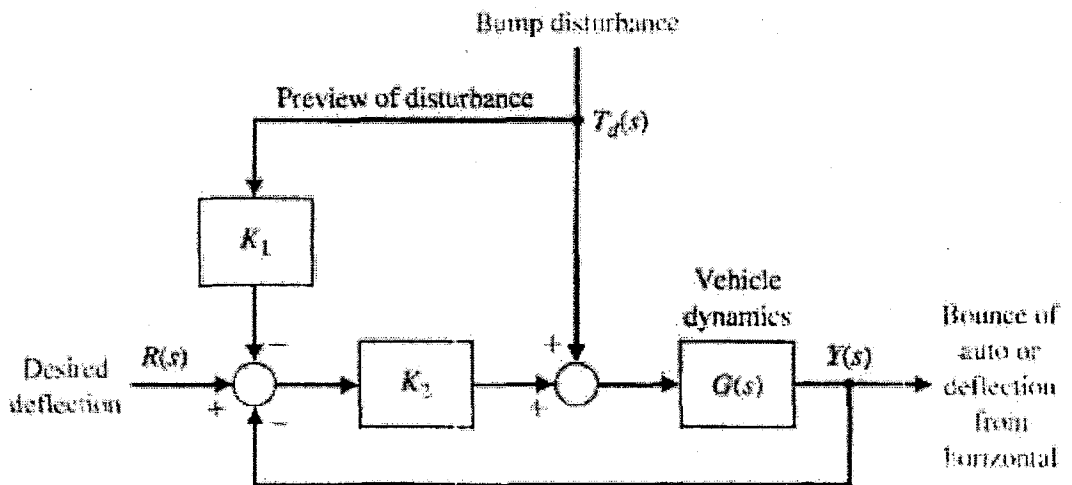


Fig.Q1-1 : Active suspension system.

3. Use block diagram reduction techniques to determine an expression for the transfer function of the system shown in Fig.Q1-2. [6 marks]

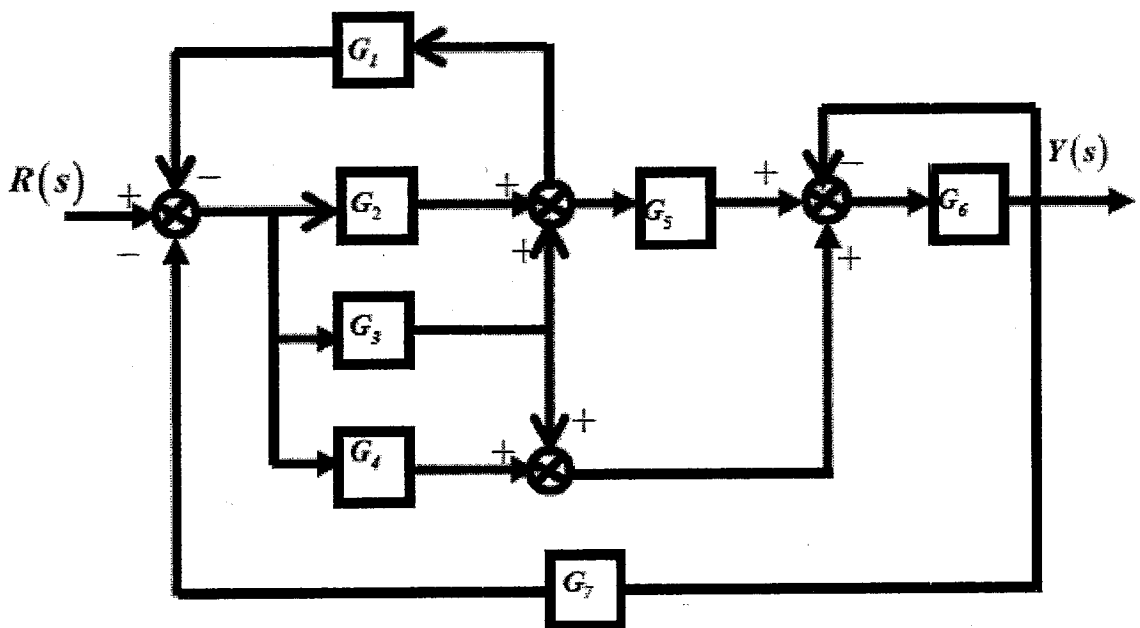


Fig.Q1-2

## Question 2

1. For the systems whose open loop-transfer function are shown below

$$G_1(s) = \frac{4}{(s+1)(s+2)} \quad \text{and} \quad G_2(s) = \frac{2}{s(s+4)(s+6)}$$

- (i). Determine for each system the position, velocity and acceleration error constants

[3 marks]

- (ii). For the system number two,  $G_2(s)$ , determine the steady-state errors to unit step

input, ramp input,  $r(t) = t$ , and to parabolic input  $r(t) = \frac{1}{2}t^2$

[6 marks]

2. Consider the armature-controlled dc motor system that is shown in Fig.Q2.

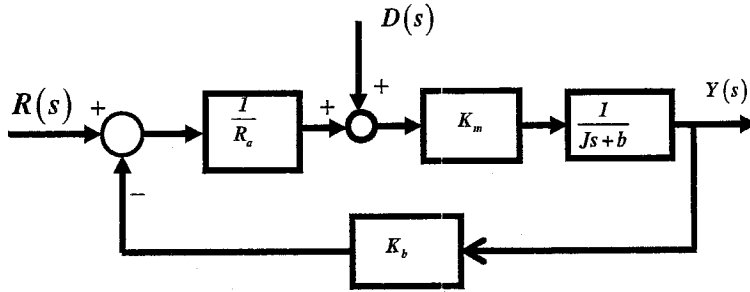


Fig.Q2

- (i). Find the transfer function  $T_I(s)$  from input  $R(s)$  to output  $Y(s)$  for  $D(s)=0$ .

[2 marks]

- (ii). Find the sensitivity of this transfer function to changes in the parameter  $J$ .

[2 marks]

- (iii). Find the sensitivity of this transfer function to changes in the parameter  $K_m$ .

[4 marks]

- (iv). Using the expression of the transfer function  $T_I(s)$  find the steady state error when the ramp input  $r(t)$  is applied..

[3 marks]

### Question 3

For the control system configuration shown in Fig.Q.3, let

$$KG(s) = K \frac{(s-1)(s-2)}{(s+1)(s+2)}$$

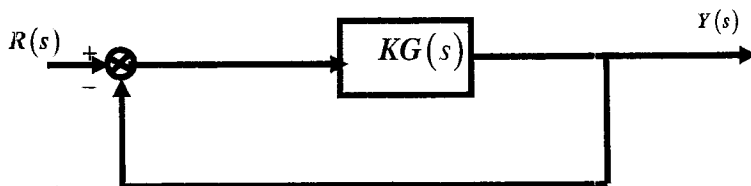


Fig.Q3

- (i). Sketch root locus, showing its direction, where  $K=0$ , and where  $K$  is infinity

[10 marks]

(ii). Find the range of gain  $K$  for closed loop control system stability. [4 marks]

(iii) Apply angle criteria to determine whether  $-1+j1$  lies on the root locus. [6 marks]

#### **Question 4**

The gain-phase plot/ Nichols chart for an open-loop transfer function  $G(j\omega)/K$  of a unit-feedback control system is shown in Fig. Q.4. For  $K=1$ , find approximately the following performance characteristics of the system.

- |       |                                                     |           |
|-------|-----------------------------------------------------|-----------|
| (i)   | Gain-crossover frequency (rad/sec)                  | [2 marks] |
| (ii)  | Phase-crossover frequency (rad/sec)                 | [2 marks] |
| (iii) | Gain margin                                         | [3 marks] |
| (iv)  | Phase margin (deg)                                  | [3 marks] |
| (v)   | Maximum magnitude/resonance peak, $M_{p\omega_r}$ . | [3 marks] |
| (vi)  | Resonant frequency $\omega_r$ (rad/sec) .           | [3 marks] |
| (vii) | Band width of the closed-loop system                | [4 marks] |

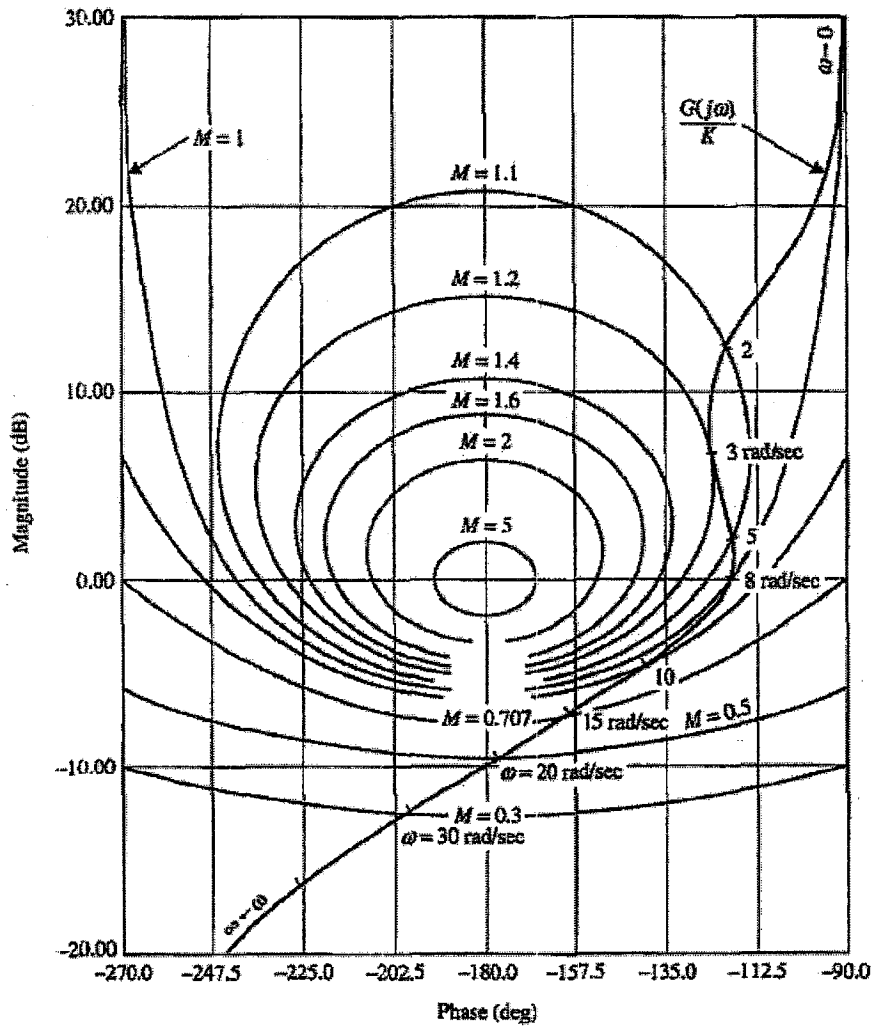


Fig.Q4

## Section B (Answer at least two (2) questions)

### Question 1

(i) Consider the system defined by

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -6 & -8 & -5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u$$

$$y = [1 \quad 0 \quad 0] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

Assume that the output can be accurately measured.

Design a minimum order observer assuming that the desired Eigen values are:

$$s_1 = -2 + j2\sqrt{3}, \quad s_2 = -2 - j2\sqrt{3}$$

[10]

(ii) Find the solution of

$$y(k+2) - 3y(k+1) + 2y(k) = r(k)$$

Where  $r(k) = 3^k, y(0) = 0, y(1) = 1$

[5]

(iii) Consider the system below represented by a differential equation with input  $k$  and output  $z$ ;

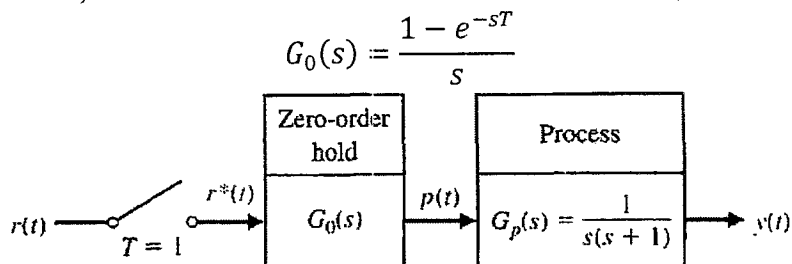
$$\frac{d^3 z}{dt^3} + 7 \frac{d^2 z}{dt^2} + 19 \frac{dz}{dt} + 13z = 13 \frac{dk}{dt} + 26k$$

Obtain the state space representation of the system.

[5]

### Question 2

(i) Consider the system shown in the figure below for  $T = 1$ . The transfer function of the zero-order hold is;



For  $T = 1$ , obtain the response of this system to a unit impulse (at least three (3) sampling instants).

[10]

(ii) For  $x_1(t)$  and  $x_2(t)$  of the system described by

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -3 & -2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Where the initial conditions are

$$\begin{bmatrix} x_1(0) \\ x_2(0) \end{bmatrix} = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

[8]

(iii) Consider the system described by

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ -2 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Is this system controllable and observable?

[2]

### Question 3

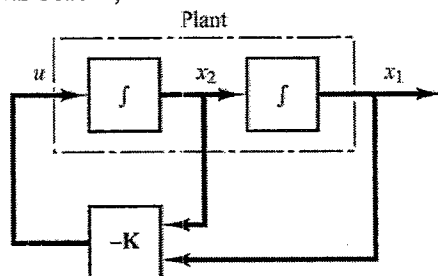
(i) Consider the plant transfer function;

$$G_p(z) = \frac{0.0004(z + 0.2)(z + 2.8)}{(z - 1)^2(z - 0.28)}$$

Design a dead-beat controller for a unit step input. After how many sampling instances does the output follow the input?

[10]

(ii) Consider the system shown below;



Assume the control signal to be;

$$u(t) = -\mathbf{K}\mathbf{x}(t)$$

Determine the optimal feedback gain matrix  $\mathbf{K}$  such that the following performance index is minimized:

$$\int_0^{\infty} (\mathbf{x}^T \mathbf{Q} \mathbf{x} + u^2) dt$$

Where;

$$\mathbf{Q} = \begin{bmatrix} 1 & 0 \\ 0 & \mu \end{bmatrix}$$

[6]

(iii) Consider the system given by;

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -25 & -4 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

Obtain the transfer function of the system.

[4]

#### Question 4

- (i) Using the pole-placement-with-observer approach, design the control system shown in Figure Q4.1. Assume that the desired closed-loop poles for the pole placement are located at

$$s = -2 + j\sqrt{2}, s = -2 - j\sqrt{2}$$

and the desired observer poles are located at

$$s = -10, s = -10$$

Obtain the transfer function of the observer controller. [NB: determine the constant  $N$  so that the steady-state output  $y(\infty)$  is unity when the input is a unit-step input.]

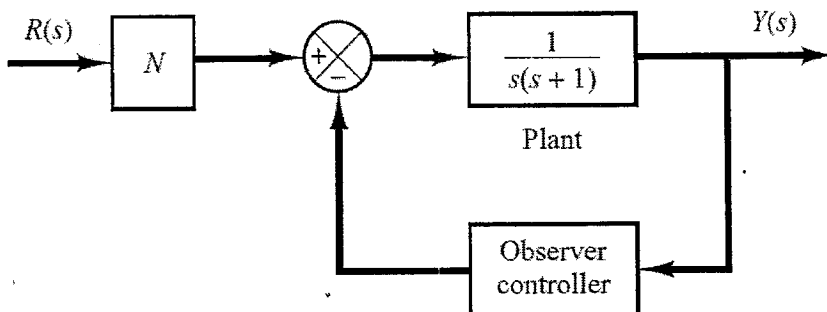


Figure Q4.1

[10]

(ii) Given the characteristic equation

$$P(z) = z^4 - 1.2z^3 + 0.07z^2 + 0.3z - 0.08 = 0$$

Determine the stability of the system using the *Jury* test.

[8]

(iii) Define the concept of *state* of a dynamic system.

[2]

**THE END**

## Appendix

FORMULA/INFO SHEET: Given a function  $F(s)$ , the Cauchy Principle of the Argument states that  $Z=N+P$ , where  $Z$  and  $P$  are the number of zeros and poles, respectively, of  $F(s)$  enclosed by an arbitrary clockwise  $s$ -plane contour. This contour must not pass through any of the poles or zeros of  $F(s)$ .  $N$  = the number of clockwise encirclements of the origin of the  $F(s)$  plane made as  $s$  takes values along the CW  $s$ -plane contour.

Initial Value Theorem:  $f(0) = \lim_{s \rightarrow \infty} sF(s)$

Final Value Theorem:  $f(\infty) = \lim_{s \rightarrow 0} sF(s)$

$$Laplace\left\{\frac{df}{dt}\right\} = sF(s) - f(0) \qquad Laplace\left\{\frac{d^2f}{dt^2}\right\} = s^2F(s) - sf(0) - f'(0)$$

Time Delay Theorem: If  $F(s)$  is Laplace trans of  $f(t)u(t)$ , then Laplace trans of  $f(t - t_0)u(t - t_0)$  is  $e^{-st_0}F(s)$

|                           |                                                                                          |                                                   |                                                      |
|---------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------|------------------------------------------------------|
| <u>f(t)</u>               | <u>F(s)</u>                                                                              | <u>f(t)</u>                                       | <u>F(s)</u>                                          |
| $u(t) \text{ or } 1(t)$   | $\frac{1}{s}$                                                                            | $te^{-at}u(t)$                                    | $\frac{1}{(s+a)^2}$                                  |
| $tu(t) \text{ or } t1(t)$ | $\frac{1}{s^2}$                                                                          | $2 M e^{-\sigma t} \cos(\omega t + \phi)u(t)$     |                                                      |
|                           | $\frac{ M e^{j\phi}}{s + \sigma - j\omega} + \frac{ M e^{-j\phi}}{s + \sigma + j\omega}$ |                                                   |                                                      |
| $e^{-at}u(t)$             | $\frac{1}{s+a}$                                                                          | $(\cos \omega t)u(t)$                             | $\frac{s}{s^2 + \omega^2}$                           |
| $(\sin \omega t)u(t)$     | $\frac{\omega}{s^2 + \omega^2}$                                                          | Note: $u(t) \equiv 1(t)$ , the unit step function |                                                      |
| $R(s)$                    | $G(s)$                                                                                   | $C(s)$                                            | $T_c(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)}$ |
|                           | $H(s)$                                                                                   |                                                   |                                                      |

Root locus angle condition: The phase of GH equals  $180^\circ$ ,  $r$  is a positive or negative odd integer.  
Root locus construction rules:

### Root locus construction rules:

1. The root locus is symmetrical about the real axis of the s-plane.
2. The root locus on the real axis is found to the left of an odd number of real poles and zeros of GH.
3. The branches of the root locus begin at the poles of GH, and they terminate at the zeros of GH.

4. The points at which the root locus breaks away from and enters to the real axis can be determined by finding the maximum and minimum points of the gain  $K$  as a function of  $s$  with  $s$  restricted to real values.

5. Angle of asymptote:  $\theta_l = \frac{(1+2l)(180^\circ)}{p_{ex}}, l = 0, 1, \dots, p_{ex} - 1$       Origin      of

asymptote:  $\sigma_i = \frac{\sum_{i=1}^n \text{Re}(p_i) - \sum_{i=1}^m \text{Re}(z_i)}{p_{ex}}$

where  $p_{ex}$  is the pole-zero excess (# poles - # zeros) of GH.

Steady state errors:  $e_{ss\text{step}} = \frac{1}{1+K_p} = 1 - T_c(0), K_p = \lim_{s \rightarrow 0} G(s)H(s)$  ;

$e_{ss\text{ramp}} = \frac{1}{K_v}, K_v = \lim_{s \rightarrow 0} sG(s)H(s)$

For a second order system,  $\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}, t_p = \frac{\pi}{\omega_n \sqrt{1-\zeta^2}}, PO = 100e^{-\zeta\pi/\sqrt{1-\zeta^2}}$

The Nyquist Stability Criterion (based upon Cauchy's Principle of the Argument): Given that  $F(s)=1+G(s)H(s)$ ,  $Z=N+P$ , where the clockwise  $s$ -plane contour encloses the complete right half plane (RHP). Thus,  $Z$  = the number of RHP zeros of  $1+G(s)H(s)$ ,  $P$  = the number of RHP poles of  $1+G(s)H(s)$  (this is the same as the number of RHP poles of  $G(s)H(s)$ ), and  $N$  = the number of clockwise encirclements of  $-1$  made by the Nyquist diagram (in the complex  $G(s)H(s)$  plane). Note that  $Z$  is equivalently the number of RHP poles of the closed loop transfer function, and  $Z$  must equal zero for closed loop system stability.

Bode lag compensator design equations:  $\omega_0 = 0.1\omega_d$ , where  $\omega_d$  is the desired zero dB gain crossover frequency (based upon the phase margin specification), and  $\omega_p = \frac{\omega_0}{K|G(j\omega_d)|}$ ,

where gain  $K$  is selected to satisfies a steady state accuracy specification.

## Linear algebra

Determinant of a 2x2 matrix

$$|A| = \begin{vmatrix} a & b \\ c & d \end{vmatrix} = ad - bc$$

Determinant of a 3x3 matrix

$$|A| = \begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} = a \begin{vmatrix} e & f \\ h & i \end{vmatrix} - b \begin{vmatrix} d & f \\ g & i \end{vmatrix} + c \begin{vmatrix} d & e \\ g & h \end{vmatrix}$$

Inverse of a 2x2 matrix

$$A^{-1} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}^{-1} = \frac{1}{\det A} \begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$$

Controllability matrix

$$[B \mid AB \mid \dots \mid A^{n-1}B]$$

Output controllability

$$[CB \mid CAB \mid CA^2B \mid \dots \mid CA^n]$$

Observability matrix

$$[C^* \mid A^*C^* \mid \dots \mid (A^*)^{n-1}C^*]$$

State feedback gain matrix

Using the desired eigenvalues (desired closed-loop poles), write the desired characteristic polynomial:

$$(s - \mu_1)(s - \mu_2) \dots (s - \mu_n) = s^n + \alpha_1 s^{n-1} + \dots + \alpha_{n-1} s + \alpha_n$$

and determine the values of

$$\alpha_1, \alpha_2, \dots, \alpha_n.$$

The required state feedback gain matrix  $K$  can be determined from Equation

$$K = [\alpha_n - a_n \mid \alpha_{n-1} - a_{n-1} \mid \dots \mid \alpha_2 - a_2 \mid \alpha_1 - a_1] T^{-1}$$

Ackerman's formula

$$\phi(\tilde{A}) = \tilde{A}^n + \alpha_1 \tilde{A}^{n-1} + \dots + \alpha_{n-1} \tilde{A} + \alpha_n I = 0$$

$K$

$$= [0 \ 0 \ \dots \ 0 \ 1][B \mid AB \mid \dots \mid A^{n-1}B]^{-1} \phi(\tilde{A})$$

Full state observer

$$\dot{\hat{x}} = (A - K_e C)\hat{x} + Bu + K_e y$$

Minimum order observer

$$\begin{bmatrix} \dot{\hat{x}}_a \\ \dot{\hat{x}}_b \end{bmatrix} = \begin{bmatrix} A_{aa} & A_{ab} \\ A_{ba} & A_{bb} \end{bmatrix} \begin{bmatrix} \hat{x}_a \\ \hat{x}_b \end{bmatrix} + \begin{bmatrix} B_a \\ B_b \end{bmatrix} u$$

$$y = [1 \ 0] \begin{bmatrix} \hat{x}_a \\ \hat{x}_b \end{bmatrix}$$

where  $A_{aa}$  = scalar

$A_{ab} = 1 \times (n-1)$  matrix

$A_{ba} = (n-1) \times 1$  matrix

$A_{bb} = (n-1) \times (n-1)$  matrix

$B_a$  = scalar

$B_b = (n-1) \times 1$  matrix

$$\ddot{\eta} = (A_{bb} - K_e A_{ab})\ddot{\eta} + [(A_{bb} - K_e A_{ab})K_e + A_{ba} - K_e A_{aa}]y + (B_b - K_e B_a)u$$

Canonical forms

Consider the system defined by;

$$\begin{aligned} {}^{(n)}y + a_1 {}^{(n-1)}y + \dots + a_{n-1} \dot{y} + a_n y &= b_0 u \\ &+ b_1 u^{(n-1)} + \dots + b_{n-1} \dot{u} + b_n u \end{aligned}$$

With transfer function;

$$\frac{Y(s)}{U(s)} = \frac{b_0 s^n + b_1 s^{n-1} + \dots + b_{n-1} s + b_n}{s^n + a_1 s^{n-1} + \dots + a_{n-1} s + a_n}$$

Controllable canonical form

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \vdots \\ \dot{x}_{n-1} \\ \dot{x}_n \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 1 \\ -a_n & -a_{n-1} & -a_{n-2} & \dots & -a_1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n-1} \\ x_n \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{bmatrix} u$$

$$y = [b_n - a_n b_0 \mid b_{n-1} - a_{n-1} b_0 \mid \dots \mid b_1 - a_1 b_0] \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n-1} \\ x_n \end{bmatrix} + b_0 u$$

Observable canonical form

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \vdots \\ \dot{x}_{n-1} \\ \dot{x}_n \end{bmatrix} = \begin{bmatrix} 0 & 0 & \dots & 0 & -a_n \\ 1 & 0 & \dots & 0 & -a_{n-1} \\ 0 & 1 & \dots & 0 & -a_{n-2} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & 1 & -a_1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n-1} \\ x_n \end{bmatrix} + \begin{bmatrix} b_n - a_n b_0 \\ b_{n-1} - a_{n-1} b_0 \\ \vdots \\ b_2 - a_2 b_0 \\ b_1 - a_1 b_0 \end{bmatrix} u$$

$$y = [0 \ 0 \ \dots \ 1] \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n-1} \\ x_n \end{bmatrix} + b_0 u$$

The transfer function of the observer controller;

$$\frac{U(s)}{Y(s)} = -K(sI - A + K_e C + BK)^{-1} K_e$$

The reduced matrix Riccati equation

$$A^T P + PA - PBR^{-1}B^T P + Q = 0$$

State transition matrix

$$\Phi(t) = e^{At} = \mathcal{L}^{-1}[(sI - A)^{-1}]$$

$$G^k = Z^{-1}[(ZI - G)^{-1}Z]$$

Solution of homogenous state equation

$$x(t) = \Phi(t)x(0)$$

Solution of nonhomogeneous state equation

$$\begin{aligned} x(t) &= e^{At}x(0) + \int_0^t e^{A(t-\tau)}Bu(\tau)d\tau \\ x(k) &= G^k x(0) + \sum_{j=1}^{k-1} G^{k-j-1}Hu(j) \end{aligned}$$

Response to a unit step input of  $k$ ;

$$x(t) = e^{At}x(0) + A^{-1}(e^{At} - I)Bk$$

Properties of the state transition matrix;

1.  $\Phi(0) = e^{A0} = I$
2.  $\Phi(t) = e^{At} = (e^{-At})^{-1} = [\Phi(-t)]^{-1}$  or  $\Phi^{-1}(t) = \Phi(-t)$
3.  $\Phi(t_1 + t_2) = e^{A(t_1+t_2)} = e^{At_1}e^{At_2} = \Phi(t_1)\Phi(t_2) = \Phi(t_2)\Phi(t_1)$
4.  $[\Phi(t)]^n = \Phi(nt)$
5.  $\Phi(t_2 - t_1)\Phi(t_1 - t_0) = \Phi(t_2 - t_0) = \Phi(t_1 - t_0)\Phi(t_2 - t_1)$

### The Jury Stability Test:

$$P(z) = a_0 z^n + a_1 z^{n-1} + \dots + a_{n-1} z + a_n$$

| Row      | $z^0$     | $z^1$     | $z^2$     | $z^3$     | $\dots$  | $z^{n-2}$ | $z^{n-1}$ | $z^n$    |
|----------|-----------|-----------|-----------|-----------|----------|-----------|-----------|----------|
| 1        | $a_n$     | $a_{n-1}$ | $a_{n-2}$ | $a_{n-3}$ | $\dots$  | $a_2$     | $a_1$     | $a_0$    |
| 2        | $a_0$     | $a_1$     | $a_2$     | $a_3$     | $\dots$  | $a_{n-2}$ | $a_{n-1}$ | $a_n$    |
| 3        | $b_{n-1}$ | $b_{n-2}$ | $b_{n-3}$ | $b_{n-4}$ | $\dots$  | $b_1$     | $b_0$     |          |
| 4        | $b_0$     | $b_1$     | $b_2$     | $b_3$     | $\dots$  | $b_{n-2}$ | $b_{n-1}$ |          |
| 5        | $c_{n-2}$ | $c_{n-3}$ | $c_{n-4}$ | $c_{n-5}$ | $\dots$  | $c_0$     |           |          |
| 6        | $c_0$     | $c_1$     | $c_2$     | $c_3$     | $\dots$  | $c_{n-2}$ |           |          |
| $\vdots$ | $\vdots$  | $\vdots$  | $\vdots$  | $\vdots$  | $\vdots$ | $\vdots$  | $\vdots$  | $\vdots$ |
| $2n-5$   | $p_3$     | $p_2$     | $p_1$     | $p_0$     |          |           |           |          |
| $2n-4$   | $p_0$     | $p_1$     | $p_2$     | $p_3$     |          |           |           |          |
| $2n-3$   | $q_2$     | $q_1$     | $q_0$     |           |          |           |           |          |

$$b_k = \begin{vmatrix} a_n & a_{n-1-k} \\ a_0 & a_{k+1} \end{vmatrix}, k = 0, 1, 2, \dots, n-1$$

$$c_k = \begin{vmatrix} b_{n-1} & b_{n-2-k} \\ b_0 & b_{k+1} \end{vmatrix}, k = 0, 1, 2, \dots, n-2$$

$\vdots$

$$q_k = \begin{vmatrix} p_3 & p_{2-k} \\ p_0 & p_{k+1} \end{vmatrix}, k = 0, 1, 2$$

Stability criterion by the Jury Test: A system with the characteristic equation  $P(z) = 0$  rewritten as  $P(z) = a_0 z^n + a_1 z^{n-1} + \dots + a_{n-1} z + a_n$  where  $a_0 > 0$ , is stable if the following conditions are all satisfied:

1.  $|a_n| < a_0$
2.  $P(z)|_{z=1} > 0$
3.  $P(z)|_{z=-1} \begin{cases} > 0 \text{ for } n \text{ even} \\ < 0 \text{ for } n \text{ odd} \end{cases}$
4.  $|b_{n-1}| > |b_0|$   
 $|c_{n-2}| > |c_0|$

$\vdots$

$$|q_2| > |q_0|$$

**Deadbeat response design when the system poles and zeros are inside the unit circle**

Design criteria:

1. The system must have a zero steady state error at sampling instants.
2. The time to reach final output must be finite and minimum.
3. The controller should be physically realizable, i.e., it should be causal.

$$D_c(z) = \frac{1}{G_p(z)} = \frac{M(z)}{1 - M(z)}$$

Thus, if  $G_p(z)$  does not have poles or zeros outside the unit circle, then  $M(z)$  should have the following forms;

1. Step input:

$$R(z) = \frac{z}{z-1}$$

$$M(z) = \frac{1}{z^n}$$

2. Ramp input:

$$M(z) = \frac{(n+1)z - n}{z^{n+1}}$$

**Deadbeat response design when some of the poles and zeros are on or outside the unit circle**

Let the plant transfer function be;

$$G_p(z) = \frac{\prod_{i=1}^K (1 - z_i z^{-1})}{\prod_{j=1}^L (1 - p_j z^{-1})} B(z)$$

where,  $K$  and  $L$  are the number of zeros and poles on or outside the unit circle and  $B(z)$  is a rational transfer function in  $z^{-1}$  with poles and zeros inside the unit circle. This implies;

$$D_c(z) = \frac{\prod_{j=1}^L (1 - p_j z^{-1})}{\prod_{i=1}^K (1 - z_i z^{-1})} \frac{M(z)}{B(z)(1 - M(z))}$$

Since we should not cancel poles or zeros which are on or outside unit circle by the

controller  $D_c(z)$ , we have to choose  $M(z)$  such that these get canceled out.

$$M(z) = \prod_{i=1}^K (1 - z_i z^{-1}) (m_k z^{-k} + m_{k+1} z^{-k-1} + \dots)$$

$$1 - M(z) = \prod_{j=1}^L (1 - p_j z^{-1}) (1 - z^{-1})^P (1 + a_1 z^{-1} + a_2 z^{-2} + \dots)$$

$P$  equals either the order of the poles of  $R(z)$  or the order of poles of  $G_p(z)$  at  $z = 1$  which ever is greater. Truncation depends on the following.

1. The order of poles of  $M(z)$  and  $(1 - M(z))$  must be equal.
2. Total number of unknowns must be equal to the order of  $M(z)$  so that they can be solved independently.

**Table of Laplace and Z-transforms**

|     | $X(s)$                              | $x(t)$                  | $x(kT)$ or $x(k)$                                          | $X(z)$                                                                                       |
|-----|-------------------------------------|-------------------------|------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| 1.  | —                                   | —                       | Kronecker delta $\delta_0(k)$<br>1 $k = 0$<br>0 $k \neq 0$ | 1                                                                                            |
| 2.  | —                                   | —                       | $\delta_0(n-k)$<br>1 $n = k$<br>0 $n \neq k$               | $z^{-k}$                                                                                     |
| 3.  | $\frac{1}{s}$                       | $1(t)$                  | $1(k)$                                                     | $\frac{1}{1-z^{-1}}$                                                                         |
| 4.  | $\frac{1}{s+a}$                     | $e^{-at}$               | $e^{-akT}$                                                 | $\frac{1}{1-e^{-aT}z^{-1}}$                                                                  |
| 5.  | $\frac{1}{s^2}$                     | $t$                     | $kT$                                                       | $\frac{Tz^{-1}}{(1-z^{-1})^2}$                                                               |
| 6.  | $\frac{2}{s^3}$                     | $t^2$                   | $(kT)^2$                                                   | $\frac{T^2 z^{-1} (1+z^{-1})}{(1-z^{-1})^3}$                                                 |
| 7.  | $\frac{6}{s^4}$                     | $t^3$                   | $(kT)^3$                                                   | $\frac{T^3 z^{-1} (1+4z^{-1}+z^{-2})}{(1-z^{-1})^4}$                                         |
| 8.  | $\frac{a}{s(s+a)}$                  | $1 - e^{-at}$           | $1 - e^{-akT}$                                             | $\frac{(1-e^{-aT})z^{-1}}{(1-z^{-1})(1-e^{-aT}z^{-1})}$                                      |
| 9.  | $\frac{b-a}{(s+a)(s+b)}$            | $e^{-at} - e^{-bt}$     | $e^{-akT} - e^{-bkT}$                                      | $\frac{(e^{-aT} - e^{-bT})z^{-1}}{(1-e^{-aT}z^{-1})(1-e^{-bT}z^{-1})}$                       |
| 10. | $\frac{1}{(s+a)^2}$                 | $te^{-at}$              | $kTe^{-akT}$                                               | $\frac{Te^{-aT}z^{-1}}{(1-e^{-aT}z^{-1})^2}$                                                 |
| 11. | $\frac{s}{(s+a)^2}$                 | $(1-at)e^{-at}$         | $(1-akT)e^{-akT}$                                          | $\frac{1-(1+aT)e^{-aT}z^{-1}}{(1-e^{-aT}z^{-1})^2}$                                          |
| 12. | $\frac{2}{(s+a)^3}$                 | $t^2 e^{-at}$           | $(kT)^2 e^{-akT}$                                          | $\frac{T^2 e^{-aT} (1+e^{-aT}z^{-1})z^{-1}}{(1-e^{-aT}z^{-1})^3}$                            |
| 13. | $\frac{a^2}{s^2(s+a)}$              | $at - 1 + e^{-at}$      | $akT - 1 + e^{-akT}$                                       | $\frac{[(aT-1+e^{-aT}) + (1-e^{-aT}-aTe^{-aT})z^{-1}]z^{-1}}{(1-z^{-1})^2(1-e^{-aT}z^{-1})}$ |
| 14. | $\frac{\omega}{s^2 + \omega^2}$     | $\sin \omega t$         | $\sin \omega kT$                                           | $\frac{z^{-1} \sin \omega T}{1-2z^{-1} \cos \omega T + z^{-2}}$                              |
| 15. | $\frac{s}{s^2 + \omega^2}$          | $\cos \omega t$         | $\cos \omega kT$                                           | $\frac{1-z^{-1} \cos \omega T}{1-2z^{-1} \cos \omega T + z^{-2}}$                            |
| 16. | $\frac{\omega}{(s+a)^2 + \omega^2}$ | $e^{-at} \sin \omega t$ | $e^{-akT} \sin \omega kT$                                  | $\frac{e^{-aT} z^{-1} \sin \omega T}{1-2e^{-aT} z^{-1} \cos \omega T + e^{-2aT} z^{-2}}$     |
| 17. | $\frac{s+a}{(s+a)^2 + \omega^2}$    | $e^{-at} \cos \omega t$ | $e^{-akT} \cos \omega kT$                                  | $\frac{1-e^{-aT} z^{-1} \cos \omega T}{1-2e^{-aT} z^{-1} \cos \omega T + e^{-2aT} z^{-2}}$   |
| 18. | —                                   | —                       | $a^k$                                                      | $\frac{1}{1-az^{-1}}$                                                                        |
| 19. | —                                   | —                       | $a^{k-1}$<br>$k = 1, 2, 3, \dots$                          | $\frac{z^{-1}}{1-az^{-1}}$                                                                   |
| 20. | —                                   | —                       | $ka^{k-1}$                                                 | $\frac{z^{-1}}{(1-az^{-1})^2}$                                                               |
| 21. | —                                   | —                       | $k^2 a^{k-1}$                                              | $\frac{z^{-1}(1+az^{-1})}{(1-az^{-1})^3}$                                                    |
| 22. | —                                   | —                       | $k^3 a^{k-1}$                                              | $\frac{z^{-1}(1+4az^{-1}+a^2 z^{-2})}{(1-az^{-1})^4}$                                        |
| 23. | —                                   | —                       | $k^4 a^{k-1}$                                              | $\frac{z^{-1}(1+11az^{-1}+11a^2 z^{-2}+a^3 z^{-3})}{(1-az^{-1})^5}$                          |
| 24. | —                                   | —                       | $a^k \cos k\pi$                                            | $\frac{1}{1+az^{-1}}$                                                                        |

$x(t) = 0$  for  $t < 0$

## Definition of the Z-transform

$$\mathcal{Z}\{x(k)\} = X(z) = \sum_{k=0}^{\infty} x(k)z^{-k}$$

## Important properties and theorems of the Z-transform

|     | $x(t)$ or $x(k)$                     | $Z\{x(t)\}$ or $Z\{x(k)\}$                                                                                            |
|-----|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| 1.  | $ax(t)$                              | $aX(z)$                                                                                                               |
| 2.  | $ax_1(t) + bx_2(t)$                  | $aX_1(z) + bX_2(z)$                                                                                                   |
| 3.  | $x(t+T)$ or $x(k+1)$                 | $zX(z) - zx(0)$                                                                                                       |
| 4.  | $x(t+2T)$                            | $z^2X(z) - z^2x(0) - zx(T)$                                                                                           |
| 5.  | $x(k+2)$                             | $z^2X(z) - z^2x(0) - zx(1)$                                                                                           |
| 6.  | $x(t+kT)$                            | $z^kX(z) - z^kx(0) - z^{k-1}x(T) - \dots - zx(kT-T)$                                                                  |
| 7.  | $x(t-kT)$                            | $z^{-k}X(z)$                                                                                                          |
| 8.  | $x(n+k)$                             | $z^kX(z) - z^kx(0) - z^{k-1}x(1) - \dots - zx(k-1)$                                                                   |
| 9.  | $x(n-k)$                             | $z^{-k}X(z)$                                                                                                          |
| 10. | $tx(t)$                              | $-Tz \frac{d}{dz}X(z)$                                                                                                |
| 11. | $kx(k)$                              | $-z \frac{d}{dz}X(z)$                                                                                                 |
| 12. | $e^{-at}x(t)$                        | $X(ze^{aT})$                                                                                                          |
| 13. | $e^{-ak}x(k)$                        | $X(ze^a)$                                                                                                             |
| 14. | $a^kx(k)$                            | $X\left(\frac{z}{a}\right)$                                                                                           |
| 15. | $ka^kx(k)$                           | $-z \frac{d}{dz}X\left(\frac{z}{a}\right)$                                                                            |
| 16. | $x(0)$                               | $\lim_{z \rightarrow \infty} X(z)$ if the limit exists                                                                |
| 17. | $x(\infty)$                          | $\lim_{z \rightarrow 1} \left[ (1-z^{-1})X(z) \right]$ if $(1-z^{-1})X(z)$ is analytic on and outside the unit circle |
| 18. | $\nabla x(k) = x(k) - x(k-1)$        | $(1-z^{-1})X(z)$                                                                                                      |
| 19. | $\Delta x(k) = x(k+1) - x(k)$        | $(z-1)X(z) - zx(0)$                                                                                                   |
| 20. | $\sum_{k=0}^n x(k)$                  | $\frac{1}{1-z^{-1}}X(z)$                                                                                              |
| 21. | $\frac{\partial}{\partial a}x(t, a)$ | $\frac{\partial}{\partial a}X(z, a)$                                                                                  |
| 22. | $k^m x(k)$                           | $\left(-z \frac{d}{dz}\right)^m X(z)$                                                                                 |
| 23. | $\sum_{k=0}^n x(kT)y(nT-kT)$         | $X(z)Y(z)$                                                                                                            |
| 24. | $\sum_{k=0}^{\infty} x(k)$           | $X(1)$                                                                                                                |

**THE UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING  
DEPARTMENT OF MECHANICAL ENGINEERING**

**UNIVERSITY EXAMINATIONS FOR 2021 ACADEMIC YEAR**

**MEC 5051 – MACHINE DESIGN II  
PAPER I**

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**INSTRUCTIONS TO CANDIDATES:**

1. Candidates are allowed to use books, and notes (**OPEN BOOK EXAMINATION**).
  2. Time: **Three (3) hours**
  3. Answer ALL questions. Please note questions are of different mark values as shown.
  4. Calculators, drawing instruments are permitted.
  5. All questions must be answered in the answer booklet provided.
- 

**DO NOT TURN THIS PAGE UNTIL YOU ARE TOLD TO DO SO.**

### Q. 1.

Mopani Copper Mine intends to install a new system to convey copper ore from the mining site to the smelter. You have been hired to design a reverted gear train system with the module pitch for the first and second meshing gear sets as 3.12 mm and 2.40 mm respectively, and the speed ratio as 9.

Specifying all the relevant design parameters, of course taking into consideration the space limits, gear undercutting, and interference, you are required to:

- (a) Design a gear with minimum number of teeth to avoid interference. [03 marks]
- (b) Calculate the suitable numbers of teeth for the gears such that no gear will have less teeth than the gear in (a). [17 marks]

### Q.2.

In order to meet the power generation requirements, a wind turbine is designed with a rotor which is connected to a generator through a power shaft. The turbine has an input speed of 360 rpm, on the rotor, and the output speed of 1800 rpm, on the generator side.

- (a) If the generator has an output power of 50 kilowatts, calculate the torque on the connecting power shaft. [08 marks]
- (b) With a well labeled diagram, design a planetary gear train and specify the required number of teeth for each gear. [12 marks]

### Q3.

A block Making Machine is fitted with an epi-cyclic gear train designed with two gears (1 and 2) which are connected with an arm. Given that gears 1 is the driving gear with 18 teeth and gear 2 is the driven gear with 12 teeth, you are required to:

- (a) Determine the speed of gear 2 if gear 1 is fixed and the arm rotates 60rpm clockwise. [08 marks]
- (b) Calculate the speed of gear 2 if the arm rotates at 80 rpm and gear 1 makes 120 rpm clockwise. [12 marks]

### Q.4.

The new model forklift is designed with a clutch plate, whose inside and outside radii are 8cm and 12 cm respectively, and can support an axial force of 3000 N. Assuming uniform wear, determine;

- (a) the maximum pressure in the plate [08 marks]
- (b) the minimum pressure in the plate [06 marks]
- (c) the average pressure in the plate [06 marks]

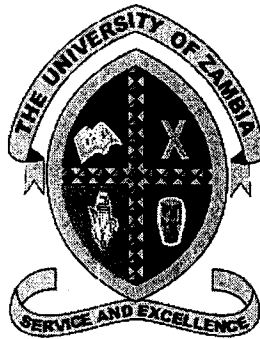
**Q.5.**

A BMW engine with power rating of 60 kW at 2000 rpm is fitted with a conic clutch having a face angle 18 deg. and a maximum diameter of 0.4 m. Given that the coefficient of friction is 0.3 and the normal pressure on the clutch is not to exceed 50 kPa, determine;

- |                                                     |            |
|-----------------------------------------------------|------------|
| (a) the required face width,                        | [08 marks] |
| (b) the axial force necessary to engage the clutch. | [12 marks] |

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**END OF MEC5051 PAPER I EXAMINATION**



UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING  
DEPARTMENT OF MECHANICAL ENGINEERING

**FINAL EXAMINATIONS FOR THE 2020 ACADEMIC YEAR**

**MEC 5455 – ALTERNATIVE ENERGY SOURCES**

**TIME ALLOWED: THREE (3) HOURS**

**CLOSED BOOK**

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**INSTRUCTIONS:**

1. Clearly indicate your **Computer Number** on the front cover of your answer booklet.
2. Answer a **TOTAL of FIVE (5)** questions.  
Any **TWO (2)** questions from **SECTION A**, and  
Any **THREE (3)** questions from **SECTION B**
3. Submit any of Questions (1,2,4 & 7) and (3,5 & 6) in **Separate Answer Booklets**.
4. Draw neat **sketches and graphs** where necessary.
5. Clearly state any **assumptions** made.

---

**SECTION A: ANSWER ANY TWO (2) QUESTIONS FROM THIS SECTION**

---

**Question 1**

- (a) Define the term "*Biomass*".
- (b) Using a suitable sketch, discuss in detail the *biomass thermal conversion pathways*, highlighting the final market products and the areas of application.

[3+17 = 20 Marks]

**Question 2**

- (a) Discuss the *technical implications* associated with the use of renewable energy.
- (b) What are the *environmental impacts* associated with geothermal power plants and what are some of the mitigation measures that can be put in place to counter these impacts?

[10+10 = 20 Marks]

**Question 3**

- (a) Explain three *safety precautions* to be taken by anyone working in a hydro power plant.
- (b) Describe the main features of a *control room* in a hydro power plant and how the power demand and supply is monitored and maintained.
- (c) What is a *bus bar*?
- (d) Briefly explain using a neat sketch what you understand by "*boom matrix*" and what it is used for.
- (e) Explain how a "*chiller plant*" within a hydro plant works and its importance.

[3+7+1+4+5 = 20 Marks]

## **SECTION B: ANSWER ANY THREE (3) QUESTIONS FROM THIS SECTION**

### **Question 4**

A 25MW wind farm comprising 50 units of 3 – blade Horizontal Axis Wind Turbines (HAWTS) is to be setup in the outskirts of the Southern Province of Zambia. Each of the wind turbines to be used at this site is designed to generate 500 KW and is 50m in diameter. A survey carried out at the site found the air density to be  $1.225 \text{ kg/m}^3$  at a height of 100m and the corresponding average monthly wind speeds at the same height are shown in *Table Q1*.

- (a) Using suitable sketches, describe the different types of Horizontal Axis Wind Turbines giving the disadvantages and advantages of each type.
- (b) Calculate the following for each of the HAWTs to be used at this site
  - (i) The maximum rpm of the rotor if each HAWT is to operate with a TSR of 6?
  - (ii) The maximum tip speed of the rotor?
  - (iii) If the generator needs to turn at 2500 rpm, what gear ratio is needed to match the rotor speed to the generator speed?
  - (iv) The maximum axial force experienced on the wind turbines.
  - (v) What is the Maximum torque experienced on the wind turbine blades and what are the effects of this torque?

*Table Q4*

| Month                    | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|--------------------------|-----|-----|-----|-----|-----|------|------|-----|-----|-----|-----|-----|
| Average Wind Speed (m/s) | 4   | 5   | 5   | 6   | 8   | 10   | 13   | 12  | 9   | 7   | 5   | 4   |

[5+15 = 20Marks]

### Question 5

- (a) Briefly explain why *automotive* batteries are not suitable for solar applications.
- (b) Design a solar PV system to meet the following requirements for a classroom block located in some village in North Western Province of Zambia, lying  $13^\circ$  south of the equator, far away from the electric grid. The location receives an average insolation of  $4.5\text{kWh/m}^2/\text{day}$ . It is desired that the system should work without any problems for a period of 2 days during period of overcast. Due to shading over the class room block, the distance from the classroom block to PV panels is likely to be long.

| ITEM                 | TYPE | QUANTITY | POWER RATING<br>(W) | DURATION OF<br>USE (HRS) |
|----------------------|------|----------|---------------------|--------------------------|
| Internal light bulbs | DC   | 30       | 15                  | 4                        |
| External light bulbs | DC   | 2        | 15                  | 12                       |
| Small radio          | DC   | 1        | 20                  | 6                        |
| Phone charger        | DC   | 2        | 1                   | 4                        |
| Laptop               | AC   | 1        | 150                 | 1                        |
| Printer              | AC   | 1        | 800                 | 1                        |
| Projector            | AC   | 1        | 1000                | 1                        |

The following components are readily available:  $120\text{Wp}$  PV panel, 7.6Amps,  $60\text{Wp}$  PV Panel, 4.2 Amps;  $100\text{Ah}$ , 50% DoD Battery,  $100\text{A}$  charge controller. Determine the following:

- Number of solar modules required and their inclination angle.
- Number of batteries required.
- Whether the  $100\text{A}$  charge controller rating is sufficient or too large.
- Inverter rating.

[2+18 = 20 Marks]

### Question 6

- (a) Describe in detail with the help of a relevant sketch the design features of an “indirect” type solar dryer.
- (b) As a consultant, you have been asked to give the size of a  $30\text{kg}$  forced convection solar dryer for drying tomatoes in three days in an area having an ambient temperature, relative humidity, and solar intensity of  $23^\circ\text{C}$  and 40% and  $550\text{W/m}^2$  respectively. On the average, the location receives an  $8\text{hr}$  sunshine period per day. Determine the:
- Average pickup rate
  - Necessary air flow rate
  - Blower power
  - Collector area

[Question 6 continues on the next page]

The following additional information is given:

|                                                         |   |                       |
|---------------------------------------------------------|---|-----------------------|
| Initial/Final moisture contents for onions in wet basis | = | 93% / 4% respectively |
| Maximum temperature                                     | = | 55°C                  |
| Bulk density of tomatoes                                | = | 1020kg/m <sup>3</sup> |
| Relative humidity of air leaving the bin                | = | 75%                   |
| Air velocity in the drying bin                          | = | 0.4m/s                |
| Air resistance for onions                               | = | 4000m <sup>-1</sup>   |
| Collector efficiency                                    | = | 62%                   |
| Motor / Blower efficiency                               | = | 33%                   |

[8+12 = 20 Marks]

### **Question 7**

A local farm cooperative society has approached you for the design of a biogas plant to take advantage of the manure that is produced from their livestock on a daily basis, the farming cooperative has a total stock of 6,000 pigs.

- Describe the main steps in the biochemical process of anaerobic digestion.
- Determine the volume of a biogas digester suitable for the output of the 6000 pigs. Refer to **Table Q2** for typical manure output parameters from farm animals.
- Determine the power available from the digester, assuming a retention time of 20 days and a burner efficiency of 0.6.
- Mention 4 parameters that are critical to the efficiency of such a plant.

**Table Q7**

| <i>Animal</i>                | <i>Total wet manure,<br/>Per animal<br/>Per day/kg</i> | <i>Of which, total solids<br/>per kg</i> | <i>Moisture mass<br/>content per wet mass</i> |
|------------------------------|--------------------------------------------------------|------------------------------------------|-----------------------------------------------|
| <i>Dairy cow (500 kg)</i>    | 35                                                     | 4.5                                      | 87%                                           |
| <i>Beef steer (300 kg)</i>   | 25                                                     | 3.2                                      | 87%                                           |
| <i>Fattening pig (60 kg)</i> | 3.3                                                    | 0.3                                      | 91%                                           |
| <i>Laying hen</i>            | 0.12                                                   | 0.03                                     | 75%                                           |

[8+5+5+2 = 20marks]

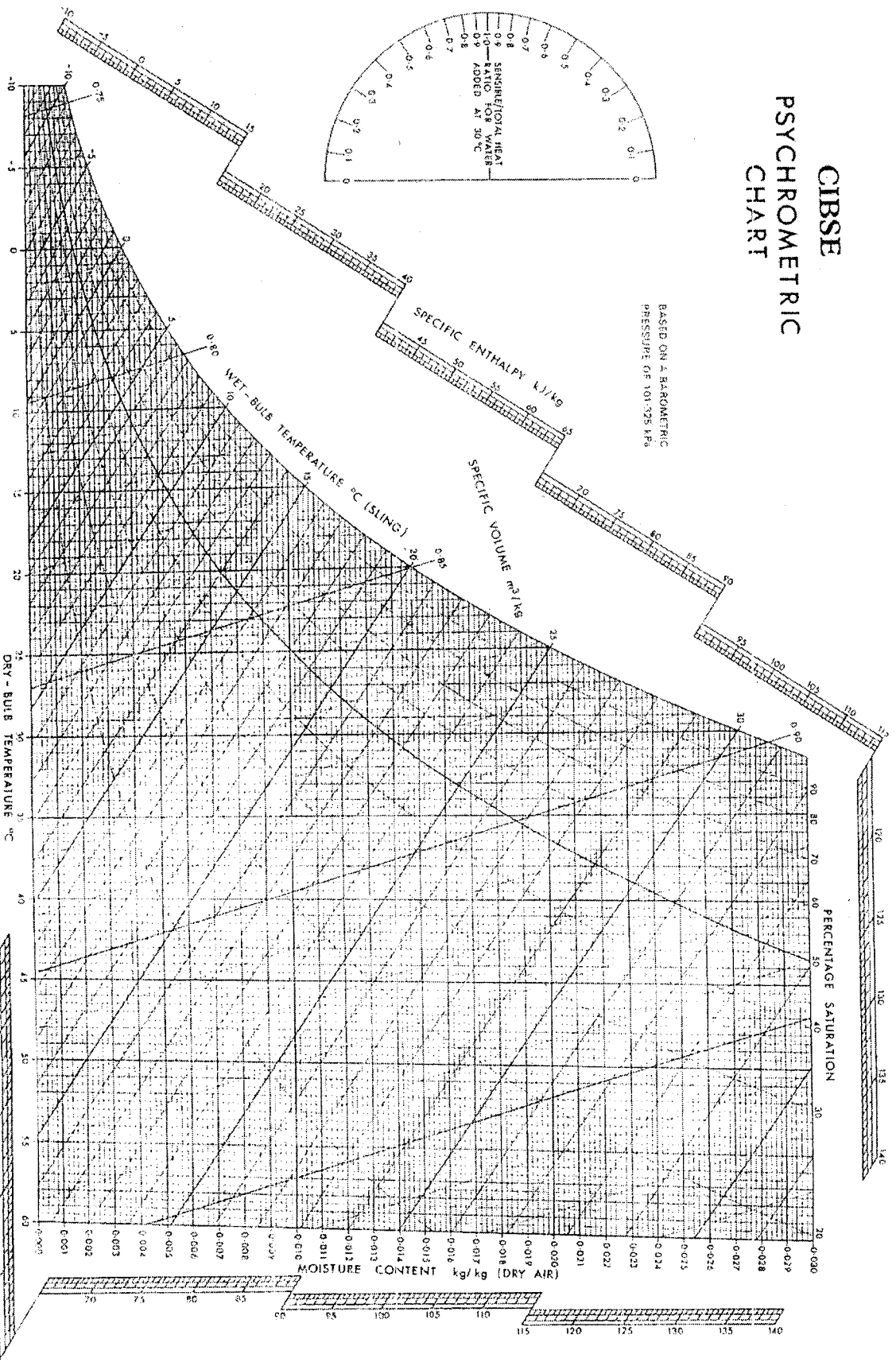
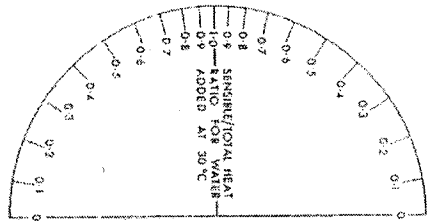
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**END OF MEC 5455 – Alternative Energy Sources  
2020 Academic Year Final Examination – November 2021**

**PREPARED BY:  
Mr. M. Musonda and Mr. S. S. Virdy**

# CIBSE PSYCHROMETRIC CHART

BASED ON A BAROMETRIC  
PRESSURE OF 101.325 kPa



**FINAL EXAMINATION – End of Term 2 - November, 2021**

**MEC5465 Refrigeration and Air Conditioning**

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**INSTRUCTIONS**

1. A total of **Five (5)** Questions is to be answered in all.
2. Draw fully labelled sketches and illustrations where necessary.
3. State any assumptions used and clearly show the working out to the solution in metric units.
4. Underline your final Answers.
5. Comment on your final answers where appropriate.
6. Marks distribution as indicated at end of each question.

(Answer **any two** questions from this section).

**QUESTION 1**

For any vapour absorption system you know, state the refrigerant and the absorber fluid and sketch the cycle, describe the function of each unit in the cycle.

**[15 Marks]**

**QUESTION 2**

Draw the actual T-s diagram for the simple vapour compression refrigeration system and state the deviations from theoretical cycle. Explain the causes of these deviations through the components and ducts of the system.

**[15 Marks]**

**QUESTION 3**

Air refrigeration systems are usually applied to hitech equipment for delicate operations. There are several systems in existence, for **any one** of the systems you know sketch the circuit diagram, the temperature entropy diagram and explain the operations and mention the applications.

**[15 Marks]**

**QUESTION 4**

List and explain the following:

- a) All the psychrometric terms
- b) All the psychrometric processes

**[7.5 Marks]**

**[7.5 Marks]**

## **SECTION B**

### **Answer Question 5 and any other two.**

#### **QUESTION 5 (compulsory)**

An auditorium for seating 50 female and 50 male persons is to be maintained at 22°C dry bulb temperature and 60% relative humidity. The ambient conditions are 40°C dry bulb temperature and 27°C wet bulb temperature. The various loads in the auditorium are as follows:

Sensible and latent heat loads per person, 80 W and 50 W respectively; lights and fans, 15 000 W; sensible heat gain through glass, walls, ceiling etc., 15 000 W. The air infiltration is 20 m<sup>3</sup>/min and recharge air supply is 100 m<sup>3</sup>/min; 66.6% of recirculated room air and 33.3% of recharge air are mixed before entering the cooling coil. The by-pass factor of the coil is 0.1.

Determine apparatus dew point, the grand total heat load and effective room sensible heat factor.

**[30 Marks]**

#### **QUESTION 6**

A refrigerator working on Bell-Coleman cycle operates between pressure limits of 1.05 bar and 8.5 bar. Air is drawn from the cold chamber at 10°C, compressed and then it is cooled to 30°C before entering the expansion cylinder. The expansion and compression follows the law  $p v^{1.3} = \text{constant}$ . Determine the theoretical C.O.P. of the system.

**[20 Marks]**

#### **QUESTION 7**

An ammonia refrigerating machine fitted with an expansion valve works between the temperature limits of -10°C and 30°C. The vapour is 95% dry at the end of isentropic compression and the fluid leaving the condenser is at 30°C. Assuming actual C.O.P. as 60% of the theoretical, calculate the kilograms of ice produced per kW hour at 0°C from water at 10°C. Latent heat of ice is 335 kJ/kg.

**[20 Marks]**

#### **QUESTION 8**

In a heating application, moist air enters a steam heating coil at 10°C, 50% RH and leaves at 30°C. Determine the sensible heat transfer, if mass flow rate of air is 100 kg of dry air per second. Also determine the steam mass flow rate if steam enters saturated at 100°C and condensate leaves at 80°C.

**[20 Marks]**

#### **QUESTION 9**

An air conditioning plant is required to supply 60 m<sup>3</sup> of air per minute at a DBT of 21°C and 55% RH. The outside air is at DBT of 28°C and 60% RH. Determine the mass of water drained and capacity of the cooling coil. Assume the air conditioning plant is first to dehumidify and then to cool the air.

**[20 Marks]**

el/11/21

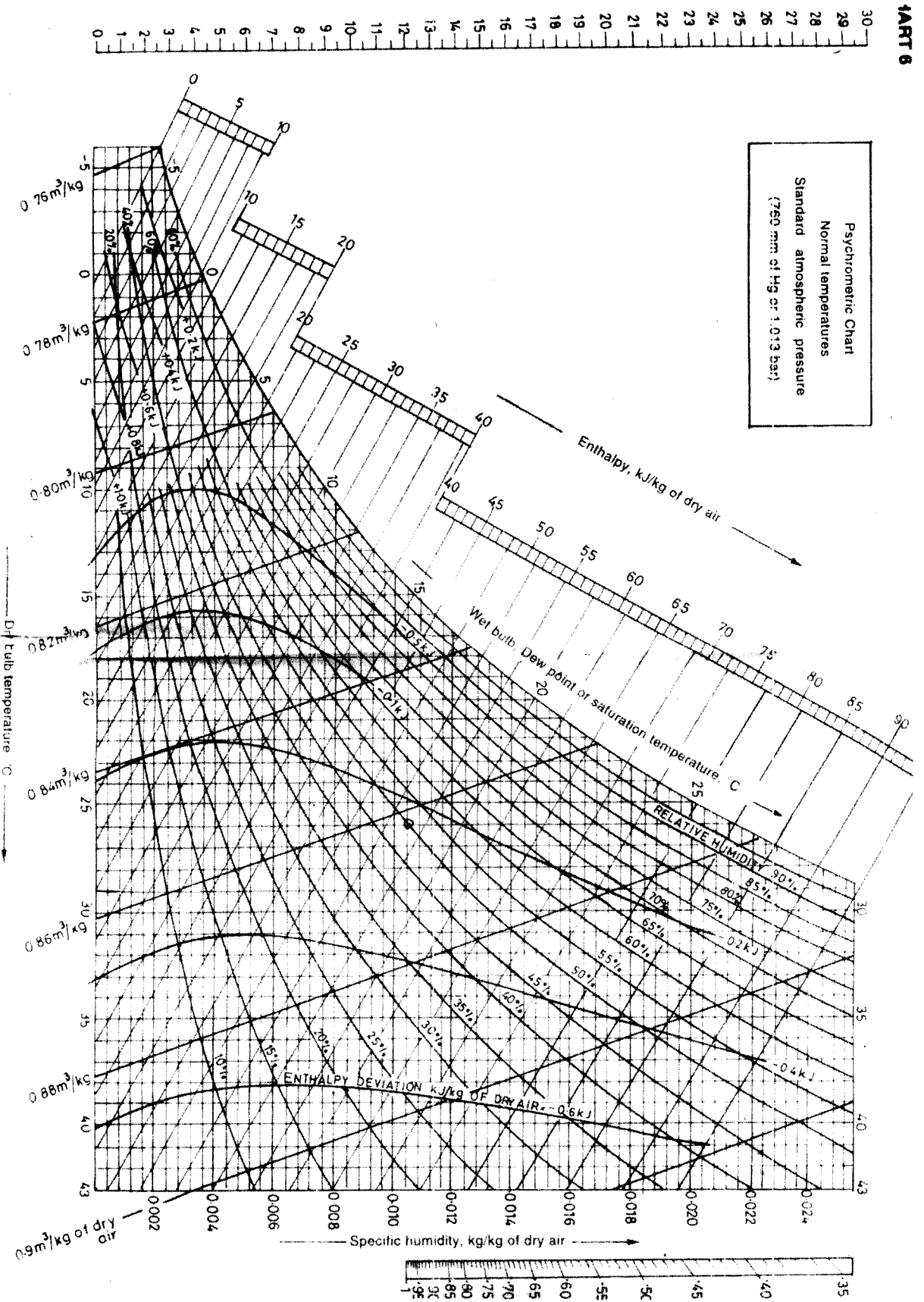
TABLE 15. PROPERTIES OF AMMONIA, NH<sub>3</sub>

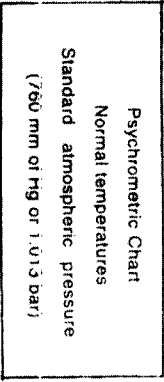
[0.1 MN/m<sup>2</sup> = 1 bar ≈ 14.5 lbf/in<sup>2</sup>]

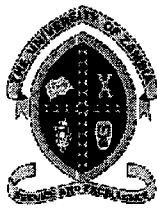
| Saturation<br>Celsius temp.,<br>°C<br><i>t</i> | Pressure<br>MN/m <sup>2</sup><br><i>p</i> | Saturated                             |                                |                                |                                |                                |                                | Superheated |          |          |          |
|------------------------------------------------|-------------------------------------------|---------------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|-------------|----------|----------|----------|
|                                                |                                           | Specific volume<br>m <sup>3</sup> /kg |                                | Specific enthalpy<br>kJ/kg     |                                | Specific entropy<br>kJ/kg K    |                                | By 50 K     |          | By 100 K |          |
|                                                |                                           | Liquid<br><i>v<sub>l</sub></i>        | Vapour<br><i>v<sub>g</sub></i> | Liquid<br><i>h<sub>f</sub></i> | Vapour<br><i>h<sub>g</sub></i> | Liquid<br><i>s<sub>f</sub></i> | Vapour<br><i>s<sub>g</sub></i> | <i>h</i>    | <i>s</i> | <i>h</i> | <i>s</i> |
|                                                |                                           |                                       |                                |                                |                                |                                |                                |             |          |          |          |
| -40                                            | 0.0718                                    | 0.00145                               | 1.552                          | zero                           | 1390                           | zero                           | 5.963                          | 1499        | 6.387    | 1606     | 6.736    |
| -35                                            | 0.0932                                    | 0.00146                               | 1.216                          | 22.3                           | 1398                           | 0.095                          | 5.872                          | 1508        | 6.202    | 1616     | 6.639    |
| -30                                            | 0.1196                                    | 0.00148                               | 0.963                          | 44.7                           | 1406                           | 0.188                          | 5.785                          | 1517        | 6.203    | 1626     | 6.547    |
| -25                                            | 0.1516                                    | 0.00149                               | 0.772                          | 67.2                           | 1413                           | 0.279                          | 5.703                          | 1526        | 6.119    | 1636     | 6.461    |
| -20                                            | 0.190                                     | 0.00150                               | 0.624                          | 89.8                           | 1420                           | 0.368                          | 5.624                          | 1535        | 6.039    | 1646     | 6.379    |
| -15                                            | 0.236                                     | 0.00152                               | 0.509                          | 112.3                          | 1426                           | 0.457                          | 5.549                          | 1543        | 5.963    | 1656     | 6.301    |
| -10                                            | 0.291                                     | 0.00153                               | 0.418                          | 135.4                          | 1433                           | 0.544                          | 5.477                          | 1552        | 5.891    | 1665     | 6.227    |
| -5                                             | 0.355                                     | 0.00155                               | 0.347                          | 158.2                          | 1439                           | 0.630                          | 5.407                          | 1560        | 5.822    | 1675     | 6.157    |
| 0                                              | 0.429                                     | 0.00157                               | 0.289                          | 181.2                          | 1444                           | 0.715                          | 5.340                          | 1568        | 5.756    | 1684     | 6.090    |
| 5                                              | 0.516                                     | 0.00158                               | 0.243                          | 204.5                          | 1450                           | 0.799                          | 5.276                          | 1576        | 5.694    | 1693     | 6.027    |
| 10                                             | 0.615                                     | 0.00160                               | 0.206                          | 227.7                          | 1454                           | 0.881                          | 5.214                          | 1583        | 5.634    | 1702     | 5.967    |
| 15                                             | 0.728                                     | 0.00162                               | 0.175                          | 251.4                          | 1459                           | 0.963                          | 5.154                          | 1590        | 5.576    | 1711     | 5.909    |
| 20                                             | 0.857                                     | 0.00164                               | 0.149                          | 275.2                          | 1463                           | 1.044                          | 5.095                          | 1597        | 5.521    | 1719     | 5.853    |
| 25                                             | 1.001                                     | 0.00166                               | 0.128                          | 298.9                          | 1466                           | 1.124                          | 5.039                          | 1604        | 5.468    | 1728     | 5.800    |
| 30                                             | 1.167                                     | 0.00168                               | 0.111                          | 323.1                          | 1469                           | 1.204                          | 4.984                          | 1610        | 5.417    | 1736     | 5.750    |
| 35                                             | 1.350                                     | 0.00170                               | 0.096                          | 347.5                          | 1471                           | 1.282                          | 4.930                          | 1616        | 5.368    | 1744     | 5.702    |
| 40                                             | 1.554                                     | 0.00173                               | 0.083                          | 371.5                          | 1473                           | 1.360                          | 4.877                          | 1622        | 5.321    | 1752     | 5.655    |
| 45                                             | 1.782                                     | 0.00175                               | 0.073                          | 396.8                          | 1474                           | 1.437                          | 4.825                          | 1628        | 5.275    | 1760     | 5.610    |
| 50                                             | 2.033                                     | 0.00178                               | 0.063                          | 421.9                          | 1475                           | 1.515                          | 4.773                          | 1633        | 5.230    | 1767     | 5.567    |

Freezing point at 1 atm = -77.7 °C

Critical point: Celsius temp. = 132.4 °C  
pressure = 11.30 MN/m<sup>2</sup> (113.0 bar)







**THE UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING  
DEPARTMENT OF MECHANICAL ENGINEERING**

**UNIVERSITY EXAMINATIONS  
END OF YEAR EXAMINATIONS, 2020**

**MEC 5551 – ENVIRONMENTAL ENGINEERING  
QUESTION PAPER**

**Read the following instructions carefully before you start writing:**

- 
- 1. This Examination is Closed Book.*
  - 2. Time Allowed: Three (3) Hours.*
  - 3. Section A is compulsory.*
  - 4. Answer any Four (4) questions from Section B.*
  - 5. All questions carry 20 marks each.*
- 

**[DO NOT TURN THE PAGE OVER UNTIL YOU ARE TOLD TO DO SO]**

## **ANSWER QUESTION ONE: THIS SECTION IS COMPULSORY**

### **Question One**

You are asked to design a waste water treatment plant in Lusaka for a community with a population of 350,000 people.

- a) Assuming that the daily per capita solids contribution from the mixed sludge is 48g. Calculate the necessary design data for sludge drying beds for sludge for the proposed treatment plant.
- b) Describe some measure you will take to prevent soil and ground water contamination as well as minimise odour nuisance in the vicinity of your proposed waste water treatment plant.
- c) Resource recovery is a requirement for your waste water treatment plant. Describe the various ways you can recover both energy and material from your plant.
- d) Using a suitable diagram, show the general layout for this proposed wastewater treatment plant.

**[8+4+4+4 marks]**

## **SECTION B: ANSWER ANY FOUR QUESTIONS IN THIS SECTION**

### **Question Two**

- a) Illustrate the three-pillar model of sustainability.
- b) Describe a technology which you think has contributed positively to sustainable development.
- c) What are renewable and non-renewable energy resources? Why do you think non-renewable energy resources such as coal are preferred for energy utilization?
- d) With the aid of a suitable sketch, describe the hydrological cycle and list its main components.

**[4+4+4+8 marks]**

### **Question Three**

- a) State four different sources of waste water that are produced from a community.
- b) With the help of a neat sketch describe the process of primary treatment of waste water.
- c) What do you understand by secondary treatment of waste water?
- d) Describe with a neat sketch the treatment of sewage by the trickling filter process. Write the advantages and disadvantages of the process.

**[4+6+4+6 marks]**

### **Question Four**

- a) Define “Municipal Solid Waste” and mention two sources.
- b) Explain the role of a transfer station in solid waste management?
- c) Explain the difference between compaction and size reduction of municipal solid waste.
- d) A collection vehicle is found to be able to service customers at a rate of 2 customers per minute. If actual time spent for collection is 6 hours per day, compute;

- i) The number of customers served per day.
- ii) Calculate the number of collection vehicles needed for a district with 10,000 houses (services) that are to be collected once per week. Collection is to be done on Mondays, Tuesdays, Thursdays, and Fridays, leaving Wednesdays for special projects and maintenance. A single collection vehicle can service 250 houses in a single day and still have time to take the full loads to the landfill.

$$\text{Take } N = \frac{SF}{XW}$$

Where  $N$  = number of collection vehicles required;

$S$  = total number of households serviced

$F$  = collection frequency, (number of collections per week);

$X$  = number of households a single truck can service per day

$W$  = number of workers per week.

[4+4+4+8 marks]

### Question Five

- a) What are the basic characteristics of a modern landfill site? List any three.
- b) What is landfill gas? What is an advantage of landfill gas?
- c) What is the difference between incineration and pyrolysis?
- d) With the aid of a simple flow diagram describe the phases of composting indicating the general temperature ranges and type of bacteria present for each phase.

[6+4+10 marks]

### Question Six

- a) Define air pollution.
- b) What are the common sources of particulate matter both natural and anthropogenic?
- c) What is fog?
- d) Briefly describe the Air Quality Index (AQI).
- e) Discuss the concept of source reduction as an air pollution prevention approach.
- f) Briefly describe the operation of electrostatic precipitators.

[2+4+2+4+4+4 marks]

### Question Seven

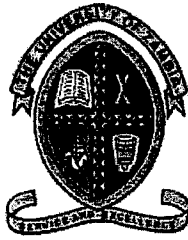
- a) Mention the objectives of an Environmental Impact Assessment (EIA).
- b) What is a Life Cycle Assessment (LCA)? Give a simple example.
- c) Using a 38% recycling rate for aluminium cans,
  - i) Find the primary energy required to produce the aluminium in a 0.36L aluminium can having a mass of 16g.
  - ii) How much energy is saved when a can is recycled instead of being thrown away?

| <b>ENERGY REQUIREMENTS FOR ALUMINIUM PRODUCED FROM BAUXITE<br/>AND FROM RECYCLED ALUMINIUM</b> |                                 |                            |                                   |
|------------------------------------------------------------------------------------------------|---------------------------------|----------------------------|-----------------------------------|
| <b>Source</b>                                                                                  | <b>Electricity<br/>(kWh/kg)</b> | <b>Fossil Fuel (kJ/kg)</b> | <b>Primary Energy<br/>(kJ/kg)</b> |
| Bauxite                                                                                        | 15                              | 60,000                     | 220,600                           |
| Recycled Aluminium                                                                             | 0.08                            | 4,200                      | 5,060                             |
| Recycling Savings                                                                              | 14.92                           | 55,800                     | 215,540                           |
| Percent Savings                                                                                | 99%                             | 93%                        | 98%                               |

[6+4+10 marks]

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**END OF MEC 5551 EXAMINATION – NOVEMBER 2021**  
**F K CHITALU**



**THE UNIVERSITY OF ZAMBIA  
SCHOOL OF ENGINEERING  
DEPARTMENT OF MECHANICAL ENGINEERING**

**MEC 5855 - AUTOMOBILE ENGINEERING**

**TERM II FINAL EXAMINATIONS – NOVEMBER 2021**

**TIME: THREE (3) Hours**

**[Closed Book]**

**Instructions:**

1. Answer **TWO (2)** questions from section A and **Three (3)** questions from section B.
2. All questions carry **equal marks**.
3. Show **ALL** your workings (draw sketches, graphs, etc.) and state any assumptions made.
4. Write your **computer number** on each and every sheet used.
5. All mobile phones **MUST** be switched off or put on flight mode.

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## SECTION A

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### **Question 1**

- 1.1 What do you understand by 'Wear' in automobile engineering? In your answer, discuss the various types of wear which are likely to occur during exploitation of motor vehicles. How is this wear qualitatively measured and what measures can be undertaken to reduce it?

**[Q1 Total: 20 Marks]**

### **Question 2**

- 2.1 Describe, with help of sketches, design features, and function of each element of the power transmission system of a motor vehicle.
- 2.2 What physico-chemical properties would you recommend for transmission oils to reduce abrasive and mechanical corrosive wear of transmission components?

**[Q2 Total: 10+10 = 20 Marks]**

### **Question 3**

- 3.1 (i) Write short notes on vehicle body materials.  
(ii) Briefly explain how passenger vehicles are classified.
- 3.2 Today's almost all automobiles are fitted with power assisted steering system to reduce the steering effort by the driver. Describe, with help of sketches, design features and operation of the power assisted steering system commonly used in automobiles.

**[Q3 Total: 10+10 = 20 Marks]**

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## SECTION B

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### Question 4

- 4.1 As an Automobile Engineer at Toyota Zambia, you are tasked to select a car that can climb a steeper grade. Two cars, similar in all respects, except that one has rear wheels drive and the other front wheel drive, are used on the test track. If the engine power does not limit the ability to climb grades, state which car can ascend the steeper grade, if the weight of each car is 14239 N with 50% on each axle, the wheel base is 2.666 m, the CG above the ground is 0.5334 m, and if the coefficient of friction of the track is 0.6, what is the difference in grades which either can ascend if engine power is not the limitation? (% grade =  $\tan\theta \times 100$ ).

[Q4 Total: 20 Marks]

### Question 5

- 5.1 A truck weighing 58860 N has a frontal area of 5.6m<sup>2</sup>. The overall top gear ratio and the second gear ratio are 6.2:1 and 15:1 respectively. The transmission efficiency in top gear is 90% and that in second gear is 80%. The rolling resistance is 17.65 N per 1000 N of truck weight and the wind resistance coefficient is 0.027. If the truck is running on a level road at a maximum speed of 88 km/h, and assuming the total resistance in N is given by the formula

$$R = KW + K_g AV^2 + W \sin\theta$$

Where, A is in m<sup>2</sup>; V in km/h and W in N, calculate:

- (i) The engine kW required at the maximum truck speed.
- (ii) The engine rpm at maximum truck speed if the driving wheels have an effective diameter of 0.81 m.
- (iii) The maximum grade that the truck can negotiate at above engine rpm in the second gear.
- (iv) The maximum drawbar-pull available at level road at the above engine rpm in second gear.

[Q5 Total: 20 Marks]

### Question 6

- 6.1 Starting from first principle, show that the stopping time for a car on application of brakes varies directly as the initial speed; whereas the stopping distance varies as the square of the speed. Assume that the forces acting on the vehicle will be constant throughout the brake application.
- 6.2 A motor vehicle has wheel base of 2.64m, the height of its CG above the ground is 0.61 m and 1.12m from the rear axle. If the car is travelling at 40 km/h on a level track, determine the minimum distance in which the car may be stopped when:-
- (i) The rear wheels are braked.
  - (ii) The front wheels are braked.

[Q6 Total: 12+8 = 20 Marks]

### **Question 7**

- 7.1 Draw the vibration models of a half car and quarter car. Derive the equations of motion for the above half car and quarter car models (assuming only pitching motion in one plane for a half car model).
- 7.2 For a vehicle with forward acceleration  $f$  moving on level ground with front wheel drive, show with a neat sketch that the normal forces acting are given by;

$$R_F = \frac{l}{b + \mu h} W \quad \text{and} \quad R_R = \frac{b - l + \mu h}{b + \mu h} W$$

Where,  $b$  is wheel base,  $h$  is height of CG from the road surface,  $l$  is distance of CG from rear axle,  $\mu$  is coefficient of adhesion between the tyres and the road surface and  $W$  is the weight of the vehicle.

[Q7 Total: 12+8 = 20 Marks]

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**END OF MEC 5855 – AUTOMOBILE ENGINEERING EXAMINATION, NOVEMBER, 2021.**

Prepared by: Mr. J.K. Musa