Professional Engineers Registration Examination

FUNDAMENTALS *of* Engineering Examination 2027

Information for Applicants

professional engineers board Singapore
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Content Page

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1 INTRODUCTION

The mission of the Professional Engineers Board is to safeguard life, property, and welfare of the public by setting and maintaining high standards for registering professional engineers and by regulating and advancing the practice of professional engineering.

The Professional Engineers Board registers professional engineers in the branches of civil, electrical, mechanical and chemical engineering. A person applying for registration as a professional engineer to the Professional Engineers Board is required to hold an approved degree or qualification listed in the Professional Engineers (Approved Qualifications) Notification 2009 and acquired not less than 4 years of relevant practical experience. He is also required to sit and pass examinations prescribed by the Board. The applicant is required to sit and pass the Fundamentals of Engineering Examination and following that, to sit and pass the Practice of Professional Engineering Examination. In addition, the applicant is required to attend an interview.

The following sections set out the requirements and details for the Fundamentals of Engineering Examination 2027 while details on other application requirements are available on the PEB website at www.peb.gov.sg.

2 ELIGIBILITY TO SIT FOR EXAMINATION

The Fundamentals of Engineering Examination tests an applicant's knowledge of fundamental engineering subjects in civil, electrical, mechanical or chemical engineering. A person may apply to sit for the Fundamentals of Engineering Examination if he is undertaking a full time undergraduate engineering degree programme of not less than 4 years, or an equivalent programme approved by the Board, and is in his final year of study or after he has obtained an approved degree or qualification listed in the Professional Engineers (Approved Qualifications) Notification 2009 or has proper and recognised academic qualifications in engineering accepted by the Board.

3 FEES

The fees for an application to sit for the Fundamentals of Engineering Examination is $350.

4 DATES OF EXAMINATION

The dates for the Fundamentals of Engineering Examination 2027 are:

a) Civil Engineering – 6 January 2027
b) Chemical Engineering – 6 January 2027
c) Electrical Engineering – 7 January 2027
d) Mechanical Engineering – 7 January 2027

5 VENUE

The venue would be determined by PEB and successful applicants would be informed of the details of the venue.

6 APPLICATION

Application and payment shall be made online via PEB portal on PEB's website by 30 September 2026. Please refer to the User Guides for PEB Portal for Fundamentals of Engineering Examination for guidance on submitting your application (https://www1.peb.gov.sg/user-guides-for-peb-portal/). Applicants are advised to send in their applications early to allow time for processing.

7 STRUCTURE OF EXAMINATION

A summary of the structure of the Fundamentals of Engineering Examination is shown in the table below. The examination is 'open book' and further details are given in **Annex A: Format and Syllabus, Reading Lists and Sample Questions / Questions From Past Year Papers.**

Subjects	Time Allocated	Format
FEE Part 1 Core engineering subjects in civil/mechanical/electrical/chemical engineering	*3 hours & 10 mins (9.00am – 12.10pm)	• 40 Multiple Choice Questions (MCQ)
FEE Part 2 Core/Elective subjects in civil/electrical/mechanical/chemical engineering	*3 hours & 10 minutes (2.00pm – 5.10pm)	• Answer 5 out of 9 questions (civil) • Answer 5 out of 7 questions (electrical, mechanical, chemical)

* includes 10 minutes for reading the exam questions, etc.

For FEE (Civil) 2027, only answers based on Eurocodes and the relevant Singapore Annexes will be accepted. For transportation-related questions, AASHTO code is acceptable. Answers based on other codes and standards will not be accepted.

8 FINAL RESULTS AND NOTIFICATION

Examination results will be given to candidates on a Pass/Fail basis. No examination scores or marks will be given to candidates. Examination results will be released in April 2027.

9 EXAMINATION APPEALS

A candidate who has failed the examination may submit a written appeal in hard copy to request a review of his/her performance. The appeal is to be received by PEB within **2 weeks after the date of results notification letter** and late appeals would not be considered. The result of the appeal/review will be sent by written mail to the appeal candidate. The appeal candidate would not be able to review the examination paper.

10 REVIEW COURSES

The Board does not endorse any review courses or materials provided as study aids.

11 NO REFUND OF FEES FOR ACCEPTED CANDIDATES

The application fee for the examination is non-refundable for candidates who have been accepted to sit for the examination.

12 REQUEST FOR ACCOMMODATION

Candidates who require special accommodation due to a disability may submit a written request. The request is to be received by PEB not later than 6 weeks before the date of examination and late requests will not be considered. PEB’s decision will be conveyed to the applicant by written mail not later than one week before the examination date.

Annex A: FORMAT AND SYLLABUS, READING LISTS, SAMPLE QUESTIONS AND QUESTIONS FROM PAST YEAR PAPERS

I Fundamentals Of Engineering Examination (Civil)

The examination will focus on testing the fundamentals of civil engineering. The 6-hour examination will comprise two parts. Part 1 catering for breadth, will comprise questions on core civil engineering subjects, typical of courses covered during the 1st and 2nd year of a 4-year civil engineering undergraduate course. Part 2 catering for depth, will comprise more core and elective civil engineering courses covered during the 3rd and 4th year of a 4-year civil engineering undergraduate course.

For FEE (Civil) 2027, only answers based on Eurocodes and the relevant Singapore Annexes will be accepted. For transportation-related questions, AASHTO code is acceptable. Answers based on other codes and standards will not be accepted.

Format

- **FEE Part 1 (Civil) (3 hours & 10 mins) – 40 MCQ questions**

  - CE 101 Mechanics of Materials
  - CE 102 Structural Mechanics
  - CE 103 Structural Analysis
  - CE 104 Soil Mechanics
  - CE 105 Fluid Mechanics

- **FEE Part 2 (Civil) (3 hours & 10 mins) – 5 out of 9 questions**

  - CE 201 Reinforced and Prestressed Concrete Structures (2 Qs)
  - CE 202 Steel Structures (2 Qs)
  - CE 203 Geotechnical Engineering (2 Qs)
  - CE 204 Transportation (1 Q)
  - CE 205 Hydraulics and Hydrology (1 Q)
  - CE 206 Environmental Engineering (1 Q)

Syllabus

- **CE 101 Mechanics of Materials**

  - **Mechanics of Materials**
    Strength, stiffness and deformability; Stress-strain relations; ductility and brittle fracture; time-dependent properties; creep, creep rupture; relaxation; cyclic load behaviour.

- **Concrete Technology**
  Concrete-making materials, properties of fresh and hardened concrete, mixing, placing, and curing, mix design, destructive and non-destructive tests, quality control, durability, and special concrete.
- **Steel**
  Basic metallurgy, mechanical properties and applications, welding technology and corrosion.

- **<u>CE 102 Structural Mechanics</u>**

  - **Structural Mechanics**
    Statics and kinetics of particles, equilibrium of rigid bodies, kinematics and plane motion of rigid bodies, analysis of simple trusses and beams, analysis of structural members subjected to tension, compression, torsion, and bending, including such fundamental concepts as stress, strain, and elastic behaviour. Bar forces in compound and complex trusses. Bending moment, shear and axial forces of beams and frames.

- **<u>CE 103 Structural Analysis</u>**

  - **Structural Analysis**
    Displacements of elastic determinate structures: principle of virtual work and energy theorems. Analysis of indeterminate structures. Deformation of indeterminate structures and influence line method. Displacement techniques using slope-deflection and moment distribution methods. Plastic theory and analysis. Theory and applications of modern structural analysis. Concepts of equilibrium, compatibility and force-displacement relationships. Direct stiffness method. Matrix formulation of trusses, beams and frames. Stability concepts and elastic stability analysis of framed structures.

- **<u>CE 104 Soil Mechanics</u>**

  - Basic geology, unified soil classification system, mechanical properties, effective stress principle, shear strength, compressibility, and seepage and consolidation; Mohr-Coulomb failure criterion (drained and undrained), settlement calculations, rate of consolidation using classical Terzaghi theory.

- **<u>CE 105 Fluid Mechanics</u>**

  - **Fluid Statics**
    Fluid properties; hydrostatic pressure and thrust; buoyancy; stability of floating bodies.

- **Fluid Motion**
  Continuity equations; Bernoulli's equation; linear momentum equation.

- **Similitude**
  Dimensional analysis; design of hydraulic models.

- **<u>CE 201 Reinforced and Prestressed Concrete Structures</u>**

  - **RC Design**
    Basic structural members and structural systems. Loads and load effects. Section analysis and design for bending. Design for shear, torsion and bond. Corbels. Serviceability and durability requirements. Design of short and slender columns. Design of slab systems. Concentrated loads on slabs. Design of foundations. Retaining walls. Reinforced concrete detailing.

  - **Prestressed Concrete Design**
    Basic concepts of prestressing. Materials and prestressing systems. Prestressed losses and time dependent deformation. Behaviour and design of members subject to flexure, shear and combined axial and bending action.

- **<u>CE 202 Steel Structures</u>**

  - **Steel Design**
    Limit state design. Material properties and structural responses. Local buckling and section classifications. Design of fully restrained beams. Shear buckling and design of plate girder. Web bearing and buckling. Design of web stiffeners. Lateral-torsional buckling and design of laterally unrestrained beams. Tension and compression members. Axially loaded members with end moments. Design of steel connections. Plastic design of portal frames. Continuous multi-storey frames.

- **<u>CE 203 Geotechnical Engineering</u>**

  - **Slope Stability and Earth Retaining Structures**
    Introduction to slope stability and earth retaining structures; slopes and embankments; earth pressure and retaining structures; deep excavations; calculation of active and passive earth pressures; design considerations pertaining to deep excavations.

  - **Foundation Engineering**
    Site investigation and interpretation of soil reports; shallow foundations and deep foundations; selection of appropriate foundation type; capacity and settlement requirements.

- <u>**CE 204 Transportation**</u>

  - **Transportation Engineering**
    Transportation systems, planning and management; geometric design of roads and intersections; design of flexible and rigid pavements.

  - **Traffic Engineering**
    Traffic flow studies; traffic data analysis; traffic management; highway and intersection capacity; traffic signal control. Parking.

- <u>**CE 205 Hydraulics and Hydrology**</u>

  - **Hydraulics**
    Friction and minor losses in pipe flow; pipe and pump systems; pipe network analysis; open channel flow; uniform flow, Manning's equation; critical flow; energy and momentum principles; hydraulic jumps; gradually varied flows, backwater computation.

  - **Hydrology**
    Processes in the hydrologic cycle: basic meteorology, rainfall precipitation, evaporation and transpiration, infiltration, sub-surface flow, surface runoff, streamflow measurement and hydrograph analysis; unit hydrograph principles and applications; frequency analysis of rainfall or flood data; reservoir and channel flood routing; urban storm drainage design, flood peak estimation.

- <u>**CE 206 Environmental Engineering**</u>

  - **Environmental Engineering**
    Basic physical, chemical and biological water quality parameters; physical, chemical, and biological processes for water and wastewater treatment; water treatment principles and design; water distribution systems; wastewater collection and pumping systems; wastewater treatment design; pretreatment, primary, secondary, tertiary treatment, and anaerobic digestion.

Recommended Reading List for Civil Engineering

FEE Part 1 (Civil)

CE101 Mechanics of Materials

1) Hibbeler, R. C., "Mechanics of Materials" 9th Edition SI units, 2014.

CE102 Structural Mechanics

1) West, H. H. and Geshwinder, L. F. "Fundamentals of Structural Analysis" 2nd Edition, John Wiley and Sons, Inc, 2002.

CE103 Structural Analysis

1) West, H. H. and Geshwinder, L. F. "Fundamentals of Structural Analysis" 2nd Edition, John Wiley and Sons, Inc, 2002.

CE104 Soil Mechanics

1) Knappett, J.A. and Craig, R.F., "Craig's Soil Mechanics" 9th edition, CRC Press. 2019.

CE105 Fluid Mechanics

1) Finnemore, E.J., and Franzini. J.B. "Fluid Mechanics with Engineering Applications." 10^{th} ed. Boston: McGraw Hill. 2002.
2) Young, D.F., Munson, B., Okiishi T.H. "A Brief Introduction to Fluid Mechanics", John Wiley and Sons, 3rd edition, 2004.

FEE Part 2 (Civil)

CE201 Reinforced and Prestressed Concrete Structures

1) E. O'Brien, A. Dixon and E. Sheils, "Reinforced and Prestressed Concrete Design to EC2: The Complete Process" 2nd Edition, Spon Press, 2013.
2) P. Bhatt, T.J. MacGinley and B.S. Choo, "Reinforced Concrete Design to Eurocodes – Design Theory & Examples" 4th Edition, CRC Press Taylor& Francis Group, 2014.

CE202 Steel Structures

1) Gardner L and Nethercot D, Designers' guide to Eurocode 3: Design of Steel Buildings, EN 1993-1-1, -1-3 and -1-8, 2nd Edition, Thomas Telford, 2011.
2) Steel building design: Concise Eurocodes, Steel Construction Institute (SCI) Publication P362, 2009.
3) Steel Building Design: Worked Examples – Open Sections, Steel Construction Institute (SCI) Publication P364, 2009.
4) Martin, L. and Purkiss, J., "Structural Design of Steelwork to EN 1993 and EN 1994", 3rd edition, Butterworth-Heinemann, UK, 2008.

CE203 Geotechnical Engineering

1) J. A. Knappett, and R. F. Craig, "Craig's Soil Mechanics" 9th Edition, CRC Press. 2019.
2) D. P. Coduto, M. R. Yeung, and W. A. Kitch, "Geotechnical Engineering: Principles and Practices", 2nd edition, Pearson, 2011.
3) Michael Tomlinson and John Woodward, "Pile Design and Construction Practice", 6th Edition, CRC Press, 2014.

CE204 Transportation

1) Mannering F. L. and Washburn, S. S. "Principles of Highway Engineering and Traffic Analysis" 7th Edition, Wiley, 2020.
2) Garber N. and Hoel, L. "Traffic and Highway Engineering" 4th Edition, Cengage Learning, 2010.
3) Papagiannakis, A.T. and Masad, E.A. "Pavement Design and Materials", Wiley. 2012.

CE205 Hydraulics and Hydrology

1) Linsley, R. K. Kohler, M. A. and Paulhus, J. L. H. "Hydrology for Engineers", SI Edition, McGraw Hill Book Co. 1998.

2) Chow, V. T. Maidment, D.R., Mays, L. W., "Applied Hydrology", McGraw Hill Book Co, 1988.
3) Chadwick, A., Morfett, J., and Borthwick, M., "Hydraulics in Civil and Environmental Engineering", 4th Edition, Spon Press, 2004.

CE206 Environmental Engineering

1) Viessman, W. and Hammer, M.J. "Water Supply and Pollution Control", 7th Edition, Pearson Prentice Hall, 2004.

Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 1 (Civil)

For FEE (Civil) 2027, only answers based on Eurocodes and the relevant Singapore Annexes will be accepted. Answers based on other codes and standards will not be accepted.

(Actual paper comprises 40 Multiple Choice Questions (MCQ) of 2.5 marks each. Answer all questions.)

1 Which cement is advantageous when concrete is to be used in seawater or exposed directly along the seacoast?

(a) Quick setting cement
(b) High alumina cement
(c) Ordinary Portland cement
(d) Slag or pozzolana cement

2 Increasing the carbon content of steel will reduce

(a) Ductility
(b) Brittleness
(c) Strength
(d) Hardness

3 For the steel truss shown in Figure Q3, what is the elongation of member AB given that AB is a solid rod of diameter = 20 mm and modulus of elasticity = 200 GPa. Select the closest answer from the following:

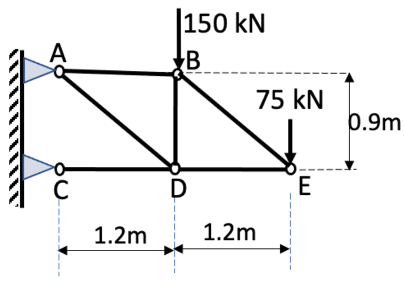


Figure Q3

(a) 0.76 mm
(b) 0.95 mm
(c) 1.43 mm
(d) 1.91 mm

4 A circular reinforced concrete column shown in Figure Q4, with total cross section area of 0.07 m^2, is reinforced by 6 steel bars (total steel cross section area is 0.003 m^2) to support a centric force of 1 MN. The total length of the column is 4 m and the modulus of elasticity for concrete is 25 GPa whereas

that for the steel bars is 200 GPa. Which value below is closest to the average normal stress in the steel, assuming that the concrete and steel reinforcements are fully bonded?

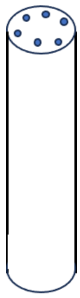


Figure Q4

(a) 168 MPa
(b) 88 MPa
(c) 44 MPa
(d) 11 MPa

5 For the structural model shown in Figure Q5, what is the magnitude of the maximum bending moment along section ABC of the lower beam AE.

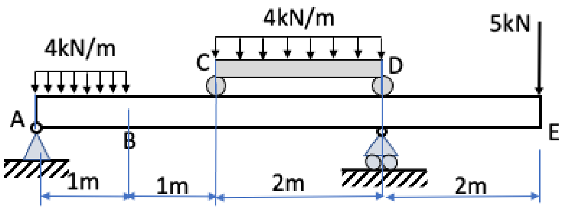


Figure Q5

(a) 3 kNm
(b) 2 kNm
(c) 1 kNm
(d) None of the above

6 For the frame shown in Figure Q6 where the beam and columns have plastic moment capacities of M, what is the minimum collapse load?

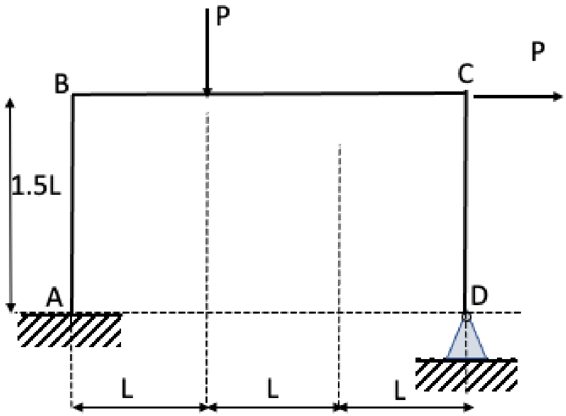


Figure Q6

(a) M/L
(b) 1.6M/L
(c) 2M/L
(d) 3M/L

7 An undisturbed soil sample has a volume of 196 cm^3 and weighs 333 g. Its water content is 45%. The specific gravity of the soil is 2.65. Determine the dry unit weight and degree of saturation of the soil.

(a) 18.5 kN/m^3, 45.0%
(b) 16.7 kN/m^3, 74.5%
(c) 15.4 kN/m^3, 82.3%
(d) 11.5 kN/m^3, 94.5%

8 Which of the following laboratory tests is able to give the total and effective shear strength parameters of a clay soil?

(a) Unconfined Compression test
(b) Unconsolidated Undrained triaxial test
(c) Consolidated Drained triaxial test
(d) None of the above

9 In Figure Q9, what is the pressure downstream of the flow reducer, P_2, if energy losses in flow can be neglected?

Useful Formula:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

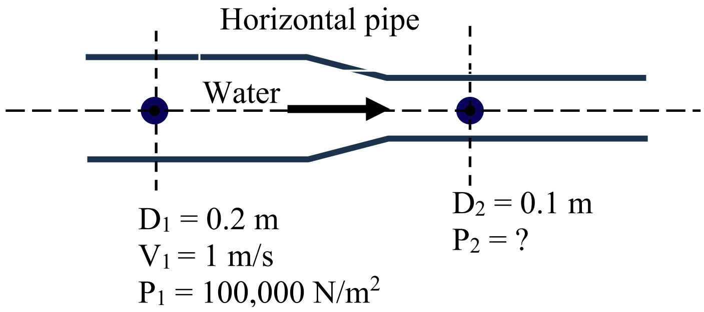


Figure Q9

(a) 98,500 N/m2
(b) 92,500 N/m2
(c) 68,500 N/m2
(d) None of the above

10 What is the magnitude of the resultant hydrostatic thrust F_R acting on the 1 m diameter circular gate mounted on the side of a water tank in Figure Q10?

Useful formula:
$F_R = \rho g A h_c$

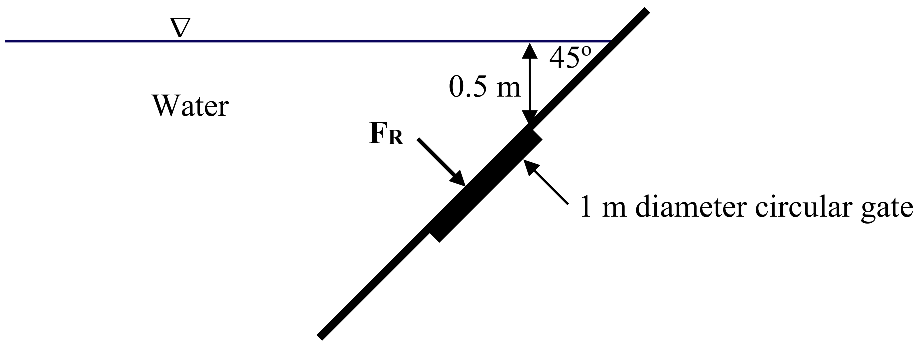


Figure Q10

(a) 6,576 N
(b) 3,582 N
(c) 2,724 N
(d) None of the above

Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 2 (Civil)

For FEE (Civil) 2027, only answers based on Eurocodes and the relevant Singapore Annexes will be accepted. Answers based on other codes and standards will not be accepted.

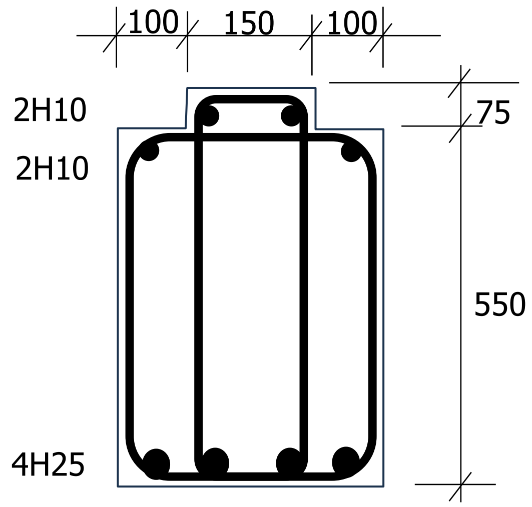
(Actual paper comprises 9 questions. Answer 5 questions)

Question 1

(a) Figure Q1(a) shows the cross section of a precast beam. Calculate the ultimate bending resistance of the cross-section with the design data listed below in accordance to Eurocode 2. You can assume that compression steels are yielded in your calculation. State your other assumptions, if any.

Design data and assumptions:
Concrete grade of precast beam: *C40/50*
Yield strength of reinforcement bar: f_{yk} = 500 N/mm^2
Density of reinforced concrete = 25 kN/m^3
Concrete cover = 25 mm
Shear link = 10 mm

(14 Marks)



Note: Drawing not to scale, units in mm unless stated otherwise

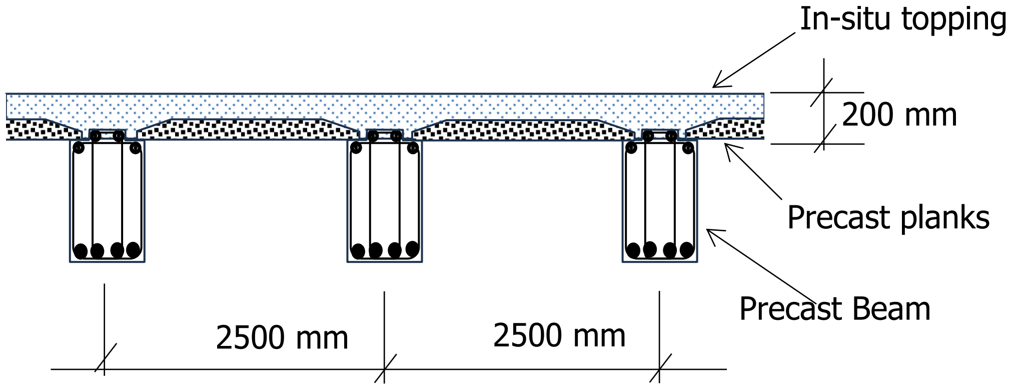
Figure Q1(a)

(b) Figure Q1(b) below shows the construction arrangement of the precast beam spaced at 2.5m centre to centre, supporting precast planks and in-situ slab topping.

Based on the ultimate strength calculated in Q1(a) above, and design data shown below, calculate the allowable span of the precast beam based on load combination during construction stage.

Construction variable action = 1.0 kN/m2
Partial factor for variable action during construction = 1.05
Partial factor for permanent action during construction = 1.35

(6 Marks)



Note: Drawing not drawn to scale
Figure Q1(b)

Question 2

Figure Q2 shows a steel platform supporting an equipment and a working platform. The equipment is sitting on 4 numbers of stumps. When fully loaded, factored design action for the equipment is given as 975 kN, and factored Design Action for working platform is given as 20 kN/m^2. You can use table and data provided to assist your calculations.

(a) Ignoring self-weight of the structural framing, calculate and draw the shear force and bending moment diagram for beam ABCD shown in Figure Q2.

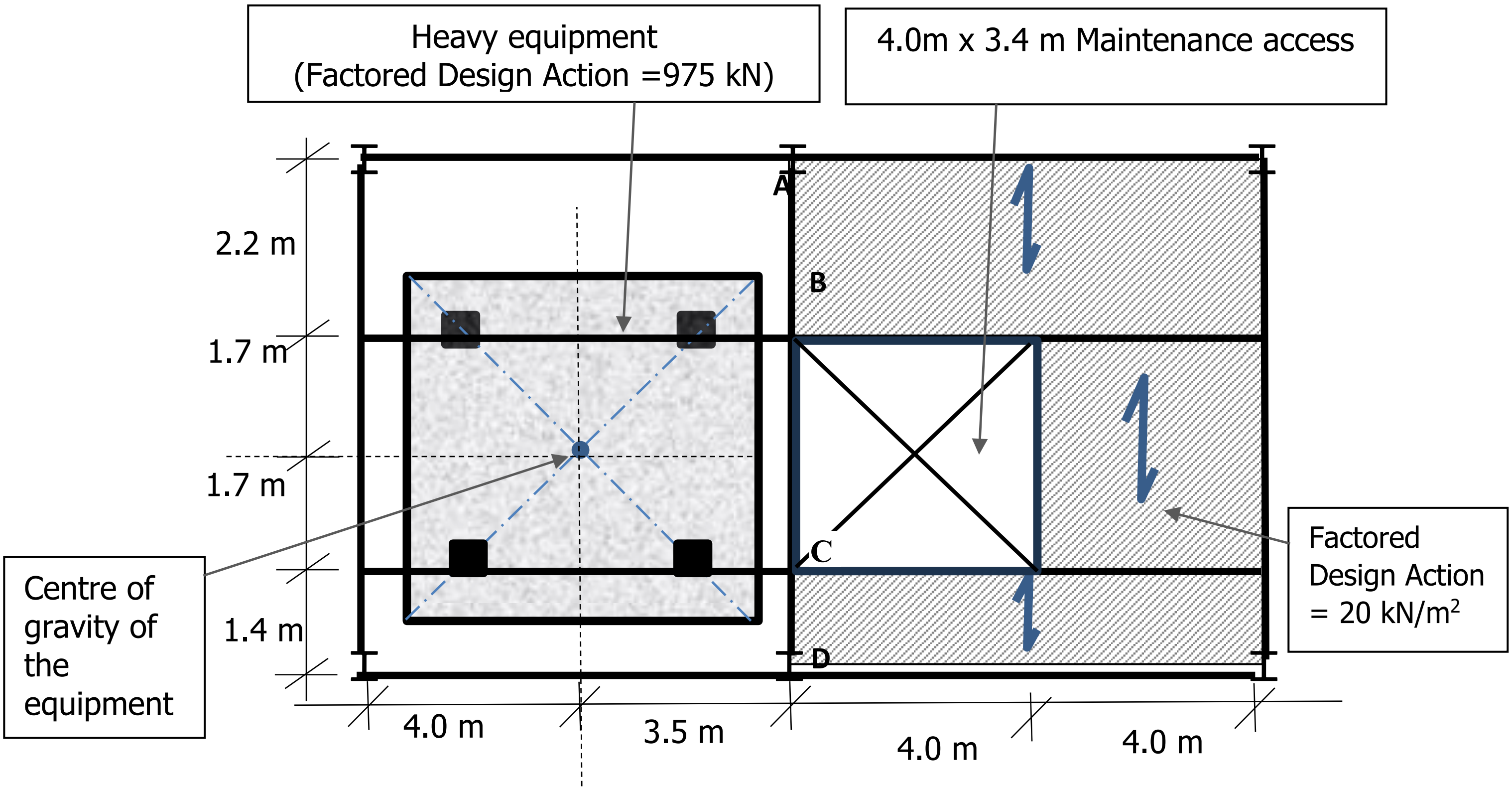
(10 Marks)

(b) Using steel grade of S355, check if UB533x210x82 is sufficient to provide Lateral Torsional Buckling (LTB) resistance in accordance to Eurocode 3. Other design checks are not required. You can assume that lateral restraints are provided at point A, B, C & D. State other assumptions in your calculations, if any.

(7 Marks)

(c) Regardless of the design check results in Q2(b) above, assume that design check on LTB failed by a margin of 10%, propose two possible solutions to improve the LTB resistance for beam ABCD, provide sketches for your proposed solutions. No calculation is required for the proposed solutions. Assumed that the platform columns, main beams and secondary beams have been erected, but the equipment and platform deck are not yet installed.

(3 Marks)



PLAN VIEW (Note: drawings are not drawn to scale)
Figure Q2

Question 3

(a) A rectangular short column of size 350 mm by 500 mm is required to resist an axial load of 3600 kN. What is the area of steel required? Provide a sketch showing the reinforcement details, including the links to be provided.

(8 marks)

(b) Re-design the rectangular column in Part (a), of size 350 mm and 500 mm to resist an additional bending moment of 300 kNm. Provide a sketch showing the revised reinforcement details, including the links to be provided.

(12 marks)

Assume a clear cover of 30 mm to the links. Use f_{ck} = 32 N/mm^2 and f_{yk} = 500 N/mm^2. State clearly why the respective reinforcing bar sizes are chosen.

Design aids in the form of design charts or tables may be provided.

Question 4

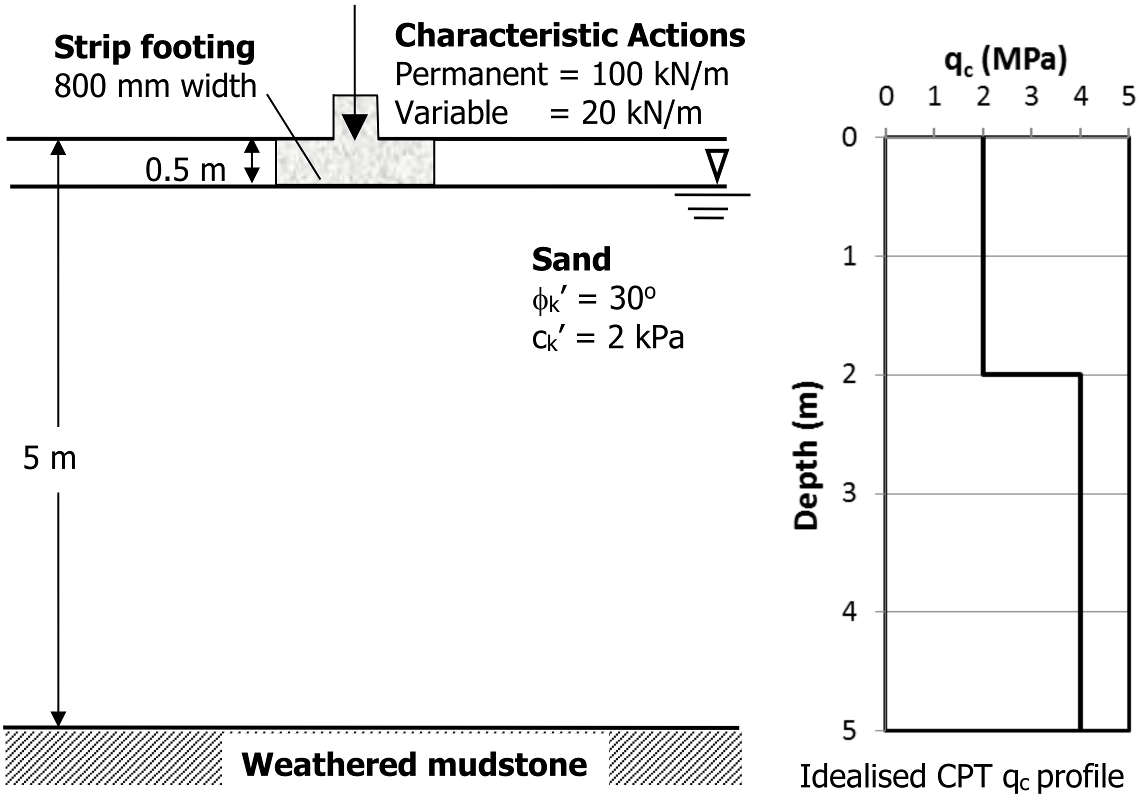
A warehouse on concrete footings is to be built at a rural site. The soil profile, soil properties and idealised CPT q_c profile of the site are shown in Figure Q4. The characteristic unit weight of the sand is 16 kN/m^3 above and below the groundwater table. One of the strip footings is shown in Figure Q4. The characteristic unit weight of concrete is 25 kN/m^3.

(a) Determine if the strip footing shown in Figure Q4 is satisfactory with respect to ultimate limit state for bearing capacity using Eurocode 7 Design Approach 1, Combinations 1 and 2.

(12 Marks)

(b) Using the idealised CPT q_c profile, sketch the strain influence diagram and estimate the settlements of the strip footing shown in Figure Q4 immediately and 25 years after construction using Schmertmann method. Assume E = 3.5q_c.

(8 Marks)



Note: Drawing not drawn to scale

Figure Q4

Question 5

(a) The flow-density fundamental relationship on a roadway is approximated by:

$$q = \begin{cases} 73.33k & \text{for } 0 \le k \le 30 \\ 2934 - 24.45k & \text{for } 30 \le k \le 120 \end{cases}$$

where k is measured in vehicles/lane/kilometre. On a given day, the flow on the roadway is estimated to be 1,600 veh/lane/h. However, at 10:00 a.m., an incident takes place, dropping the capacity to 1,200 veh/lane/h. Thirty minutes after the occurrence, the incident is cleared and the capacity is restored to its normal value. Considering no upstream ramps within the range of the queue resulting from this incident, what are the speeds of the forming and clearing waves that result?

(10 Marks)

(b) A dual-lane, two-way connector is envisioned to link the level Road Segment A to the level Road Segment B, as shown in Figure Q5. To determine its feasibility, several key factors should be taken into consideration. The driver reaction time is set at 2.5 seconds, the standard driver eye height is 1.050 metres, the tyre-pavement friction coefficient stands at 0.35, the designated object height for stopping is 0.15 metre, and the ramp is designed for a speed of 54 km/h. Perform applicable calculations to check if it is feasible to develop the connector.

(10 Marks)

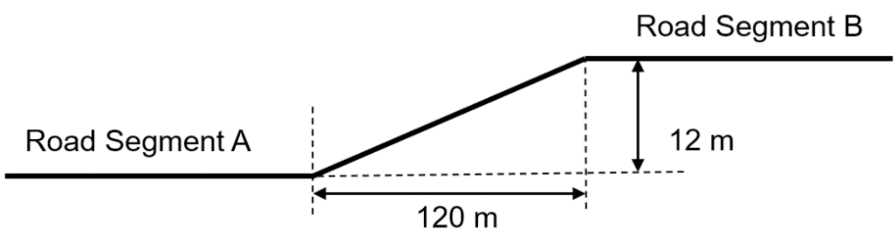


Figure Q5

The following formulas may be useful:

$$d_r = vt_r\,;\; d_b = \frac{v^2}{2g(f \pm G)}$$

$$L_{min} = \begin{cases} \dfrac{AS^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2} & \text{when } S \le L \\ 2S - \dfrac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A} & \text{when } S > L \end{cases}$$

$$L_{min} = \begin{cases} \dfrac{AS^2}{200[0.6 + S(\tan 1^0)]} = \dfrac{AS^2}{120 + 3.5S} & \text{when } S \le L \\ 2S - \dfrac{200[0.6 + S(\tan 1^0)]}{A} = 2S - \dfrac{120 + 3.5S}{A} & \text{when } S > L \end{cases}$$

Question 6

A trapezoidal channel has a bottom width b = 10 m and a side slope of 1 vertical to 3 horizontal. The longitudinal channel bed slope S_o is 0.002 and the Manning's roughness coefficient, n = 0.025. The uniform flow depth in the channel is y_o = 2 m.

(a) Calculate the discharge, Q (m^3/s) in the trapezoidal channel.

(10 Marks)

(b) Calculate the critical flow depth, y_c in the channel.

(4 Marks]

(c) Is the flow regime subcritical or supercritical? Show calculations to justify your answer.

(3 Marks)

(d) What is the type of channel slope under this flow condition? Show calculations to justify your answer.

[Hint: Open channel slope can be classified into 5 types: Mild, Steep, Critical, Horizontal or Adverse]

(3 Marks)

<u>Useful equations:</u>

Manning's equation, $Q = \frac{1}{n} A R_h^{2/3} S_o^{1/2}$

Critical flow condition for non rectangular channel: $\frac{Q^2 B_c}{g A_c^3} = 1$

Froude number for non rectangular channel, $Fr = \frac{V}{\sqrt{g y_h}}$

where R_h = hydraulic radius, A = cross-sectional flow area, B_c = top width of non rectangular channel at critical flow condition, A_c = cross-sectional flow area at critical flow condition, g = gravitational acceleration, y_h = hydraulic mean depth = A/B, B = top width.

Question 7

(a) A primary clarifier with a surface area overflow rate of 55 m^3/m^2.day receives a wastewater from an equivalent population of 45,000 having a capita flow rate of 550 L/d and a per capita suspended solids (SS) of 32 g/d.

(i) Determine the clarifier **diameter** and **depth** based on a 2-hour hydraulic retention time.

(4 marks)

(ii) Determine the volume of primary sludge produced daily if 75% of the SS are removed by the clarification process. Assume that the sludge contains 1.5% SS, the sludge specific gravity is 1.005, and a water density of 1,000 kg/m^3.

(4 marks)

(b) An activated sludge process is used to treat a combined wastewater from two separate sources of seafood processing and raw sugar refining, respectively. The seafood processing produces a wastewater stream of 200 m^3/d with 550 BOD_5/L, and the sugar refinery produces another wastewater stream of 320 m^3/d with 650 BOD_5/L. The activated sludge reactor is operating at an organic loading rate of 4 kg BOD_5/m^3.d.

(i) Calculate the **volume** of the reactor and the **hydraulic retention time** based on the combined wastewater flow and BOD_5 concentration.

(6 marks)

(ii) For a Food/Microorganism ratio of 0.6 kg BOD_5/kg MLVSS.d, what MLVSS concentration should be maintained in the aeration tank?

(3 marks)

(iii) Estimate the mean cell residence time, assuming an effluent volatile solids concentration of 20 mg/L and the daily amount of waste sludge is 95 m^3 that contains 1% of volatile solids.

(3 marks)

Given:

Hydraulic retention time = BOD_5 concentration/ Organic loading rate

$F/M = (Q \times S)/ (V_r \times MLVSS)$

Mean cell residence time, $\theta_C = V_r \times MLVSS/ (Q_e \times X_e + Q_w \times X_r)$

Where:

F/M is food to Microorganism ratio
Q is Flow rate
S is organic concentration BOD_5
V_r is volume of reactor
θ_C is Mean cell residence time
MLVSS is Mixed Liquor Volatile Suspended Solid
Q_e is effluent flow rate m^3/d
X_e is effluent volatile solids
Q_w is waste sludge flow rate m^3/d
X_r is volatile solid in sludge

II Fundamentals Of Engineering Examination (Electrical)

The examination will focus on testing the fundamentals of electrical power engineering. The 6-hour examination will comprise two parts.

Format

- **FEE Part 1 (Electrical) (3 hours & 10 mins) - 40 MCQ questions**
  - EE 101 Principles of Power Engineering
- **FEE Part 2 (Electrical) (3 hours & 10 mins) - 5 out of 7 questions**
  - EE 201 Power System Analysis and Utilization

Syllabus

- **EE 101 Principles of Power Engineering**
  - **Three-phase Circuits and Systems**
    Review of single-phase circuits. Three-phase voltage generation. Phasor diagrams. Wye and delta connections. Balanced / unbalanced three-phase loads. Active, reactive and apparent power. Power measurements. Power factor correction.
  - **Magnetism and Magnetic Circuits**
    Magnetic fields. Magnetic materials and magnetization curves. Magnetic equivalent circuits. Electromagnetic induction. Sinusoidal excitation. Magnetic losses.
  - **Transformers**
    Ideal transformer. Equivalent circuits. Phasor diagrams. Determination of parameters. Performance evaluation. Autotransformers. Three-phase transformers. Phase shift transformers.
  - **AC and DC Machines**
    DC Machines: operating principle, voltage and torque equations, classification, torque-speed characteristics, losses and efficiency. Three-phase induction motors: operating principle, assist starting, starting methods, equivalent circuit, torque-speed characteristics, losses and efficiency. Brushless DC motor, PMSM.
  - **Power Electronics**
    Introduction to power conversion. Harmonics. AC to DC conversion. DC to DC conversion. DC to AC conversion. DC servo motor drive systems. AC variable-speed induction motor drive systems. Permanent magnet and stepping motor drive systems. Power Electronics devices.

- **Fundamental of Power Systems**
  Energy sources. Per unit system. Power system components and representation: synchronous generators, transmission lines and cables. Load representations. Power transfer. Power system stability.

- **Power Flow Modelling**
  System components modelling. Formulation of power flow equations. Methods of power flow solution.

- **Applications of High-voltage Engineering**
  Insulation materials and properties. Electrical breakdown in gases, liquids, and solids. High voltage cables. High voltage switchgear. Lightning and surge protection. Acceptance and routine tests on apparatus.

- **<u>EE 201 Power System Analysis and Utilizations</u>**

  - **Power System Operation and Control**
    Governor control systems. Active power and frequency control. Production and absorption of reactive power. Methods of voltage control. Reactive power and voltage control. Application to transmission and distribution systems.

  - **Analysis of Symmetrical and Unsymmetrical Faults**
    Three-phase faults and fault level calculations. Symmetrical components. Sequence impedances and sequence networks. Unsymmetrical faults.

  - **Electric Power Distribution Systems**
    Distribution system configurations. Primary and secondary distribution. Ring, radial and inter-connected systems. Distribution substation layout. Planning criteria and network design.

  - **Building Services Engineering**
    Estimation of power demand. Conductor sizing and correction factors. Earthing system, earth fault and touch voltage.

  - **General Protection Principles**
    Basic protection principles. Instrument transformers. Coordination of IDMTL and DTL overcurrent and earth protection for distribution systems. Differential protection of feeders and transformers.

  - **Electric Drives**
    Controlled converter fed DC motor drives. Chopper circuit configurations in DC drives. Inverter fed AC drives. Variable voltage and variable frequency operation. Power quality and harmonics.

- **Sustainable Energy Technology and Applications**
  Distributed energy resources. Sustainable energy technology. Solar PV technology. PV system design. Grid-tied PV systems. Energy conversion and energy storage system.

Recommended Reading List for Electrical Engineering

FEE Part 1 (Electrical)
EE 101 Principles of Power Engineering

1) Guru Bhag S and Hiziroglu Huseyin R, Electric Machinery and Transformers, 3rd Edition, Oxford University Press, 2001.

2) Sen Paresh Chandra, Principles of Electric Machines and Power Electronics, Hoboken, NJ: John Wiley & Sons, 2014.

3) Chapman Stephen J, Electric Machinery and Power System Fundamentals, 1st Edition, McGraw-Hill, 2002.

4) Wildi Theodore, Electrical Machines, Drives and Power Systems, 6th Edition, Pearson/Prentice-Hall, 2006

FEE Part 2 (Electrical)
EE 201 Power System Analysis and Utilizations

1) Grainger John J and Stevenson William D, Power System Analysis.

2) Weedy B M and Cory B J, Jenkins N, Ekanayake J B, Strbac G, Electric Power Systems.

3) Code of Practice for Electrical Installations, (Singapore Standards, SS638:2018),Enterprise Singapore 2018.

4) Lakervi E and Holmes E J, Electricity Distribution Network Design, (IEE Power Engineering Series).

5) Naidu M S and Kamaraju V, High Voltage Engineering.

6) Ram Badri and Vishwakarma D N, Power System Protection and Switchgear.

7) Teo Cheng Yu, Principles and Design of Low Voltage Systems.

8) Blackburn J Lewis, Protective Relaying: Principles and Applications.

9) Code of Practice for Grid Connected Solar Photovoltaic System, The Institution of Engineering and Technology, 2015

10) David William Spitzer, Variable Speed Drives

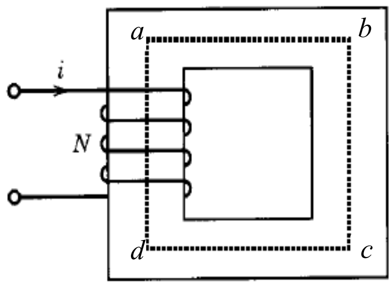
Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 1 (Electrical)

(Actual paper comprises 40 Multiple Choice Questions (MCQ) of 2.5 marks each. Answer all questions.)

1 A factory uses 3-phase, 400 V commercial power. The principal users of power are an induction motor operating at 300 kW with a power factor of 0.65 lagging and an injection moulding machine operating at 600 kVA with a power factor of 0.63 lagging. What is the power factor for the factory?

(a) 0.61
(b) 0.78
(c) 0.59
(d) 0.64

2 1-phase 230 V 50 Hz supply is connected to the coil of Figure Q2. Use the following parameters of the core and find the current in the coil.



Length of abcd = 80 cm

Cross sectional area of core = 20 cm^2

N= 180 turns

Permeability = 3.1415×10^{-3} H/m

Figure Q2

(a) 4.07 sin(ωt) A
(b) 0.407 sin(ωt) A
(c) 3.89 sin(ωt) A
(d) 0.389 sin(ωt) A

3 What is the flux density in a round iron core if its diameter is 2 cm and flux Φ is 7×10^{-5} Wb.

(a) 0.056 T
(b) 2.23×10^{-5} T
(c) 3.5×10^{-5} T
(d) 0.223 T

4 Two transformers, T1 and T2, are connected in parallel. Transformer T1 is rated at 1,500 kVA with 5% impedance, and transformer T2 is rated at 2,000 kVA with 6% impedance. The transformers have the same turns ratio, and are connected to a common 3,000 kVA load. What is the loading on each transformer?

(a) S_{T1} = 1,256 kVA, S_{T2} = 1,744 kVA
(b) S_{T1} = 1,364 kVA, S_{T2} = 1,636 kVA
(c) S_{T1} = 1,421 kVA, S_{T2} = 1,579 kVA
(d) S_{T1} = 1,714 kVA, S_{T2} = 1,286kVA

5 The field current of a separately excited DC motor is increased by 10 %. What is the expected change in motor speed?

(a) No change
(b) Increase by about 10 %
(c) Decrease by about 10 %
(d) Decrease by about 5 %

6 A motor is rated at 200 kW, 970 rev/min. What is the rated torque of the motor?

(a) 150.8 Nm
(b) 1969 Nm
(c) 1358 Nm
(d) 978.5 Nm

7 In Figure Q7, what is the theoretical maximum voltage encountered by Mosfet Q1 in the converter, given that V_{DC} = 50V and the turn ratio of N_P:N_S:N_R = 3:2:1?

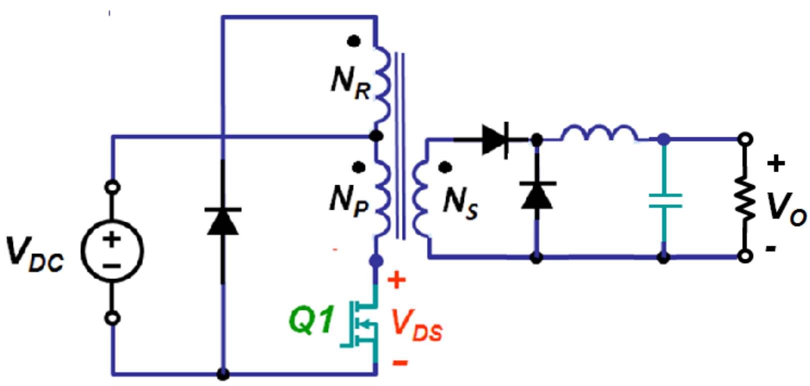


Figure Q7

(a) 100V
(b) 200V
(c) 300V
(d) 400V

8 The governor characteristic of a generator has a three percentage drop in speed from no-load to full load of 200 MW. When the power output of the generator is reduced to 60 % of its rated capacity, determine the new governor setting and associated governor characteristic to maintain the frequency of the machine at 1.0 p.u.

(a) 1.08 %
(b) 1.2 %
(c) 1.8 %
(d) 5 %

9 In the solution algorithm of the power flow problems, what would need to be computed first before other quantities are calculated?

(a) Active and reactive power flows in all the lines
(b) Voltage magnitude and phase angle of each bus
(c) Active and reactive power losses in each line
(d) Line currents

10 If a power system has 10 load buses and 6 generator buses (inclusive of the slack bus), what is the total number of independent power flow equations that needs to be set up?

(a) 25
(b) 24
(c) 23
(d) 20

Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 2 (Electrical)

(Actual paper comprises 7 questions. Answer 5 questions)

Question 1

A star-connected generator rated 360 MW at 18 kV, and 0.85 power factor (pf) lag is connected to an infinite bus. The synchronous reactance is specified as 1 ohm per phase. Determine:

(a) The armature current (I_a), the generated emf (E line-to-line), power angle (δ), active power (P), and reactive power (Q) at the rated conditions.
(10 marks)

(b) Assume that the prime mover input to the generator of part (a) is reduced by 50% without changing the excitation. Find the new operating conditions, i.e., I_a, δ, P, Q and pf if the generator has zero internal losses.
(10 marks)

Question 2

A 50-MVA, 12.5 kV generator has a direct-axis sub-transient reactance of 0.25 per unit. The negative- and zero-sequence reactances are, respectively, 0.35 and 0.10 per unit. The neutral of the generator is solidly grounded. When a single line-to-ground fault occurs at the generator terminals with the generator operating unloaded at rated voltage, determine

(a) the sub-transient current (in amperes) in the generator, and
(8 marks)

(b) the line-to-line voltages (in kV) for sub-transient conditions.
(12 marks)

Question 3

(a) Distribution system configurations can be classified by their topology, such as radial, loop, and mesh systems, which describe how power flows and redundancy are structured.

(i) Explain how power flow differs between a radial and a loop distribution system.

(2 marks)

(ii) Why is a mesh distribution system generally considered more reliable than a radial distribution system?

(2 marks)

(iii) An industrial park requires high supply reliability and allows multiple feeder connections. Which topology would best suit this requirement, and why?

(2 marks)

(iv) Explain why "redundancy" is a key differentiating feature among the radial, loop, and mesh topologies.

(2 marks)

(b) Low voltage distribution systems (400V phase-to-phase, and 230V phase-to-neutral) are supplied by the secondary windings of the distribution transformers.

(i) Explain why the secondary windings are star-connected while the primary windings are delta connected?

(4 marks)

(ii) Distribution transformers often have a Dyn11 vector group designation. Explain what each part of the "Dyn11" indicates.

(4 marks)

(iii) During a line-to-ground fault on the secondary side of a delta-star distribution transformer, explain how the winding configuration influences fault current behaviour and system protection.

(4 marks)

Question 4

The electrical single line diagram of an existing factory is shown in Figure Q4.

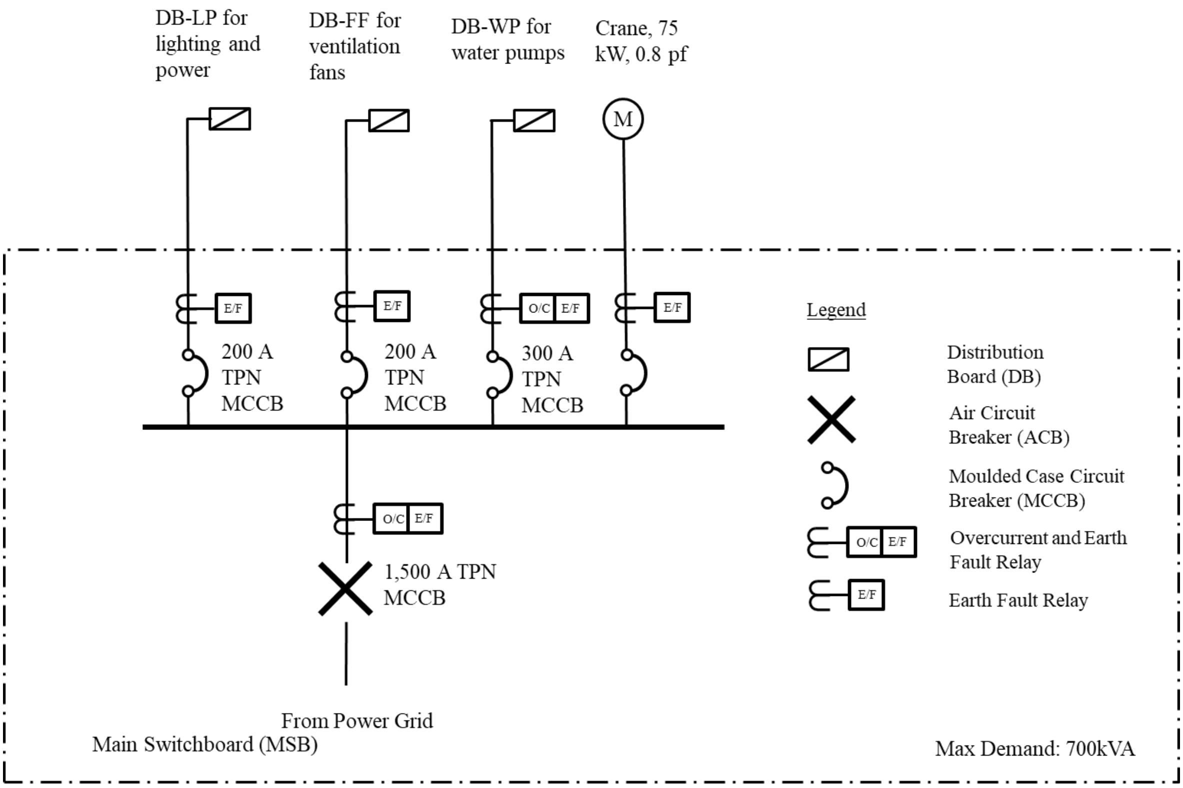


Figure Q4: Single Line diagram of the existing facility

(a) A 75 kW, 3-phase, 400 V crane motor with a power factor of 0.8 is supplied from the Main Switchboard (MSB) via a 60-metre long, single core, copper cable with PVC insulation. The cable is installed individually in a trunking, and the voltage drop must not exceed 1.5% of the supply voltage. Using the Tables 4.1, 4.2, determine the minimum cable size required for this crane motor installation.

(4 marks)

Available size of Moulded Case Circuit Breaker (MCCB):
60 A, 100 A, 150A, 200 A, 250 A, 320 A, 400 A, 500 A, 630 A

(b) The external earth fault loop impedance measured at the Main Switchboard (MSB) (Z_e) is 0.45 ohm. Calculate the earth fault current when a single-phase to earth fault occurs at the crane motor terminal. The size of the Circuit Protective Conductor (CPC) is selected based on Tables 4.3 and 4.4 below.

(2 marks)

(c) The distribution circuit to the crane is provided with a Definite Time lag (DTL) Earth Fault Relay with current setting of 5 A and time setting of 0.5 sec. Determine whether the CPC is able to withstand the thermal constraints during the earth fault in (b). K value of PVC cable is 115.

(2 marks)

(d) A factory expansion requires additional fire fighting equipment to be installed to comply with the fire safety requirements. An automatic mains failure emergency generator must be provided to supply power to all fire fighting equipment during power outages. The electrical and starting kVA of the fire fighting equipment are listed in Table 4.5 below. Determine the minimum rated kVA of the emergency generator.

(4 marks)

Available kVA rating of generators:
100 kVA, 150 kVA, 200 kVA, 250 kVA, 300 kVA, 400 kVA, 500 kVA, 600 kVA, 700 kVA, 800kVA, 1,000 kVA.

(e) Using the existing single line diagram shown in Figure Q4 as reference, design the electrical single line diagram for the factory expansion including the emergency generator supply. Your diagram should clearly indicate the number of poles and current rating of all additional circuit breakers required. Cable sizes and protection relays are not required to be shown.

(8 marks)

CURRENT-CARRYING CAPACITY (amperes):

Ambient temperature: 30°C
Conductor operating temperature: 70°C

Conductor cross-sectional area	Reference Method 4 (enclosed in conduit in thermally insulating wall etc.)		Reference Method 3 (enclosed in conduit on a wall or in trunking etc.)		Reference Method 1 (clipped direct)		Reference Method 11 (on a perforated cable tray horizontal or vertical)		Reference Method 12 (free air)		
									Horizontal flat spaced	Vertical flat spaced	Trefoil
	2 cables, single-phase a.c. or d.c.	3 or 4 cables, three-phase a.c.	2 cables, single-phase a.c. or d.c.	3 or 4 cables, three-phase a.c.	2 cables, single-phase a.c. or d.c. flat and touching	3 or 4 cables, three-phase a.c. flat and touching or trefoil	2 cables, single-phase a.c.or d.c. flat and touching	3 or 4 cables, three-phase a.c. flat and touching or trefoil	2 cables, single-phase a.c. or d.c. or 3 cables three-phase a.c.	2 cables, single-phase a.c. or d.c. or 3 cables three-phase a.c.	3 cables trefoil, three phase a.c.
1	2	3	4	5	6	7	8	9	10	11	12
(mm²)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1	11	10.5	13.5	12	15.5	14	-	-	-	-	-
1.5	14.5	13.5	17.5	15.5	20	18	-	-	-	-	-
2.5	19.5	18	24	21	27	25	-	-	-	-	-
4	26	24	32	28	37	33	-	-	-	-	-
6	34	31	41	36	47	43	-	-	-	-	-
10	46	42	57	50	65	59	-	-	-	-	-
16	61	56	76	68	87	79	-	-	-	-	-
25	80	73	101	89	114	104	126	112	146	130	110
35	99	89	125	110	141	129	156	141	181	162	137
50	119	108	151	134	182	167	191	172	219	197	167
70	151	136	192	171	234	214	246	223	281	254	216
95	182	164	232	207	284	261	300	273	341	311	264
120	210	188	269	239	330	303	349	318	396	362	308
150	240	216	300	262	381	349	404	369	456	419	356
185	273	245	341	296	436	400	463	424	521	480	409
240	320	286	400	346	515	472	549	504	615	569	485
300	367	328	458	394	594	545	635	584	709	659	561
400	-	-	546	467	694	634	732	679	852	795	656
500	-	-	626	533	792	723	835	778	982	920	749
630	-	-	720	611	904	826	953	892	1138	1070	855
800	-	-	-	-	1030	943	1086	1020	1265	1188	971
1000	-	-	-	-	1154	1058	1216	1149	1420	1337	1079

Table 4.1: Current carrying capacity of single-core PVC insulated, non-armoured copper cable

VOLTAGE DROP (per ampere per metre): Conductor operating temperature: 70°C

Conductor cross-sectional area	2 cables d.c.	2 cables, single-phase a.c.									3 or 4 cables, three-phase a.c.											
		Reference Methods 3 & 4 (enclosed in conduit etc. in or on a wall)			Reference Methods 1 & 11 (clipped direct or on trays, touching)			Reference Method 12 (spaced*)			Reference Methods 3 & 4 (enclosed in conduit etc. in or on a wall)			Reference Methods 1, 11 & 12 (in trefoil)			Reference Methods 1 & 11 (flat and touching)			Reference Method 12 (flat spaced*)		
1	2	3			4			5			6			7			8			9		
(mm²)	(mV/A/m)	(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)		
1	44	44			44			44			38			38			38			38		
1.5	29	29			29			29			25			25			25			25		
2.5	18	18			18			18			15			15			15			15		
4	11	11			11			11			9.5			9.5			9.5			9.5		
6	7.3	7.3			7.3			7.3			6.4			6.4			6.4			6.4		
10	4.4	4.4			4.4			4.4			3.8			3.8			3.8			3.8		
16	2.8	2.8			2.8			2.8			2.4			2.4			2.4			2.4		
		r	x	z	r	x	z	r	x	z	r	x	z	r	x	z	r	x	z	r	x	z
25	1.75	1.80	0.33	1.80	1.75	0.20	1.75	1.75	0.29	1.80	1.50	0.29	1.55	1.50	0.175	1.50	1.50	0.25	1.55	1.50	0.32	1.55
35	1.25	1.30	0.31	1.30	1.25	0.195	1.25	1.25	0.28	1.30	1.10	0.27	1.10	1.10	0.170	1.10	1.10	0.24	1.10	1.10	0.32	1.15
50	0.93	0.95	0.30	1.00	0.93	0.190	0.95	0.93	0.28	0.97	0.81	0.26	0.85	0.80	0.165	0.82	0.80	0.24	0.84	0.80	0.32	0.86
70	0.63	0.65	0.29	0.72	0.63	0.185	0.66	0.63	0.27	0.69	0.56	0.25	0.61	0.55	0.160	0.57	0.55	0.24	0.60	0.55	0.31	0.63
95	0.46	0.49	0.28	0.56	0.47	0.180	0.50	0.47	0.27	0.54	0.42	0.24	0.48	0.41	0.155	0.43	0.41	0.23	0.47	0.40	0.31	0.51
120	0.36	0.39	0.27	0.47	0.37	0.175	0.41	0.37	0.26	0.45	0.33	0.23	0.41	0.32	0.150	0.36	0.32	0.23	0.40	0.32	0.30	0.44
150	0.29	0.31	0.27	0.41	0.30	0.175	0.34	0.29	0.26	0.39	0.27	0.23	0.36	0.26	0.150	0.30	0.26	0.23	0.34	0.26	0.30	0.40
185	0.23	0.25	0.27	0.37	0.24	0.170	0.29	0.24	0.26	0.35	0.22	0.23	0.32	0.21	0.145	0.26	0.21	0.22	0.31	0.21	0.30	0.36
240	0.180	0.195	0.26	0.33	0.185	0.165	0.25	0.185	0.25	0.31	0.17	0.23	0.29	0.160	0.145	0.22	0.160	0.22	0.27	0.160	0.29	0.34
300	0.145	0.160	0.26	0.31	0.150	0.165	0.22	0.150	0.25	0.29	0.14	0.23	0.27	0.130	0.140	0.190	0.130	0.22	0.25	0.130	0.29	0.32
400	0.105	0.130	0.26	0.29	0.120	0.160	0.20	0.115	0.25	0.27	0.12	0.22	0.25	0.105	0.140	0.175	0.105	0.21	0.24	0.100	0.29	0.31
500	0.086	0.110	0.26	0.28	0.098	0.155	0.185	0.093	0.24	0.26	0.10	0.22	0.25	0.086	0.135	0.160	0.086	0.21	0.23	0.081	0.29	0.30
630	0.068	0.094	0.25	0.27	0.081	0.155	0.175	0.076	0.24	0.25	0.08	0.22	0.24	0.072	0.135	0.150	0.072	0.21	0.22	0.066	0.28	0.29
800	0.053		-		0.068	0.150	0.165	0.061	0.24	0.25		-		0.060	0.130	0.145	0.060	0.21	0.22	0.053	0.28	0.29
1000	0.042		-		0.059	0.150	0.160	0.050	0.24	0.24		-		0.052	0.130	0.140	0.052	0.20	0.21	0.044	0.28	0.28

Table 4.2: Voltage drop of single-core PVC insulated, non-armoured copper cable

Cross-sectional area of line conductor S	Minimum cross-sectional area of the corresponding protective conductor	
	If the protective conductor is of the same material as the line conductor	If the protective conductor is not of the same material as the line conductor
(mm²)	(mm²)	(mm²)
$S \leq 16$	S	$\frac{k_1}{k_2} \times S$
$16 < S \leq 35$	16	$\frac{k_1}{k_2} \times 16$
$S > 35$	$\frac{S}{2}$	$\frac{k_1}{k_2} \times \frac{S}{2}$

Table 4.3: Minimum cross-sectional area of protective conductor in relation to the cross-sectional area of associated line conductor, where:

k1 is the value of k for the line conductor, k2 is the value of k for the protective conductor (assume k value for PVC cable is 115 and k value for XLPE cable is 143)

Area of conductor (mm^2)	Resistance of copper (mΩ/m) at 20 °C
1.5	12.1
2.5	7.41
4	4.61
6	3.08
10	1.83
16	1.15
25	0.727
35	0.524
50	0.387
70	0.263

Table 4.4: Resistance of copper conductor at 20 °C

Starting sequence of equipment*	Equipment	Electrical Load (kVA)	Quantity	Starting kVA
1	Roller shutter	11	1	33
2	Smoke control fans	22	1	132
3	Fire Lift	25	1	60

Table 4.5: The electrical and starting kVA of the firefighting equipment

* All the equipment is three-phase, 400 V, the equipment is started in sequence. The next equipment will start after the preceding equipment has reached steady state.

Question 5

(a) A 22kV feeder is protected by an IDMT overcurrent relay with IEC standard inverse characteristic. The plug setting (PS) is 5A and time multiplier setting (TMS) is 0.23. Calculate the relay operating time when a current of 10 A and 50 A is injected.

Inverse definite minimum time (IDMT)

$$t = \frac{K \times [TMS]}{(I/Is)^{\alpha} - 1}$$

Where
- t = operation time
- K = constant
- I = fault current
- Is = current threshold setting
- α = constant
- TMS = time multiplier (0.025 to 1.2 in steps of 0.025)

Curve description	Constants		Minimum operation
Short time inverse	K = 0.05	α = 0.04	1.05 Is
Standard inverse	K = 0.14	α = 0.02	1.05 Is

Table 5: Formula and constants of IDMTL characteristic curve to IEC Standard

(5 marks)

(b) The specifications of a 500/5 current transformer (CT) is 5P20, 5 VA and CT resistance is 0.10 Ω. The CT connected burden is 1.25 VA. Calculate the actual accuracy limiting factor (ALF) and convert it to primary of the CT?

(5 marks)

(c) A 22 kV/400V 1MVA Dy11 transformer is protected by an IDMTL overcurrent (OC) relay with IEC standard inverse characteristic on the 22 kV side. The current transformer ratio is 75/1. The OC relay plug setting (PS) is 0.75 A and time multiplier setting (TMS) is 0.35.

The transformer LV phase L1 cable developed an earth fault current of 10,000 A. Calculate the relay operating time. Which phase(s) showed trip indication?

(10 marks)

Question 6

(a) A permanent-magnet DC servo motor has the following parameters:

Rated torque, T_{rated} = 10 Nm
Rated speed, N_{rated} = 3500 rpm
Torque constant, K_T = 0.5 Nm/A
Voltage constant, K_E = 50 V/1000 rpm
Armature resistance, R_a = 0.4 Ω

Calculate the terminal voltage V_t in steady state if the motor is required to deliver a torque of 5 Nm at a speed of 1500 rpm.

(8 Marks)

(b) When inverter-fed variable-frequency control is applied to induction motors, constant voltage/frequency (V/f) ratio is maintained. Motor torque-speed curves for various frequencies from full-load motoring to full-load braking can be assumed to be parallel straight lines, each passing through corresponding synchronous speed without significant error, as shown in Fig. Q6.

An induction motor has a full-load speed of 1430 rpm when supplied from an inverter at its rated frequency of 50 Hz and rated voltage. Determine

(i) Speed for a frequency of 40 Hz and 80% of full-load torque.
(ii) The frequency for a speed of 1000 rpm and full-load torque.
(iii) The torque for a frequency of 30 Hz and speed of 850 rpm.
(iv) The torque for a frequency of 40 Hz and speed of 1300 rpm (regenerative braking mode).

Note:
We can use simple trigonometry to calculate the torque-speed relationship because motor torque-speed curves for various frequencies from full-load motoring to full-load braking can be assumed to be parallel straight lines, each passing through corresponding synchronous speed.

(12 Marks)

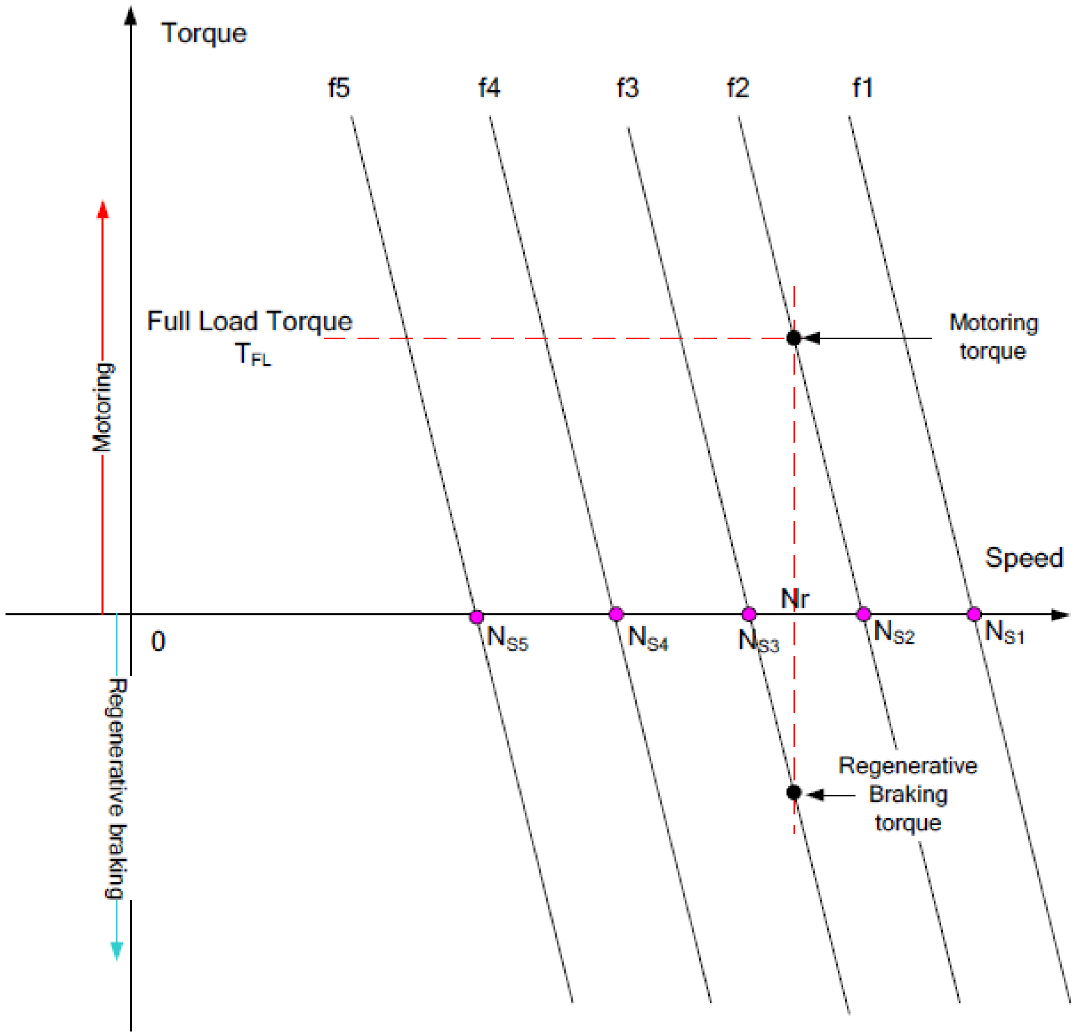


Figure Q6 – Torque-speed curve of an induction motor under constant V/f control

Question 7

(a) High penetration of inverter-based Distributed Energy Resources (DERs) has fundamentally changed the operational paradigm of distribution networks—from passive radial systems to active networks.
Discuss the implications for (i) voltage regulation, (ii) protection coordination, and (iii) system inertia.

(5 marks)

(b) What is anti-islanding protection, and why is it mandatory in grid-tied inverters?

(5 marks)

(c) You are an electrical engineer in a renewable energy consultancy firm in Singapore. Your client—a mid-sized logistics company—wants to install a grid-tied, non-storage solar PV system on the rooftop of its warehouse in Jurong Industrial Estate. The following data is provided:

- Annual electricity consumption: 320,000 kWh
- Available roof area: 1,200 m^2 (flat concrete roof; no major obstructions, but surrounded by low-rise buildings)
- Grid connection: 400 V, 3-phase, 50 Hz
- Average daily global horizontal irradiance (GHI): 4.8 $kWh/m^2/day$ (similar to Peak Sun Hours)
- Desired solar energy offset: 70% of annual consumption
- Expected system performance ratio (PR): 0.76 (accounts for high temperature losses, soiling from urban dust/haze, wiring, inverter, and mismatch)

Your procurement department has secured a brand of PV module with the following key performance parameters:

- Power per module/panel: 585 W
- Dimensions per module/panel: 2.58 m2

Design Requirements:

i. Calculate the required DC PV array capacity (kW).
ii. Verify that the gross roof area of 1,200 m^2 is sufficient to achieve the desired solar offset of 70% of annual consumption.
iii. Estimate annual AC energy yield and CO_2 savings (use Singapore's grid emission factor: 0.413 kg CO_2/kWh).

(10 marks)

III Fundamentals Of Engineering Examination (Mechanical)

The examination will focus on testing the fundamentals of mechanical engineering. The 6-hour examination will comprise two parts:

Format

- **FEE Part 1 (Mechanical) (3 hours & 10 mins) – 40 MCQ questions**
  - ME 101 Control and Instrumentations
  - ME 102 Dynamics and Vibrations
  - ME 103 Fluid Mechanics
  - ME 104 Mechanics and Materials
  - ME 105 Manufacturing Technology
  - ME 106 Thermodynamics and Heat Transfer

- **FEE Part 2 (Mechanical) (3 hours & 10 mins) – 5 out of 7 questions**
  - ME 201 Control and Instrumentations
  - ME 202 Dynamics and Vibrations
  - ME 203 Fluid Mechanics
  - ME 204 Mechanics and Materials
  - ME 205 Manufacturing Technology
  - ME 206 Thermodynamics and Heat Transfer

Syllabus

- **ME 101/201 Control And Instrumentations**
  - **Modelling of Linear Systems**
    Introduction to control systems. Mathematical modelling of electro-mechanical systems. Transfer functions representation of physical components. Block diagram manipulation.
  - **Dynamic Response Analysis**
    Transient response analysis and performance indices. Poles and zeros concept, dominant pole concept of high order systems. Characteristic equation. Steady state errors and system types.
  - **Principles of Feedback Control**
    Open loop versus closed loop control. Analysis of system type. Error elimination and disturbance rejection. Types of feedback systems. PID controller. Stability and Routh-Hurwitz method.
  - **Root Locus Techniques**
    Qualitative analysis of the Root Locus. Guidelines for sketching a Root Locus. General concepts of dynamics compensator design. Design by Root Locus: PI, PD, PID, Lead and Lag compensators. Feedback compensation and realisation.

- **Frequency Domain Analysis**
  Concept of frequency response. Bode plots. Nyquist plot and Nyquist stability criterion. Stability margins. Closed loop frequency domain characteristics. Design of compensator via Bode plots - Lead, Lag & Lag-lead controller. Design examples.

- **Measurement System**
  Models and classification for measurement systems and their time and frequency domain behaviours. Performance specifications.

- **Analog Devices and Measurement**
  Introduction to basic measurement devices for analog signals and measurement principles. Conditioning of analog signals for transmission and processing.

- **Digital Devices and Measurement**
  Fundamental differences between analog and digital systems. Sampling theorem and fundamentals of data acquisition.

- **Sensors**
  Measurement for common engineering applications: position, speed, stress, strain, temperature, vibration and acceleration, pressure and flow. Semiconductor sensors and micromechanical devices.

- **<u>ME 102/202 Dynamics And Vibrations</u>**

  - **Dynamics**

    Kinematics of Particle
    Uniform rectilinear motion; Uniform accelerated rectilinear motion; Rectangular components of velocity and acceleration; Motion relative to a frame in translation; Tangential and normal components; Radial and transverse components. Newton's second law; Equations of motion; Angular momentum of a particle; Principle of conservation of energy; Principle of conservation of momentum.

    Kinematics of Rigid Bodies
    General plane motion; Coriolis acceleration. Equations of plane motion for a rigid body; Angular momentum of a rigid body in plane motion; Principle of work and energy for a rigid body; Principle of impulse and momentum for the plane motion of a rigid body; Conservation of angular momentum.

  - **Mechanical Vibrations**

    Vibration Without Damping
    Simple harmonic motion; Energy method; forced vibration.

Damped Vibration
Damped free vibration; Damped forced vibration.

- **ME 103/203 Fluid Mechanics**

  - **Basic concepts**
    Understanding fluids as compared to solids and gases. Properties of fluids: Density, pressure and viscosity. Pressure measurements. Buoyant forces and Archimedes' Principle. Stability of submerged and floating bodies. Stability of a ship.

  - **Fluid Motion**
    Real and ideal fluids. Momentum and forces in fluid flow: Continuity equation, momentum equation, energy equation, Bernoulli's equation.

  - **Pipe Flow**
    Laminar and turbulent flows in pipes. Moody diagram, losses and fittings, energy equation for real laminar flow in pipes. Equation of motion for turbulent flow. Mixing length hypothesis. Fully turbulent flow in pipes. Head and flow calculations in pump-piping systems.

  - **Fluid Machinery**
    Fundamental theory and performance. Pumps and fans, turbines: Concepts and performance characteristics. Cavitation and surge phenomena.

  - **Flow Resistance and Propulsion**
    Boundary layer, surface roughness, form drag. Water jet theory: Basic principle, fundamental thrust equation. Ship propulsion: Introduction to propulsion system, powering of ship, propeller theory, propeller-hull interaction.

- **ME 104/204 Mechanics And Materials**

  - **Material properties and behaviour**
    Yield and ultimate tensile stress, proof stress, elastic modulus. Yield and Strength failure criteria- Tresca and Von-Mises.

    Temperature effects- temperature expansion coefficient, creep and stress relaxation. Post-yield effects- elastic-plastic, bilinear hardening and strain hardening. Fatigue effects- S/N curves.

  - **Stress and Strain**
    Basic stress and strain for elastic bodies- direct stress and strain, shear stress and strain, Mohr's circle. Stress and Strain transformations - two and three-dimensional, 4 elastic constants E, ν, k and G.

- **Bending of beams**
  Second moments of area of structural sections, Free body, shear force and bending moment diagrams. Elastic and inelastic bending of beams. Combined tension and bending of beams, Deflection and slopes of beams. Shear stress in beams, Statically indeterminate beams.

- **Bending of plates and cylindrical shells**
  Symmetric membrane bending theory of circular plates and shells under fixed and freely supported boundaries. Discontinuity stresses of cylinder to flat, cone or hemispherical shells junctions.

- **Torsion of prismatic bars and closed sections**
  Torsion of circular solid section and open thin-walled sections, shear stresses and deformation, shear flow in thin walled open and closed sections.

- **Buckling of columns**
  Euler buckling theory, perfect and imperfect columns, effect of end fixings on critical buckling loads.

- **Thermal loading**
  Thermal stresses in beams and cylinders due to a through thickness temperature gradient, thermal stresses in compound bars of different materials under uniform temperature.

- **Internal pressure loading**
  Membrane theory, thin and thick-walled cylinders under pressure.

- **<u>ME 105/205 Manufacturing Technology</u>**

  - **Introduction**
    Cutting tool materials. Single and multi-point tools. Types of wear. Manufacturing processes: cold and hot working, rolling, extrusion, forging, sheet and metal blanking and forming, cold forming, welding, brazing, soldering, casting, powder metallurgy, plastics technology. Non-conventional machining: electro-discharge machining.

  - **Metal Removal**
    Introduction to machine tools and machining operations – Generating motions of machine tools, machines using single point tools, machines using multipoint tools, machines using abrasive wheels. Mechanics of metal cutting – Chip formation, forces acting on the cutting tool and their measurement, the apparent mean shear strength of the work material, chip thickness, friction in metal cutting. Cutting tool materials – Major tool material types. Tool life and tool wear – Forms of wear in metal cutting. Economics of metal cutting operations – Choice of feed, speed and depth of cut, tool life for minimum cost and minimum

production time, estimation of factors needed to determine optimum conditions.

- **Metrology**
  Basic measuring instruments and their applications (Linear and angular measurement, roundness, flatness and surface finish measurement).

- **Manufacturing Processes**
  Introduction to cold and hot working. Rolling - 2, 3 and 4-high rolls, cluster and planetary rolls, manufacture of blooms, billets and slabs. Extrusion - Direct and indirect extrusion, hollow extrusion, hydrostatic extrusion. Forging - Hammer, press, roll forging, open and closed die forging. Sheet metal bending and deep-drawing, punch load, drawability, Crane's constants. Shearing of sheet metal - types of shearing operation, punch and die clearance, punch force. Cold forming processes - Marforming, Guerin process, hydroforming. Welding, brazing, soldering - Arc and gas welding, pressure welding, MIG, TIG, submerged-arc, friction, resistance, laser and electron-beam welding. Casting - Sand casting, patterns, defects, die-casting, centrifugal casting, investment casting, continuous casting. Powder metallurgy - Production of powders, fabrication processes, sintering, comparison with other processes. Electro-discharge machining. Plastics technology – Properties of plastics, thermoplastics and thermosets, manufacturing of plastics.

- **<u>ME 106/206 Thermodynamics And Heat Transfer</u>**

  - **Thermodynamics**

    Fundamental concepts
    Simple concept of thermodynamic system. Types of energy interaction between system and surroundings. Properties of simple pure substances –understand the general form of property diagrams. Empirical temperature scales and thermometry. Ideal and perfect gases. Use of steam tables for substance such as water.

    First Law of Thermodynamics
    The concept of fully-resisted or quasi-static processes; work and heat interactions in adiabatic boundaries with the introduction of internal energy, kinetic, potential and enthalpy. Statement of the First law of Thermodynamics: applications relating to non-flow and simple unsteady flow (e.g., the filing of a rigid vessel) processes. First law applied to simple thermodynamic plants, e.g. power plant, compressors and expanders (without detailed knowledge of plant construction). Steady flow energy equation and its application to demonstrate the significant of enthalpy changes.

Second Law of Thermodynamics
Alternative statements of the Second Law. Reversible and irreversible processes. Internal and external irreversibility. Heat engines operating in temperature reservoirs and the efficiency of reversible engines. Entropy as a property and its relationship to heat transfer. The Clausius inequality. Isentropic and non-isentropic processes.

- **Heat Transfer**

Conduction
Heat transfer by conduction. Steady-state conduction through slab, compound walls, cylinders and spheres. Unsteady state conduction in homogeneous solids.

Convection
Heat Transfer by convection, in fluids and films. Overall heat transfer coefficients. Natural and forced convection on plane surfaces, fins, pipes and around round bundles. Heat transfer in extended surfaces- combining conduction and convection.

Radiation
Heat transfer by radiation. Laws of radiant heat transfer, black and gray bodies, geometric factors, absorptivity.

Recommended Reading List for Mechanical Engineering

- **ME 101/201 Control And Instrumentations**
  Katsuhito Ogata, "Modern Control Engineering", 5th edition, published by Prentice Hall

- **ME 102/202 Dynamics And Vibrations**
  F.B. Beer, E.R. Johnston, and W.E. Clausen, "Vector Mechanics for Engineers – Dynamics" S I version

- **ME 103/203 Fluid Mechanics**
  B.R. Munson, D.F. Young, and T.H. Okiishi, "Fundamentals of Fluid Mechanics", published by John Wiley and Son
  F.M. White, "Fluid Mechanics", 7th edition, published by McGraw-Hill

- **ME 104/204 Mechanics And Materials**
  C. Ugural, "Mechanics of Materials", published by McGraw-Hill
  R.C. Hibbeler, "Mechanics of Materials", 2nd edition SI version, published by Prentice Hall

- **ME 105/205 Manufacturing Technology**
  S. Kalpakjian, and Steven R. Schmid, "Engineering & Technology"
  W.A. Knight, and G. Boothroyd, "Fundamentals of Metal Machining and Machine Tools"

- **ME 106/206 Thermodynamics And Heat Transfer**
  Y.A. Cengel, and M.A. Boles, "Thermodynamics: An Engineering Approach", 8th edition SI version, published by Mc-Graw Hill
  Incropera, and DeWitt, "Fundamental of Heat and Mass Transfer"
  J.P. Holman, "Heat Transfer", published by McGraw-Hill

Sample Questions and Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 1 (Mechanical)

(Actual paper comprises 40 Multiple Choice Questions (MCQ) of 2.5 marks each. Answer all questions.)

1 Turbulence is a very important concept in fluid mechanics. Which of the following statement(s) on turbulence is(are) correct?

(i) Turbulence dissipates useful kinetic energy of flow to heat.
(ii) Turbulence increases the frictional drag.
(iii) Turbulence increases convective heat transfer.

(a) (i) and ii)
(b) (i) and iii)
(c) (ii) and iii)
(d) All of the above

2 A solid rectangular beam of 250mm depth is loaded by combined loading of bending moment and axial tensile force such that strain measurements showed that the top surface contracted by 200 microstrain and the bottom surface elongated by 500 microstrain longitudinally. Determine the position of the neutral axis (from the top surface) and calculate the axial stress caused by the tensile force and bending stress caused by the bending moment independently. E = 200GPa.

(a) 71.43mm, 30MPa, 200MPa
(b) 125mm, 150MPa, 150MPa
(c) 125mm, 30MPa, 200MPa
(d) 178.57mm, 30MPa, 200MPa

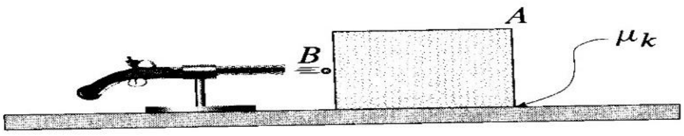
3 A hollow circular section steel rod 300mm long and internal and external diameter of 10mm and 16mm respectively is used as a torsional spring by having one end fixed and the other end free to twist. Determine the torsional twist in degrees of the resulting spring when a torque around the rod axis of 100 Nm is applied. Material G= 80 GPa. (Hint: use thick wall formula)

(a) 5.33 ^{o}
(b) 3.94 ^{o}
(c) 1.55 ^{o}
(d) 7.43 ^{o}

4 Inclusions may sometimes be found in steels of different compositions. These inclusions:

(a) are sites for potential initiation of cracks
(b) are invisible to naked-eye inspections of the steel pieces
(c) may be significantly reduced through costly special processes
(d) All of the above

5 A 21 g bullet hits a 2 kg block that is initially at rest as shown in the figure below. After the collision, the bullet becomes embedded in the block, and they slide a distance of 0.31 m. If the coefficient of kinetic friction between the block and the ground is μk = 0.7, determine the preimpact speed of the bullet.



(a) 198.5 m/s
(b) 251.2 m/s
(c) 351.5 m/s
(d) 405.2 m/s

6 A high-speed rail transportation system has a top speed of 100 m/s. For the comfort of the passengers, the magnitude of the acceleration and deceleration is limited to 2 m/s2. Determine the minimum time required for a trip of 100 km.

(a) 0.30 hr
(b) 0.25 hr
(c) 0.17 hr
(d) 0.50 hr

7 If the characteristic equation of the closed loop system is s2 + 3s + 2 = 0, then the system is:

(a) Over damped
(b) Critically damped
(c) Under damped
(d) Unstable

8 In a cyclic process, the net change of internal energy is:

(a) Equal to zero
(b) Equal to one
(c) Greater than one
(d) Smaller than one

9 In an adiabatic process, which of the following statements are correct?

(i) the temperature change is zero.
(ii) the change in internal energy is zero,
(iii) the heat interaction between system and the surroundings is zero,
(iv) the process is carried out very rapidly.

(a) All of the above
(b) (i), (ii) and (iii)
(c) (i), (ii) and (iv)
(d) (iii) and (iv)

10 Which of the following statements is correct?

(a) Tool life increases with the increase of cutting speed
(b) Tool life decreases with the increase of cutting speed
(c) Cutting speed has no influence on tool life
(d) None of the above

Sample Questions and Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 2 (Mechanical)

(Actual paper comprises 7 questions. Answer 5 questions.)

Question 1

Two reservoirs A and B are connected by a pipeline which is 100 mm in diameter for the first 10 m and 150 mm in diameter for the remaining 20 m. The entrance from and exit to the reservoir are sharp, and the expansion from the 100 mm to 150 mm diameter pipeline are sudden. The water surface of the upper reservoir A is 10 m above that of the lower reservoir B.

(a) Tabulate the losses of head that occur and calculate the discharge flow rate from reservoir A to reservoir B.

(10 marks)

(b) Draw the hydraulic gradient and total energy gradient along the pipeline between the two reservoirs.

(5 marks)

(c) What is the difference between total energy line and hydraulic gradient line?

(2 marks)

(d) Comment on the shape of the energy and hydraulic gradient lines.

(3 marks)

The Darcy-Weisbach equation for frictional head loss h_f along a pipe is

$$h_f = 4f \frac{l}{d} \frac{V^2}{2g}$$

where f is friction factor, V is velocity of flow in pipe, l is length, d is diameter and g is gravity.

You may take f = 0.01 for the pipes, g = 9.81 m^2/s, density of water ρ = 1000 kg/m^3, atmospheric pressure P_a = 101 kPa, the entrance and exit loss coefficients from and to the reservoir as 0.5 and 1 respectively. The expansion loss from pipe 1 to pipe 2 is given by

$$\left[1 - \frac{A_1}{A_2}\right]^2 \frac{V_1^2}{2g}$$

where A_1 and A_2 are areas of pipe 1 and 2 respectively, and V_1 is the velocity in pipe.

Question 2

In the figure below, a motor drives a stepped shaft which are attached two pulleys A and B which are connected to machine loads. The torques to drive the loads at the pulleys, Ta and Tb are equal and exerted in the same direction. The motor is outputting a power of 300 KW and shaft speed is 3000 RPM.

(a) Calculate the torques at sections OA and AB.

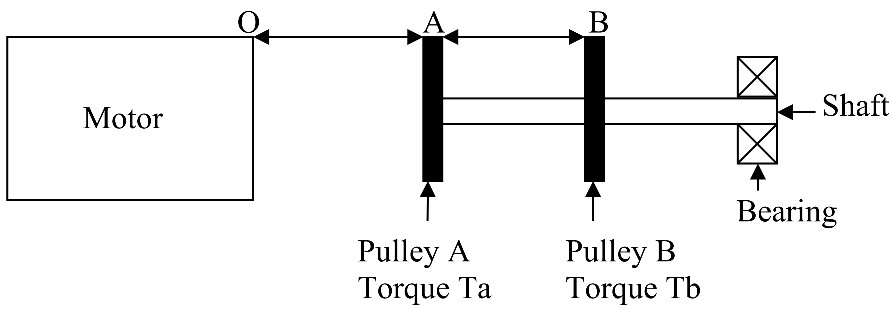
(4 marks)

(b) Assuming the shaft sections OA and AB are circular and solid, and the maximum allowable material shear stress is 110 Nmm-2, calculate the minimum diameters of each section.

(8 marks)

(c) To reduce the cost of machining the step, and while retaining the same material, it is decided that hollow circular sections be used while keeping the outer diameter constant at 40mm for the whole length. Calculate the minimum internal diameters of sections OA and AB. Recommend a common shaft inner diameter to satisfy both sections.

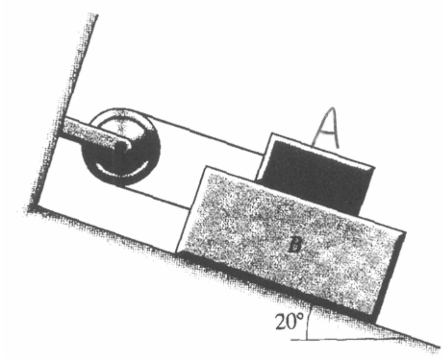
(8 marks



Question 3

If mA = 10 kg, mB = 40 kg, and the coefficient of kinetic friction between all surfaces is μk = 0.11, what is the acceleration of B down the inclined surface?

(20 marks)



Question 4

Two thin sheets of 0.4 wt% C plain carbon steel are held together by an aluminium alloy rivet. List the possible types of corrosion that might arise. Suggest how corrosion might be minimized in such a situation.

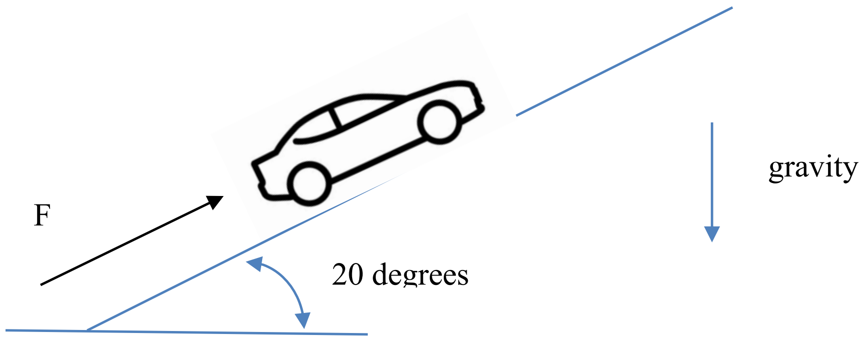
(20 marks)

Question 5

It is desired to have a car of mass 1,000 kg go up the inclined plane shown in the figure below at a constant speed of 90 km/hr. The car is initially at rest. Design a controller that will output F that pushes the car up the inclined plane to maintain the car at the desired constant speed.

State any assumptions or requirements to ensure the controller works well.

(20 marks)



Question 6

A 750-MW steam power plant burns fuel of calorific value 44 MJ/kg and generates electricity. The boiler operates at 560oC and the condenser releases waste heat at 300C. Calculate the minimum daily fuel consumption of the plant.

$$Minimum\ fuel\ consumption\ implies\ Carnot\ efficiency.$$

$$\eta_c = 1 - \frac{T_L}{T_H} = 1 - \frac{(30 + 273)}{(560 + 273)} = 0.636$$

$$Heat\ input\ to\ plant, Q = \frac{W}{\eta_c} = \frac{750}{0.636} = 1195\ MW$$

$$Mass\ flow\ rate\ of\ fuel, \dot{m} = \frac{Q}{CV} = \frac{1195}{4\ 4} = 27.16\ kg/s$$

$$Daily\ minimum\ fuel\ consumption, m = 27.16(24\ x\ 3600) = 2.347\ x\ 10^6\ kg$$

(20 marks)

Question 7

Steel bar stocks of 200 mm length and 90 mm diameter is to be used for machining a shaft of 160 mm length and 80 mm diameter using a lathe of 10 KW motor running at an efficiency of 80%. The machining time given for both roughing and finishing operations should not exceed 15 min. The specific cutting energy ps, for the work material is 2.73 GJ/m3, and the time taken to load and unload a workpiece is 2 min.

Select proper cutting conditions, tool materials and type of rake angles for both roughing and finishing operations.

(20 marks)

IV **Fundamentals Of Engineering Examination (Chemical)**

The examination will focus on testing the fundamentals of chemical engineering. The 6-hour examination will comprise two parts:

Format

- FEE Part 1 (Chemical) (3 hours & 10 mins) – 40 MCQ questions
- FEE Part 2 (Chemical) (3 hours & 10 mins) – 5 out of 7 questions

Syllabus

- **ChE 101: Chemical Engineering Principles**
  - **Mass balances**
    Unit conversion, process flow chart, phase behavior, composition, purge, bypass, reactive systems, multiple reactions, recycle, combustion.
  - **Energy balances**
    Heat capacity, Latent heat, heat of reaction, heat of solution.
- **ChE 102: Thermodynamics**
  - **Thermodynamic properties and phase diagrams**
    Enthalpy, entropy, free energy, steam tables.
  - **Thermodynamic laws and applications**
    First law, Second law, isothermal processes, adiabatic processes, cyclic processes (e.g. power cycles, refrigeration).
  - **Chemical thermodynamics**
    Phase equilibrium, chemical equilibrium, heats of reaction and mixing.
- **ChE 103: Transport Processes**
  - **Momentum transfer**
    Classification of fluids and their properties. Continuity equation. Momentum balance equation. Bernoulli equation. Flow of compressible fluids. Friction losses in flow. Equivalent diameter for non-circular conduct. Pumps and Compressors: characteristics curves, net positive suction head (NPSH), cavitation, and selection of pumps and compressors.

- **Heat transfer**
  Basic definitions. Steady state heat conduction. Thermal resistor models for composite walls. 1-D analysis of unsteady state heat conduction. Natural and forced convection. Heat exchangers. Black body radiation and calculation of energy loss from surface.

- **Mass Transfer**
  Fick's laws. Estimation of gas and liquid phase diffusivities. Steady-state and unsteady state diffusion. Pore diffusion. Convective mass transfer – calculations of fluxes and mass transfer coefficients. Mass, heat and momentum transfer analogies.

- **ChE 104: Chemical Reactors**

  Kinetics versus thermodynamics of chemical reactions. Reaction rates. Rate laws. Reaction stoichiometry versus reaction mechanism. Stoichiometric table analysis. Ideal reactor design equations. Analysis of reaction rate data. Reactor selection and sequencing. Yield versus productivity in multiple reactions. Non-isothermal operations. Residence time distributions as reactor diagnostics. Coupling of transport processes to chemical reactions. Reactors for heterogeneous catalysis.

- **ChE 105: Separation**

  Phase equilibrium, partition coefficient, driving force and mass transfer rate in the context of separation processes. Mass and energy balances around flash distillation, multi-stage distillation, absorption and stripping, and liquid-liquid extraction and membrane processes. Equilibrium and rate based design concepts of these separation processes for binary and multi-component systems. Effects of various operating variables on the separation process output, troubleshooting and process improvement.

- **ChE 106: Process Control**

  Importance of process control in chemical process industry. Architecture and hardware of a control system. Measurement noise and observability of a process variable. Dynamic behavior of a chemical process (first order, second order, dead time, recycle, etc.), and various types of open loop and closed loop responses. Types of control systems (feedback, feed forward, cascade, ratio, etc.) and their selection for a given application. Design/tuning of industrially relevant feedback controllers and their stability. Unit level (reactor, distillation column, etc.) versus plant wide control.

- **ChE 107: Process Design & Safety**

  - Need for process simulation, design, and optimization. Plant life cycle and plant design stages. Fundamentals of process simulation, process simulators and their architecture. Hierarchical approach to preliminary process synthesis. Heat integration. Process diagrams. Process optimization. Equipment selection, specification, sizing and costing. Time value of money. Plant cost estimation and profitability analyses (payback period, NPV, RORI, …).

- Importance of occupational health and loss prevention. Hazards, risks, and incident statistics. Toxic hazards, threshold limit values; Probit analysis. Industrial hygiene evaluation and control. Toxic release estimation, consequence analyses, and exposure limits. Fires and explosions, flammability and limits, and fire/explosion prevention. Relief systems and sizing. Hazard identification and risk assessment.

Recommended Reading List for Chemical Engineering

ChE 101: Chemical Engineering Principles

1) R. M. Felder, R. W. Rousseau and L. G. Bullard, "Elementary Principles of Chemical Processes" 4th edition (2015), John Wiley and Sons, Inc.

ChE 102: Thermodynamics

1) J. M. Smith, H. Van Ness, M. Abbott and M. Swihart, "Introduction to Chemical Engineering Thermodynamics" 8th edition (2018), McGraw-Hill.

ChE 103: Transport Processes

1) WELTY J.R., RORRER G. & FOSTER D.G. (2015) *Fundamentals of Momentum, Heat, and Mass Transfer, International Student Version*, 6th Edition. Publisher John Wiley & Son, New York.

ChE 104: Chemical Reactors

1) Octave Levenspiel, *Chemical Reaction Engineering*, 3rd Edition (1999), John Wiley and Sons.
2) H Scott Fogler, *Elements of Chemical Reaction Engineering*, 4th Edition (2006), Prentice Hall International Series.

ChE 105: Separation

1) Philip C. Wankat, *Separation Process Engineering*, 5th Edition (2023), Pearson Education International.
2) J D Seader and Ernest J Henley, *Separation Process Principles*, 2nd Edition (2006), John Wiley and Sons, Inc.

ChE 106: Process Control

1) Dale E Seborg, Thomas F. Edgar, Duncan A. Mellichamp and Francis J Doyle III, *Process Dynamics and Control*, 4th Edition (2016), John Wiley and Sons, Inc.
2) George Stephanopoulos, Chemical Process Control: An Introduction to Theory and Practice, Paperback Edition (2015), Pearson Education International.

ChE 107: Process Design & Safety

1) Ray Sinnott and Gavin Towler, *Chemical Engineering Design*, 5th Edition (2009), Elsevier (Butterworth & Heinemann).
2) R Turton, R C Bailie, W B Whiting, J A Shaeiwitz, D Bhattacharya, *Analysis, Synthesis, and Design of Chemical Processs*, 4th Edition (2013), Pearson Educational International.
3) D Crowl and J F Louvar, *Chemical Process Safety: Fundamentals with Applications*, 2nd Edition, Prentice Hall, 2002

Sample Questions and Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 1 (Chemical)

(Actual paper comprises 40 Multiple Choice Questions (MCQ) of 2.5 marks each. Answer all questions.)

1 A distillation column is used to strip ethanol from a feed stream containing 60 mol% ethanol, 10 mol% methanol and the rest water. The feed rate is 100 mol/s. The distillate stream of 60 mol/s contains 15 mol% methanol and 5 mol% water. What is the amount of ethanol in the bottoms stream?

(a) 12.5 mol%
(b) 30.0 mol%
(c) 67.5 mol%
(d) 80.0 mol%

2 An ideal gas initially at 600 kPa and 300 K undergoes isothermal compression from a volume of 0.005 m^3 to a volume of 0.001 m^3. What is the work done on the gas?

(a) 4.01 kJ
(b) 4.83 kJ
(c) 5.35 kJ
(d) 5.92 kJ

3 The mixture consisting of benzene (1) and ethylbenzene (2) behaves closely to an ideal solution. Vapour pressures are given by the following Antoine equations:

$$\ln P_1^{sat}/kPa = 13.8858 - \frac{2788.51}{T/^oC + 221}$$

$$\ln P_2^{sat}/kPa = 14.0045 - \frac{3279.47}{T/^oC + 213}$$

At T = 70°C, what is the pressure of a mixture containing 45 mol% benzene in the liquid phase?

(a) 11.2 kPa
(b) 39.4 kPa
(c) 73.9 kPa
(d) 101.7 kPa

4 A spherical water droplet with diameter of 1 cm is falling in air. The droplet and air temperatures are 10 °C and 25 °C, respectively. The heat transfer coefficient is 50 W/(m^2 °C). Determine the rate of change in droplet diameter. Water density and latent heat are 1000 kg/m^3 and 2260 J/g?

(a) 0.244 mm/s
(b) 7.83 mm/s
(c) 2.64 mm/s
(d) 0.664 mm/s

5 In the reverse water gas shift reaction (RWGS), green H_2 is used to convert CO_2 to CO for downstream liquid fuel production. The side reaction is the CO_2 methanation reaction. Green H_2 is the cost bearing raw material and needs to be consumed completely. A catalyst claims to have 80% CO selectivity for the RWGS at 90% conversion of CO_2. What will be the amount of green H_2 needed per mole of CO_2 in the feed?

RWGS: $CO_2 + H_2 \rightarrow CO + H_2O$
CO_2 Methanation: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

(a) 1
(b) 5
(c) 0.8
(d) 1.2

6 The ternary diagram for a partially miscible solute – carrier – solvent system is shown in Figure Q28. Pure solvent is used. Among the choices given below, what is the maximum allowable solute concentration in the feed to implement an extraction separation process?

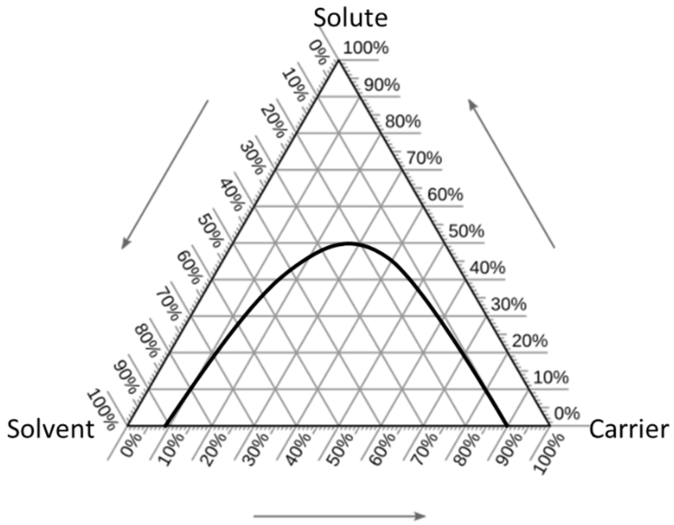


Figure Q28: Ternary diagram for a partially immiscible solute – carrier -solvent system.

(a) 80 wt%
(b) 60 wt%
(c) 40 wt%
(d) 20 wt%

7 If a process exhibits continuous oscillations after tuning, the likely cause is:

(a) Too low proportional gain.
(b) Too high integral time.
(c) Too high proportional gain and/or too low damping.
(d) Large measurement noise.

8 A worker was exposed to ammonia daily for 4 hrs at 30 ppm and 4 hrs at 25 ppm. Estimate the worker's total combined exposure and determine if his exposure is within permissible limit. Assume the following permissible exposures:

- Threshold Limit Value, Time-weighted Average of 8 hr (TLV-TWA): 25 ppm
- Threshold Limit Value, Short-Term Exposure of 15 min (TLV-STEL): 35 ppm
- Threshold Limit Value, Ceiling (TLV-C): 50 ppm

(a) Total combined TLV-TWA is 6.875 ppm, within exposure limit
(b) Total combined TLV-TWA is 13.75 ppm, within exposure limit
(c) Total combined TLV-TWA is 27.5 ppm, overexposed
(d) Total combined TLV-TWA is 55.0 ppm, overexposed

9. Ammonia synthesis ($N_2 + 3H_2 \rightarrow 2NH_3$) is an equilibrium-controlled, highly exothermic, gas-phase reaction. It needs a high pressure (100-200 bar), high temperature (>675 K), and a solid catalyst. As the designer for an ammonia plant, which one of the following real reactor equipment will you select for ammonia synthesis?

(a) Fixed bed tubular reactor
(b) Continuous stirred tank reactor
(c) Fluidized bed reactor
(d) Plug flow reactor

10 Which of the following statements is correct?

(a) Time value of money is the same as inflation.
(b) Working capital can be depreciated during a project's life.
(c) After tax cash flow is always equal to after tax profit.
(d) Net present value can be positive, zero or negative.

Sample Questions and Questions From Past Year Papers for Fundamentals Of Engineering Examination Part 2 (Chemical)

(Actual paper comprises 7 questions. Answer 5 questions.)

Question 1

A two-stage adiabatic reactor is used to produce ammonia from nitrogen and hydrogen. The single pass conversion in the first stage is 20%. Products from this stage are mixed with fresh feed containing 25 mol% N2 and 75 mol% H2 at 50 °C to produce a mixture at 400 °C. This mixture then enters the second stage reactor and the product exits at a temperature of 500 °C. The product from the second stage reactor is cooled in heat exchanger E before entering a condenser. At the condenser, all the ammonia and a small amount of nitrogen and hydrogen are removed as product P. The remaining nitrogen and hydrogen are heated up to 400 °C (using the product stream from the second stage reactor) in heat exchanger E and are then recycled to the first stage reactor as feed.

Sketch the process flow diagram, calculate the single pass conversion in the second stage reactor and the overall conversion.

The following data can be used in your calculation:
N_2(g): C_p = 29 J/mol-°C
H_2(g): C_p = 29 J/mol-°C
NH_3(g): C_p = 40 J/mol-°C

The standard enthalpy of reaction is:

$$\mathrm{N_2(g) + 3H_2(g) \rightarrow\ 2NH_3(g)} \quad \Delta H_r(400^oC) = -106\ kJ/mol$$

(20 Marks)

Question 2

A steam power plant operates on the Rankine cycle. Steam enters the turbine at 8 MPa and 600 °C. The pump and turbines are isentropic. Steam exits the condenser as a saturated liquid at a pressure of 10 kPa. Cooling water at 1500 kg/s and 20 °C is used to remove heat from the condenser. The net power output of the power plant is 52 MW.

Determine the thermal efficiency of the cycle, the mass flow rate of steam, and the exit temperature of the cooling water.

(20 marks)

Question 3

A centrifugal pump is used to transport a liquid (density: 820 kg/m^3, viscosity: 0.01 Pa s) from tank A to tank B. Tank B is at a higher elevation than tank A with a free surface height difference of 7 m. The connecting pipe of internal diameter 10 cm is 15 m long with two bends. The Darcy friction factor is:

$$f = 0.316Re^{-1/4}$$

where Re is the Reynolds number. The dimensionless equivalent length of each bend is 30. The mass flow rate is 100 kg/s.

(a) Determine Re inside the pipe.

(5 marks)

(b) Determine the hydraulic power of the pump.

(15 marks)

Question 4

A 100 L (L = Liter) PFR is currently used to process the gas phase reaction $A \rightarrow R$ to 90 % completion. Marketing is forecasting a 10 % increase in the demand for R (at the same purity) in the coming months. An idling CSTR of 40 L is available for redeployment. It is suggested that the production increase be handled by this CSTR connected in parallel with the PFR. Will this work? What about connecting the CSTR in series with the PFR? Please explain if the series arrangement is superior to the parallel arrangement (no calculation needed).

Available kinetics information: first order reaction, $-r_A = kc_A$

(20 marks)

Question 5

Figure Q5 is the schematic of a multi-stage distillation process to purify a solvent from its aqueous mixture. The boiling point of the solvent is 56 ^oC. The corresponding McCabe Thiele diagram is also shown in the same figure. The feed is a saturated liquid and contains 45 mol% solvent. It enters the column at a flowrate of 1,000 kmol/hr. Mole fractions of the solvent in the top and bottom products are 96 mol% and 2.5 mol%, respectively. The distillation column operates at atmospheric pressure and uses a total condenser and partial reboiler. The column has L/D = 1.4. The latent heat of evaporation of water at 100 ^oC is 40,680 kJ/kmol. Heat supplied to the reboiler comes from burning natural gas. The heat of combustion of natural gas is 800 kJ/mol.

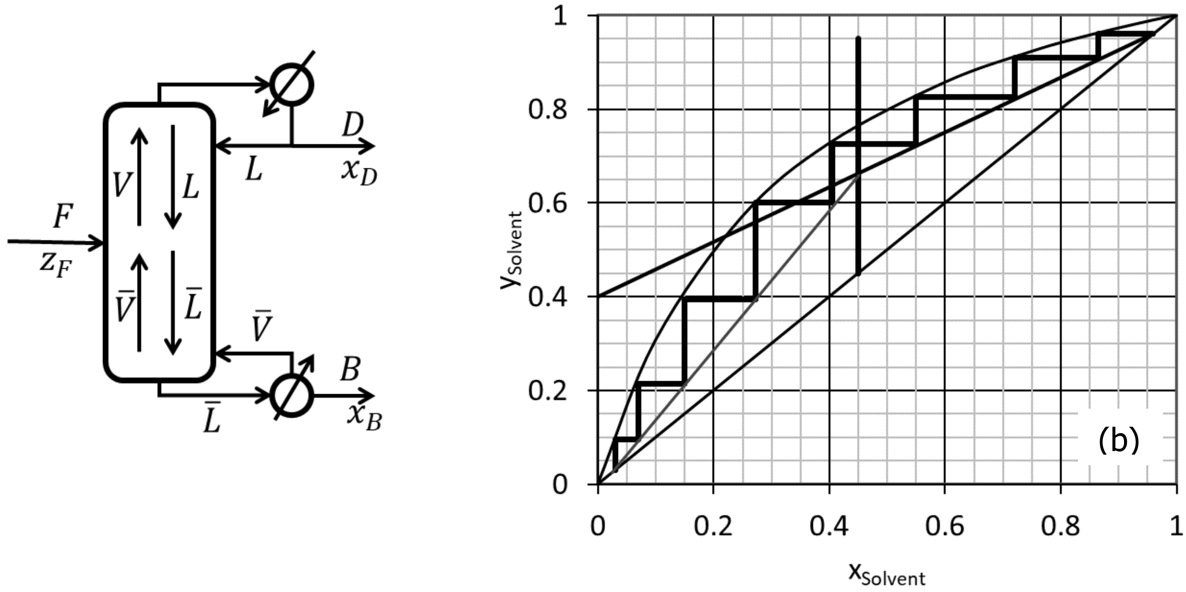


Figure Q5: (a) Schematic of a multi-stage distillation process for separating a pharmaceutical solvent from water by distillation and (b) McCabe Thiele diagram for the process.

(a) What are the (approximate) temperatures of the condenser and the reboiler?

(5 marks)

(b) Calculate the distillate flow rate.

(5 marks)

(c) Calculate the boil up ratio, $\frac{\bar{V}}{B}$.

(5 marks)

(d) Calculate the CO_2 emissions due to the heat duty of the reboiler.

(5 marks)

Question 6

A single-tank process has been operating for a long period of time with inlet flow rate of q_i = 30.4 m^3/min. After the operator increases the inlet flow rate by 10 % at t = 0, the level of water in the tank changed as shown in the Table below. The data is also plotted for your information.

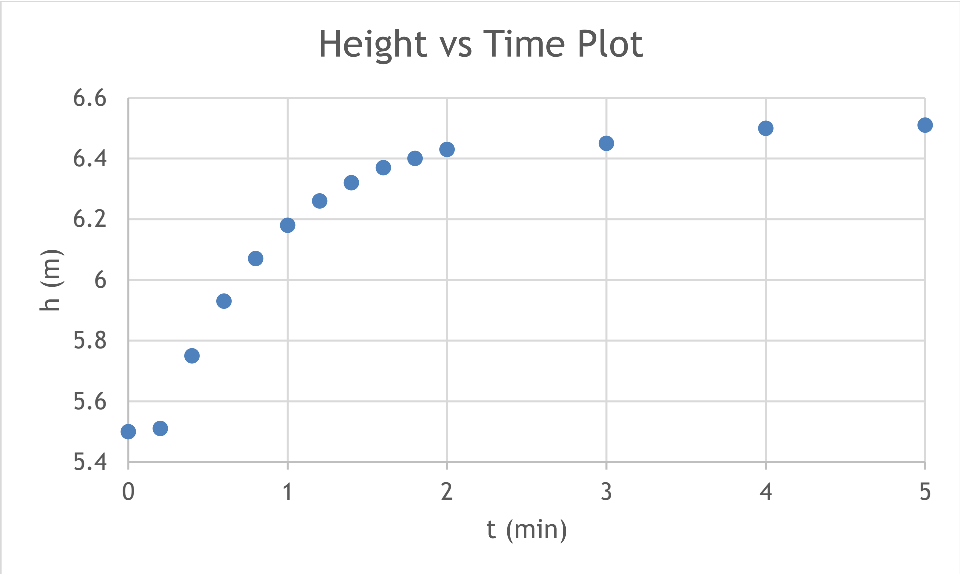
(a) Determine the transfer function for the process. Are there any shortcomings of the approach you used?

(12 marks)

(b) Use the model to design a PI-controller for the process with an effective controller design method of your choice.

(8 marks)

t (min)	h (m)	t (min)	h (m)
0	5.50	1.4	6.32
0.2	5.51	1.6	6.37
0.4	5.75	1.8	6.40
0.6	5.93	2.0	6.43
0.8	6.07	3.0	6.45
1	6.18	4.0	6.50
1.2	6.26	5.0	6.51



Question 7

Lethanol Indonesia Pte Ltd is considering a project to produce 100 million liters (L) of bioethanol per year from the abundant lignocellulosic biomass in Indonesia. You are tasked to provide a recommendation on its profitability.

Constructing a plant for bioethanol will take one year. The plant will then run for 10 years and will have no salvage value at the end. Plant construction will cost $1 per L of production capacity. Lethanol will allocate the capital investment from its own budget at the start of plant construction. For the first year of operation, it is estimated that biomass feedstock will cost 30 cents per L of bioethanol, bioethanol can be sold for 50 cents per L, and the plant will incur $5 million in other operating expenses. Lethanol uses a discount rate of 10% for the time value of money. Indonesia projects its inflation to be 3 % per annum during the plant's life. Its corporate tax rate is 20 % and depreciation is computed via the straight-line method. The start of the plant's construction will be used as time zero for the economic analysis.

(a) What is inflation? Is it any different from interest rate? Explain.

(3 marks)

(b) For the 4th year of plant's operation, compute the following.

(i) Total revenue

(2 marks)

(ii) Total production costs

(3 marks)

(iii) Depreciation

(1 mark)

(iv) Taxes

(4 marks)

(v) Total cash flow

(2 marks)

(vi) Discounted cash flow

(2 marks)

(c) Explain how you will compute NPV (Net Present Value) and provide a recommendation for this project. (Actual calculations are NOT needed)

(3 marks)