The Institution of Structural Engineers

Chartered Membership Examination

IStructE

16th APRIL 2004

Structural Engineering Design and Practice

9.30 a.m. - 1 p.m. and 1.30 - 5 p.m. (Discussion between individuals is not permitted during the lunch period).

A period of fifteen minutes is provided for reading the question paper, immediately before the commencement of the examination. Candidates are not permitted to write in answer books, or on drawing paper or to use a calculator during this time.

Candidates must satisfy the Examiners in ONE question.

Important

The written answer to the question selected and any A3 drawings must bear the candidate's number and the question number in the bottom right-hand corner. Only the answer book(s) supplied by the Institution may be used. The candidate's name should not appear anywhere in the script.

Notes to Candidates

1. TO PASS THE EXAMINATION, CANDIDATES MUST SATISFY THE EXAMINERS IN BOTH PARTS OF THE QUESTION ATTEMPTED.
2. A fair proportion of marks will be awarded for the demonstration of an understanding of fundamental engineering concepts, as distinct from calculation of member forces and sizes. NOTE: In the calculation part of all questions, establishing "form and size" is taken to mean compliance with all relevant design criteria, i.e. bending, shear, deflection, etc.
3. In all questions 50 marks are allocated to Section 1 and 50 marks to Section 2.
4. The Examiners are looking for sound structural designs. It should also be remembered that aesthetics, economy and function are important in any competent engineering scheme. Candidates should read carefully the examiners' reminder on Page 3.
5. Any assumptions made and the design data and criteria adopted must be stated.
6. Portable computers or programmable calculators may be used but sufficient calculations must be submitted to substantiate the design, and these should be set out as in practice.
7. Good clear drawings and sketches are required; they should show all salient and structural features to suitable scales and should incorporate adequate details.
8. Candidates will not be allowed to include any previously prepared calculations, notes, sketches, diagrams, computer output or other similar material in their answer books or A3 drawings. Any previously prepared information submitted by candidates will be ignored by the examiners.
9. This paper is set in SI Units.

Now read 'Reminder' on Page 3 ☞

Chartered Membership Examination, a reminder from your Examiners

The work you are about to start has many features in common with other examinations which you have tackled successfully but it also has some which are unusual.

As in every examination you must follow carefully the NOTES FOR CANDIDATES set out for your guidance on the front cover of this paper; allocate the available time sensibly and set out your work in a logical and clear way.

The unusual requirement of the examination is that you demonstrate the validity of the training and experience that you have acquired in recent years. The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of structural design problems – whether or not the problem is presented in terms that are within your actual experience.

Chartered Structural Engineers must have the ability to design and a facility to communicate their design intentions. Where you are required to list and discuss possible structural solutions you must show by brief, clear, logical and systematic presentation that you understand the general structural engineering principles involved.

In selecting and developing your design you should also remember the guidance given in the Institution's report, Aims of Structural Design, and in particular:

(1) "the structure must be safe",

(2) "a good design has certain typical features – simplicity, unity and necessity",

(3) "the structure must fulfil its intended function".

If you have difficulty in deciding the correct interpretation of a question, pay particular attention to point 5, notes to candidates, on the front cover. The examiners will take into account your interpretation – and the design you base on this – if this is clearly stated at the beginning of your answer.

Question 1
Redevelopment of a nineteenth century fire station

Client's requirements

1. A new multi-storey building is to be constructed on the site of a nineteenth century fire station building and an adjacent car park. The masonry façade of the front elevation of the existing building is to be retained. See Figure Q1.
2. The new building is to have six floors to be used for apartments, offices, leisure and car parking as shown in Figure Q1. Car parking floors are to have a floor to floor height of 3.825 m; all other floors are to have a floor to floor height of 3.675 m. A 0.3 m deep clear service zone is to be provided below all floors and the roof. All floors are to have a clear headroom of at least 2.7 m.
3. The minimum spacing of all internal columns is to be 7.2 m, centre to centre. On floors 3, 4, 5 and 6, the centre of the internal columns must be at least 6.0 m from an external elevation. Service cores are required in each of the three sections of the building. In each section, the total plan area of the service cores shall be approximately 5% of the floor plan area.
4. The client has stated that the central office section of the building, above the car parking levels, is to have fully glazed front and rear elevations. All other elevations are to be clad in masonry incorporating at least 25% glazing per storey. The roof is to be tiled.
5. An underground river crosses the site through an existing culvert constructed in masonry as shown in Figure Q1. The culvert is not capable of supporting any additional loads.
6. Due to planning restrictions, a 2.0 m wide clear zone is required to enable future maintenance to be carried out on the length of the existing retaining wall that supports the highway adjacent to the existing car park, as shown on Section B-B.

Imposed Loading

7. Roof 1.0 kN/m^2
   Offices, leisure areas and apartments 5.0 kN/m^2
   Car parking 2.5 kN/m^2
   The above loads include an allowance for partitions, services, sound insulation and finishes.

Site Conditions

8. The site is located in the centre of a large town.
   Basic wind speed is 44 m/s based on a 3-second gust; the equivalent mean hourly wind speed is 22 m/s.
   Note: The 3 second gust speed is used in the British Standard CP3 and the mean hourly wind speed is used in the British Standard 6399. Candidates using other codes and standards should choose an appropriate equivalent wind speed.
9. Ground conditions:

Borehole 1	Ground level - 0.3 m	Bituminous surfacing and sub base (car park construction).
	0.3 m - 4.0 m	Made Ground – brick, stone and clay. N values vary between 1 and 5.
	4.0 m - 7.0 m	Clay. C = 250 kN/m^2.
	7.0 m - 12.0 m	Sand and Gravel. N = 50.
	Below 12.0 m	Weathered Rock. Allowable bearing pressure = 1500 kN/m^2
Borehole 2	Ground level - 0.2 m	Unreinforced concrete slab.
	0.2 m - 3.0 m	Made Ground – brick, stone and clay. N values vary between 3 and 7.
	3.0 m - 6.0 m	Clay. C = 250 kN/m^2.
	Below 6.0 m	Weathered Rock. Allowable bearing pressure = 1500 kN/m^2.

(continued overleaf .....)

Groundwater was encountered at 4.0 m below ground level. Sulphate (SO_4) concentrations of up to 1.4g/l and pH values of 5.0 were measured in the groundwater and made ground, respectively, in both boreholes.
Details of the existing masonry retaining wall and its foundation are not known. The foundations of the existing fire station building are founded in the clay layer. These foundations are to be removed during the demolition of the fire station building and the resulting void is to be filled with well compacted imported granular material.

Omit from consideration

10. Detailed design of the access ramps, service cores, temporary works and the car parking layout.

SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After completion of the design the client asks if an additional floor can be provided in each section of the building by altering the roof profile to that shown on Sections A-A and B-B in Figure Q1. The use of the additional floor is to be the same as the top floor in each section of the building. Write a letter to the client explaining the effects that this would have on your design. (10 marks)

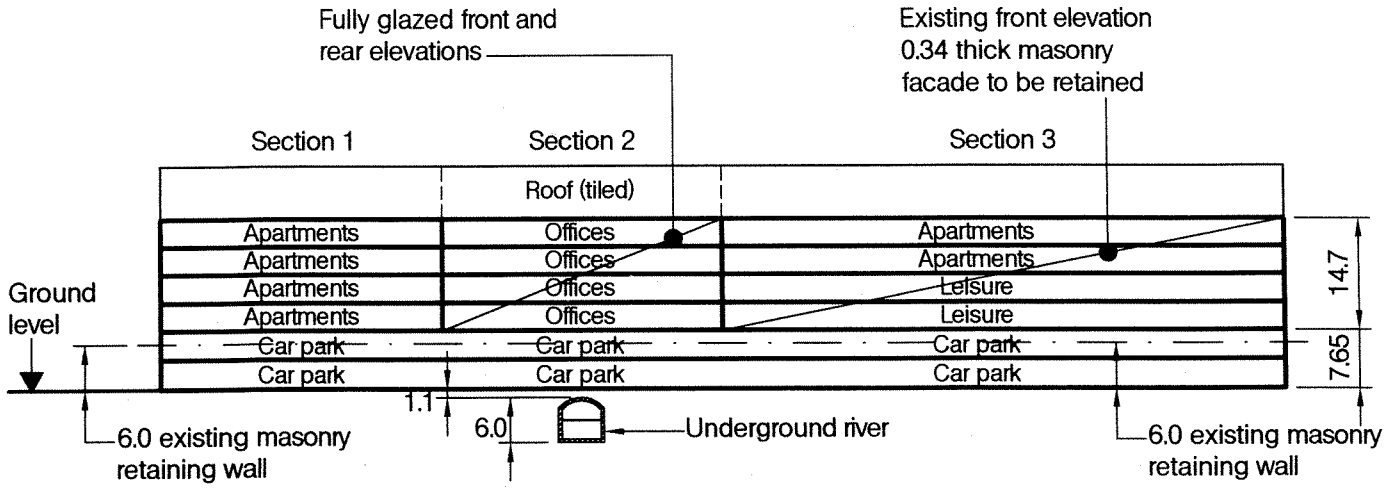
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

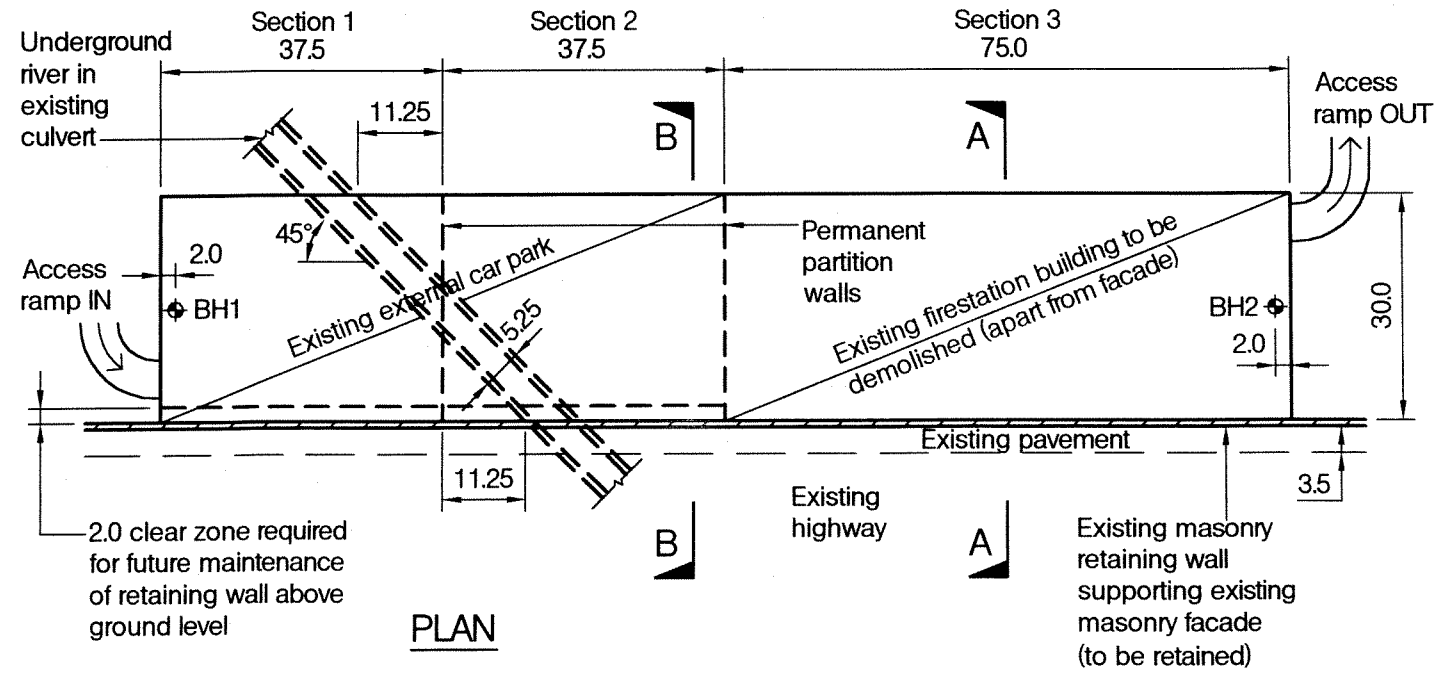
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

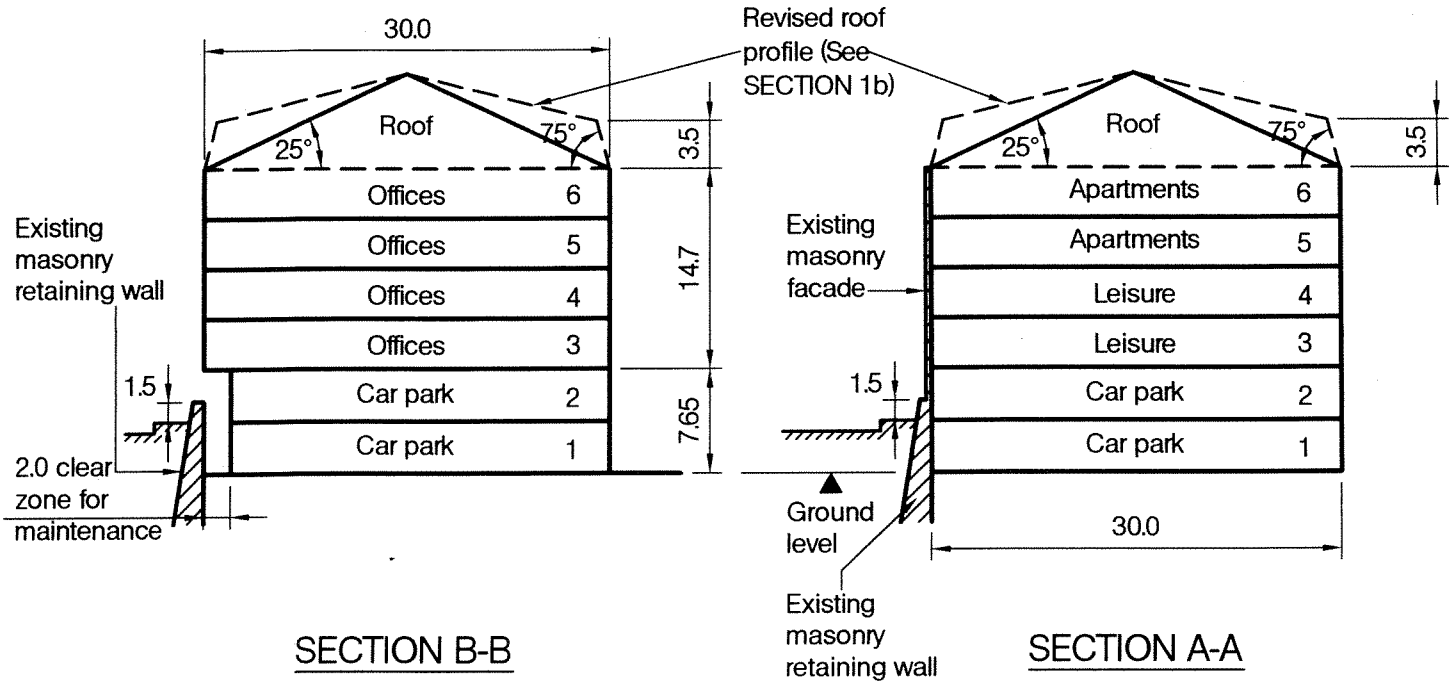
e. Prepare a detailed method statement for the safe construction of the building and describe, with the aid of sketches, any major items of temporary works necessary for your recommended solution. (10 marks)



FRONT ELEVATION



PLAN



SECTION B-B

SECTION A-A

Question 2
Place of worship

Client's requirements

1 A place of worship consisting of a main worship area with additional facilities constructed around the perimeter. See Figure Q2.
2. All external walls are to be clad in masonry. The building is to have a pitched tiled roof on two levels with a continuous band of high level glazing between the two levels.
3. No more than 5 internal columns will be permitted within the ground floor area and, to ensure uninterrupted views of the centre of the main worship area, no columns are to be placed within the hatched area shown in Figure Q2. Column sizes are to be kept to a minimum and consideration must be given to the aesthetics of the structure.
4. The main worship area is to be kept open to the roof but no roof structure is to be visible from below.
5. A minimum fire resistance of 1 hour is required for all structural elements.
6. A stream runs under the site through a 900 mm diameter reinforced concrete pipe. The top of the pipe is 4.0 m below ground level.

Imposed Loading

7. Roof 1.5 kN/m^2
   Ground floor 5.0 kN/m^2
   The above loads include an allowance for services, ceilings and floor finishes.

Site Conditions

8. The site is level and is located on the edge of a small town at the bottom of a narrow valley running towards the sea which is 4km away.
   Basic wind speed is 46 m/s based on a 3-second gust; the equivalent mean hourly wind speed is 23 m/s.
   Note: The 3 second gust speed is used in the British Standard CP3 and the mean hourly wind speed is used in the British Standard 6399. Candidates using other codes and standards should choose an appropriate equivalent wind speed.
9. Ground conditions:

Borehole 1	Ground level - 0.5 m	Silty Clay. C = 40 kN/m^2.
	0.5 m - 1.5 m	Clay. C = 100 kN/m^2.
	Below 1.5 m	Rock. Allowable bearing pressure = 5000 kN/m^2
Borehole 2	Ground level - 3.5 m	Silty Sand and Gravel. N = 5.
	3.5 m - 4.0 m	Clay. C = 100 kN/m^2.
	Below 4.0 m	Rock. Allowable bearing pressure = 5000 kN/m^2.

Groundwater was encountered at 3.0 m below ground level in borehole 2.

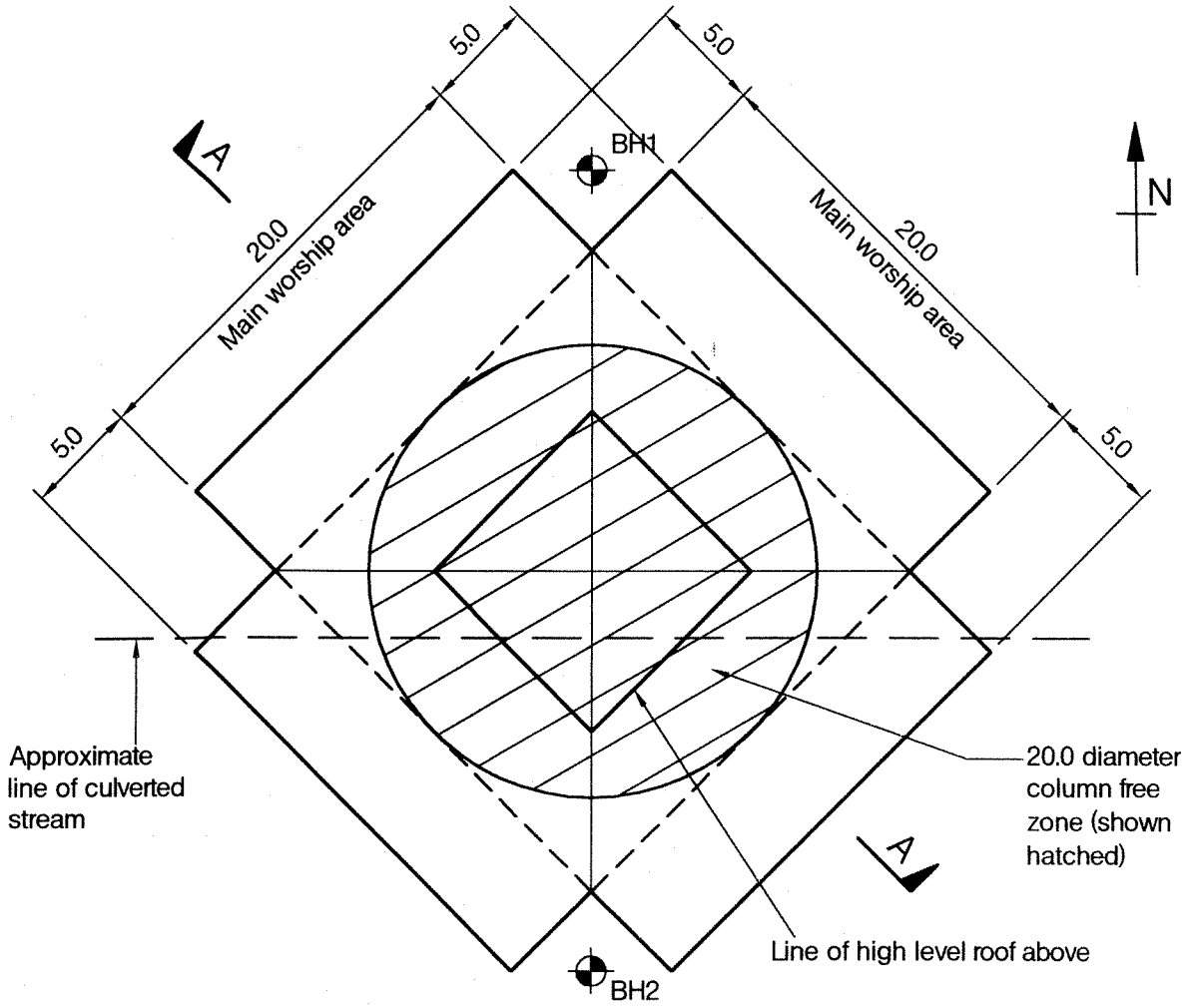
SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
b. Following completion of the design there was some minor seismic activity in the region. Write a letter to your Client explaining how your design would need to be changed to accommodate such activity. (10 marks)

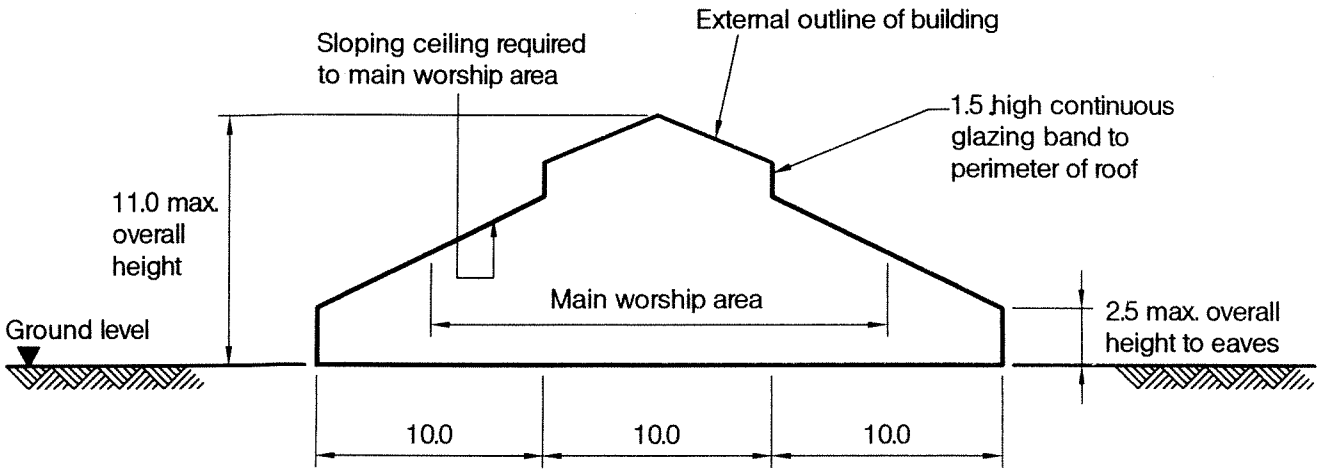
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)
d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)
e. Prepare a detailed method statement for the safe construction of the building and an outline construction programme. (10 marks)



PLAN



SECTION A-A (Culvert omitted for clarity)

Question 3
Canal aqueduct

Client's requirements

1. A new two span aqueduct structure to carry an existing canal and footpaths over a new highway. See Figure Q3.
2. The canal and footpaths cross the site of the new highway on an 8.0 m high embankment. The embankment consists of well compacted fill material and the canal has an impermeable clay lining. It is used extensively by leisure and commercial boats but may be closed during the months of September to May inclusive.
3. The canal is 6.0 m wide and has a 3.0 m wide footpath on each side. The water in the canal is normally 1.2m deep and has a 0.6 m clearance below the level of the footpaths as shown in Figure Q3.
4. The new highway is to have two traffic lanes, each 7.3 m wide with a 2.5 m wide hard strip. The lanes are separated by an 8.0 m wide central reservation. The minimum headroom requirement is 5.7 m.
5. The aqueduct is to be perpendicular to the line of the new highway and is to be constructed along the line of the existing canal.
6. Two clearance envelopes must be provided below the aqueduct for the new highway, as shown in Figure Q3.

Imposed Loading

7. Footpaths 5.0 kN/m^2

Site Conditions

8. The site is in a rural location.
9. Ground conditions:

Ground level - 0.8 m	Topsoil
0.8 m - 6.0 m	Dense Sand and Gravel. N = 30.
Below 6.0 m	Dense Sand and Gravel. N = 40.

Omit from consideration

10. Detailed design of the waterproofing and sealing of the canal at the abutments.
11. Impact from canal boats and detailed consideration of wind loading.

SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After completion of your design, the client asks for a more open aspect beneath the aqueduct, with provision for a 2.0 m wide footpath behind each highway boundary fence. The clearance envelope for vehicles will remain the same. Write a letter to the client explaining how this might be achieved. (10 marks)

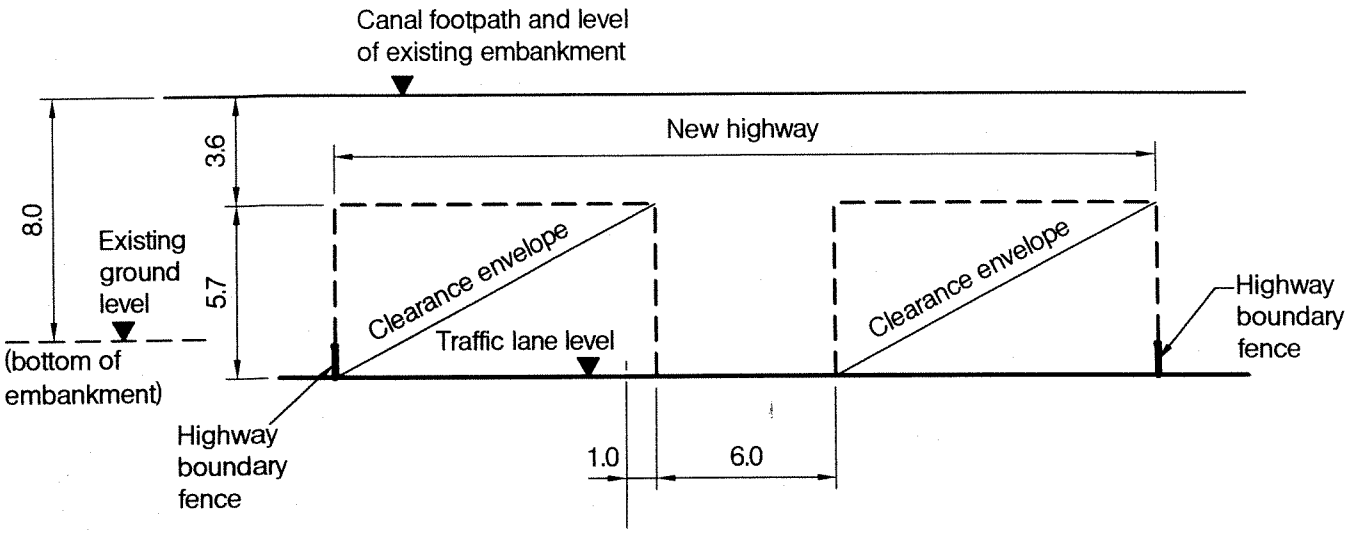
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

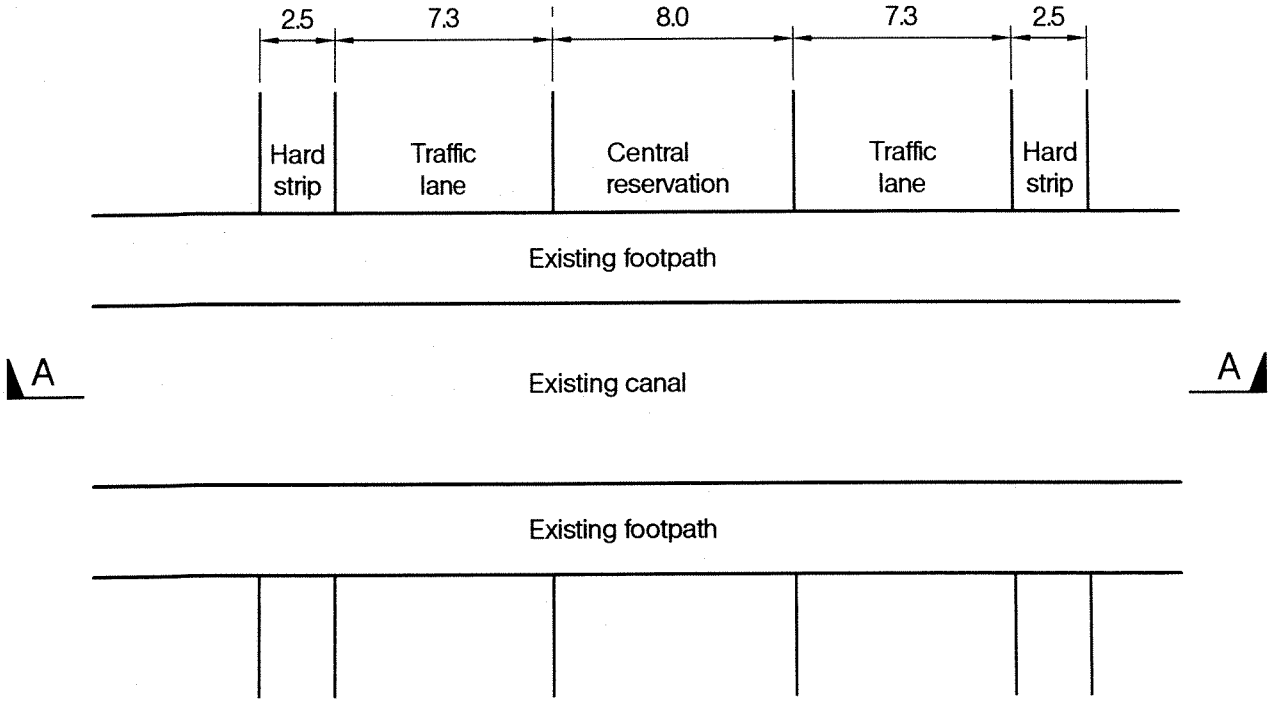
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

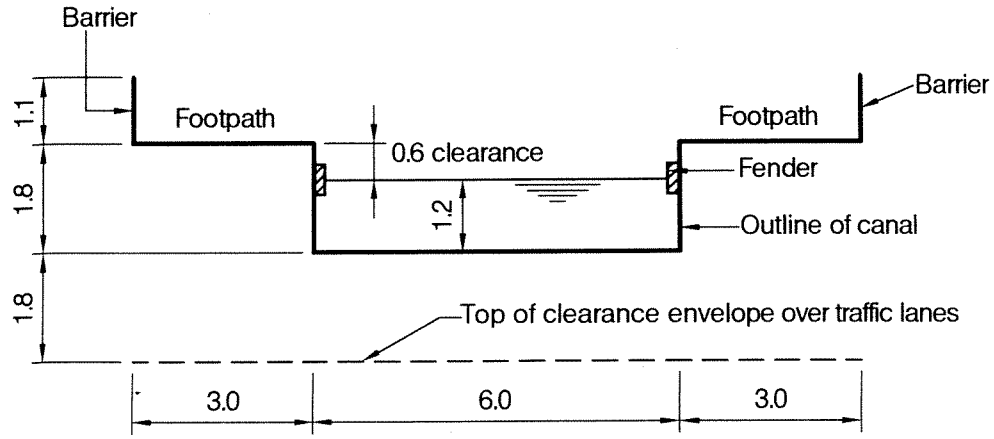
e. Identify the means of access for maintenance and inspection of the aqueduct and describe the parts of the structure that might need replacement in the future. (10 marks)



SECTION A-A



PLAN



SECTION THROUGH CANAL

Question 4
Flood alleviation tank

Client's requirements

1. A covered flood alleviation tank with a storage capacity of 9,500 m^3. See Figure Q4.
2. The floor of the tank is to be at least 4.0 m below the existing ground level and is to have a fall of 1 in 100 to the draw off points. When the tank is full, the water level is to be 3.0 m above the existing ground level and there is to be a minimum clearance of 0.4 m between the water level and the underside of the roof.
3. The tank is to be divided into two equal compartments that are capable of independent operation.
4. The roof of the tank is to be covered with a 150 mm thick layer of topsoil and is to be laid to fall to its perimeter to facilitate drainage. The roof (excluding the topsoil layer) must not be higher than 4.5 m above the existing ground level.
5. The external walls of the tank that extend above the existing ground level are to be concealed by earth embankments, as shown in Figure Q4. The permanent works (excluding any pipework) must not extend in plan beyond the site boundary which is 100 m x 100 m in size.

Imposed Loading

6. Roof (excluding the topsoil) 4.0 kN/m^2

Site Conditions

7. The site is level and is located in a rural area.
8. Ground conditions:

Ground level - 0.5 m	Topsoil
0.5 m - 16.0 m	Medium becoming dense, Sand and Gravel. N values vary linearly with depth from 10 to 25.
Below 16.0 m	Stiff Clay. C = 300 kN/m^2.

Groundwater was encountered at 1.0 m below ground level.

Omit from consideration

9. Detailed design of the draw-off chamber, pipe work, manholes, access ladders and other equipment. Detailed design of the embankment.

SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After your recommended solution has been accepted, the client asks if it is possible for the roof of your tank to support various items of industrial plant with a total imposed load of 15.0 kN/m^2. Write a letter to your client explaining how this might be achieved. (10 marks)

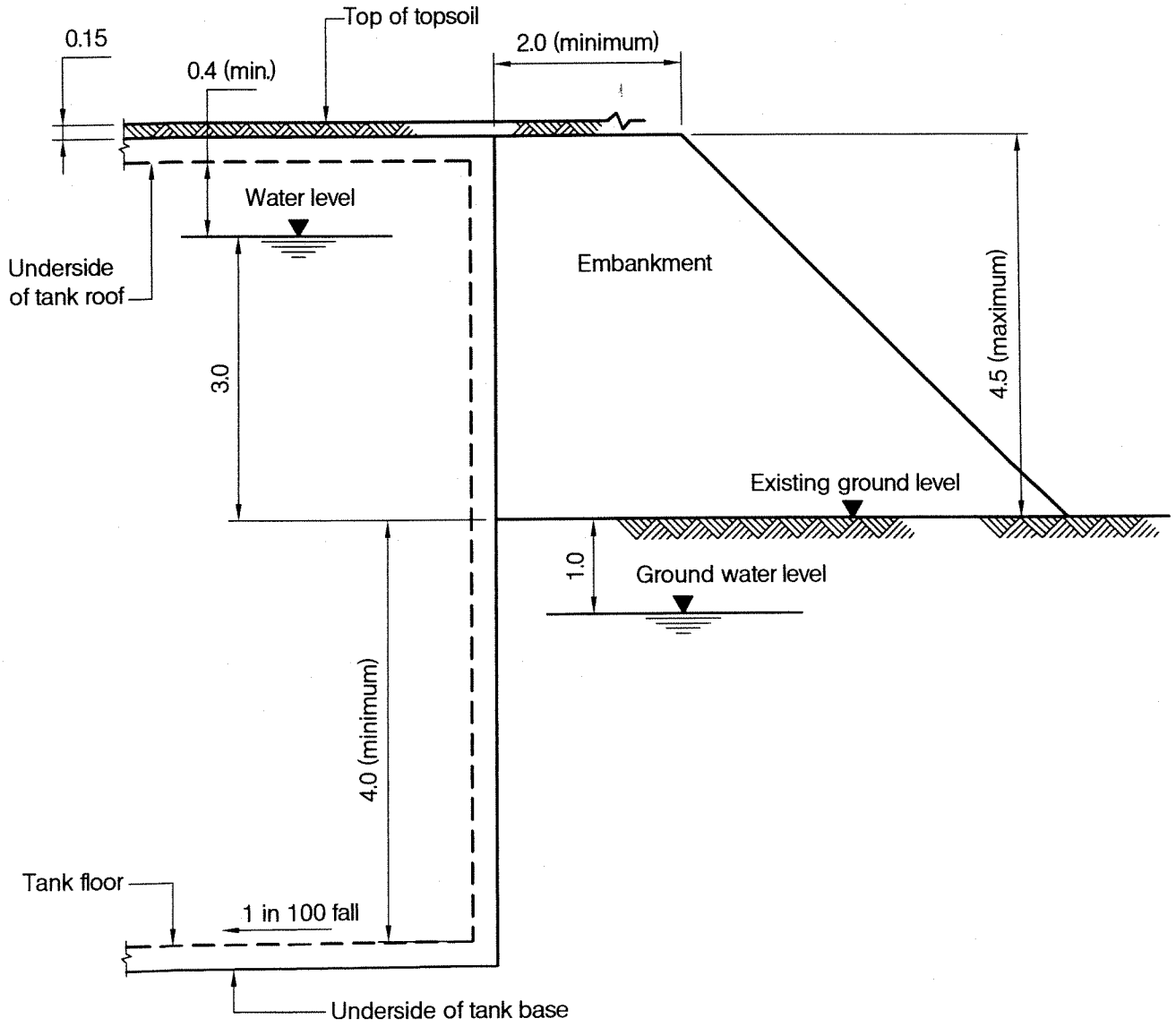
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

e. Prepare a detailed method statement for the safe construction of the tank and an outline construction programme. (10 marks)


0.15
Top of topsoil
2.0 (minimum)
0.4 (min.)
Water level
Underside
of tank roof
Embankment
3.0
4.5 (maximum)
Existing ground level
1.0
Ground water level
4.0 (minimum)
Tank floor
1 in 100 fall
Underside of tank base

SECTION

Question 5
Reservoir valve chamber and housing

Client's requirements

1. A chamber containing valves and equipment used to control the flow of water through pipes into and out of a reservoir. See Figure Q5.
2. The chamber is to have three floors with a flat roof above. The access room floor is at ground level and has a 2.0 m x 2.0 m area of removable flooring to allow access to the floors below. The control room floor supports equipment to control the valves and has a 3.0 m x 6.0 m area of removable flooring to allow access to equipment below. The valve room floor supports valves connected to pipes that enter and leave the chamber as shown in Figure Q5.
3. A stairway is required from the access room to the control room. Access from the control room floor to the valve room is by ladder.
4. All floors and the roof are to be supported by the external walls of the chamber. No internal walls or columns are permitted.

Imposed Loading

5. Roof 0.75 kN/m^2
   Each floor within the chamber 10.0 kN/m^2

Site Conditions

6. Basic wind speed is 40 m/s based on a 3-second gust; the equivalent mean hourly wind speed is 20 m/s.
   Note: The 3 second gust speed is used in the British Standard CP3 and the mean hourly wind speed is used in the British Standard 6399. Candidates using other codes and standards should choose an appropriate equivalent wind speed.
7. Ground conditions:

Ground level - 0.5 m	Made ground.
Below 0.5 m	Gravel. N = 15

   Groundwater was encountered at 1.0 m below ground level.

Omit from consideration

8. Detailed design of the stairs, ladders and the removable floors.

SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After your recommended solution has been accepted, the client requests that the chamber be increased in size to 7.0 m x 7.0 m, in plan. Write a letter to the client explaining the effects that this would have on the structure. (10 marks)

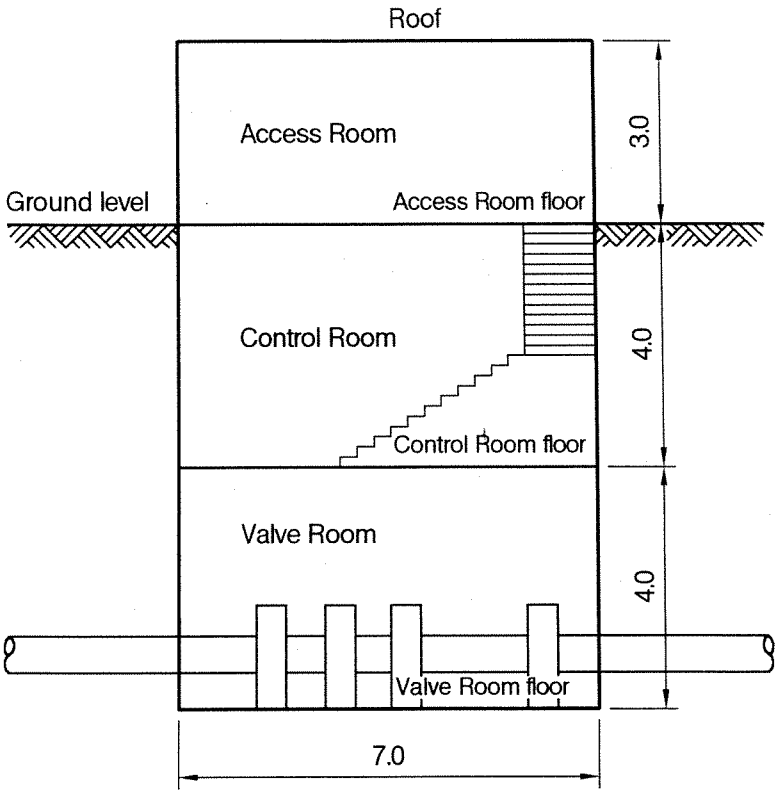
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

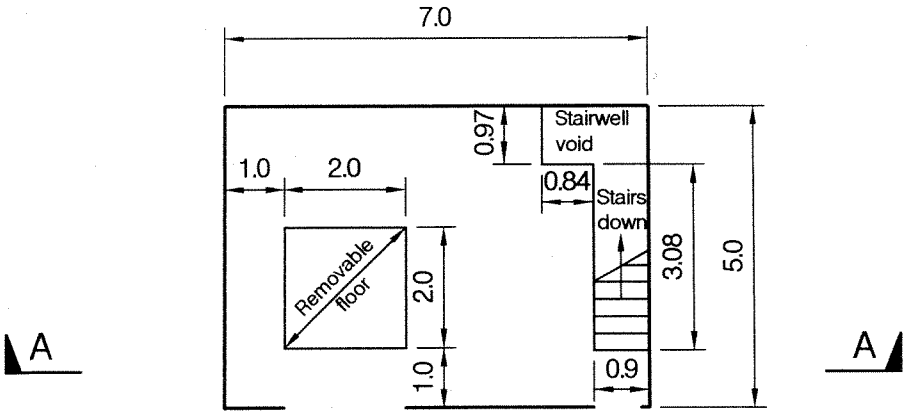
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

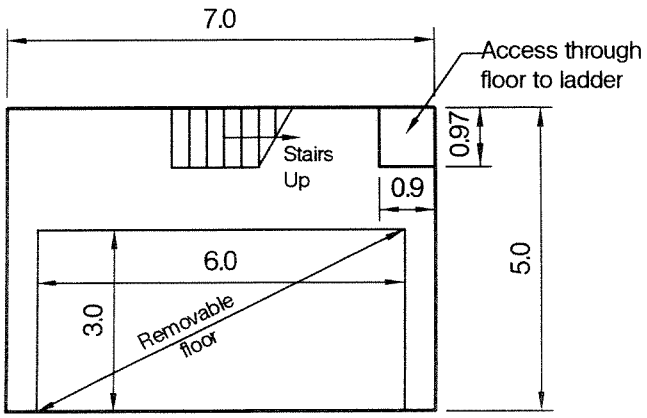
e. Prepare a detailed method statement for the safe construction of the structure and an outline construction programme. (10 marks)



SECTION A-A



PLAN ON ACCESS ROOM FLOOR



PLAN ON CONTROL ROOM FLOOR

Question 6
Community building

Client's requirements

1. A new single storey community building to be constructed on a remote site. See Figure Q6.
2. The building is to be of modular design, using standardised components, allowing ease, economy and speed of construction.
3. The design will be used for a number of similar buildings that are to be constructed in the region. In each case, the dimensions of the building will be varied from those shown on Figure Q6 to suit the anticipated number of users. As a result the client requires a design that can be easily adapted to accommodate a range of different building sizes.
4. The climate in the region is hot and humid and the provision of a power supply for mechanical ventilation cannot be guaranteed at all the sites. The client has therefore requested that maximum use is made of natural ventilation.
5. A 3.0 m x 4.0 m x 1.2 m deep sunken water pool is to be incorporated in the design.
6. Basic construction equipment will be available at all the potential sites for the building. This will include a mobile crane (maximum lift: 8000 kg at a radius of 25.0 m), a dumper truck and a manually operated concrete batching plant with a production capacity of 10 cubic metres per hour.
7. A limited supply of sand and aggregate is available from local quarries but all supplies of structural steelwork and timber have to be imported.
8. All excavation will be carried out by hand. There is an unlimited supply of local labour.

Imposed Loading

9. Roof — 0.6 kN/m^2 (plus a 900 kg suspended lighting rig and a 200 kg rooftop sign)

   Ground floor — 5.0 kN/m^2

Site Conditions

10. The site is level and is located in a remote, exposed area.
    Basic wind speed is 44 m/s based on a 3-second gust; the equivalent mean hourly wind speed is 22 m/s.
    Note: The 3 second gust speed is used in the British Standard CP3 and the mean hourly wind speed is used in the British Standard 6399. Candidates using other codes and standards should choose an appropriate equivalent wind speed.
11. Ground conditions:

Ground level - 3.2 m	Loose Sand. N = 3.
3.2 m - 5.0 m	Medium dense Sand. N = 15.
5.0 m - 10.0 m	Dense Sand. N = 30.
10.0 m - 20.0 m	Very dense Sand. N = 75.
Below 20.0 m	Sandstone. Allowable bearing pressure = 1000 kN/m^2.

Groundwater was not encountered in the ground investigation but the region is susceptible to flash flooding with 1 year return period storm intensities of 80 mm/hour.

SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After completion of your design, the client requests a modification to allow the buildings to be constructed on sites with differing ground conditions and with slopes of up to 1 (vertical) in 15 (horizontal). Write a letter to the client explaining how your design would be modified to accommodate these changes. (10 marks)

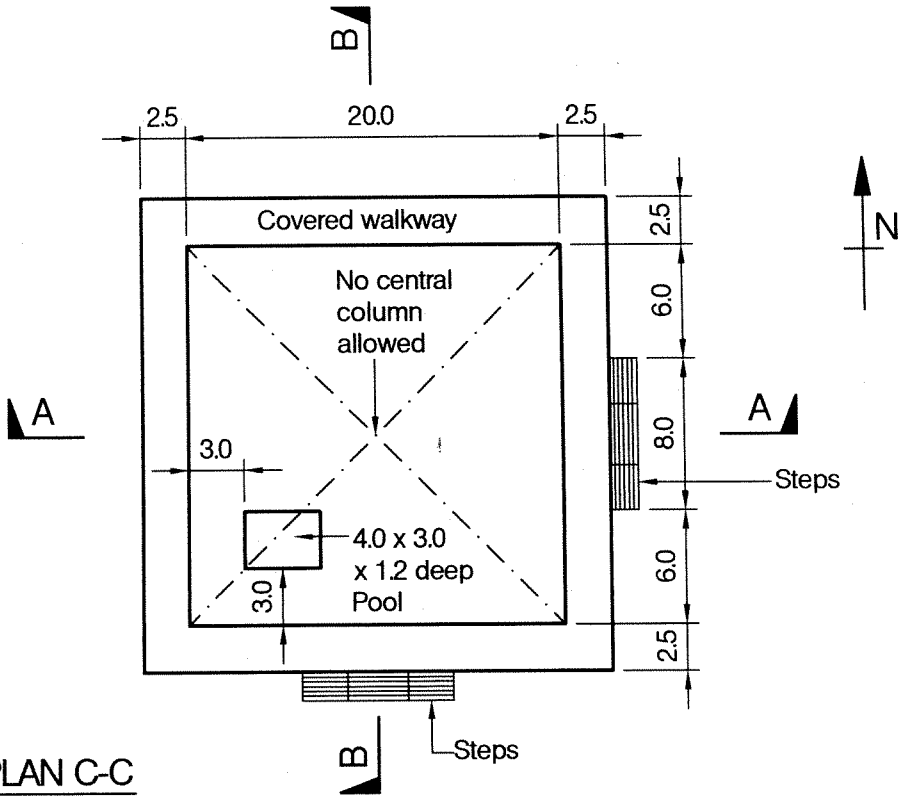
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

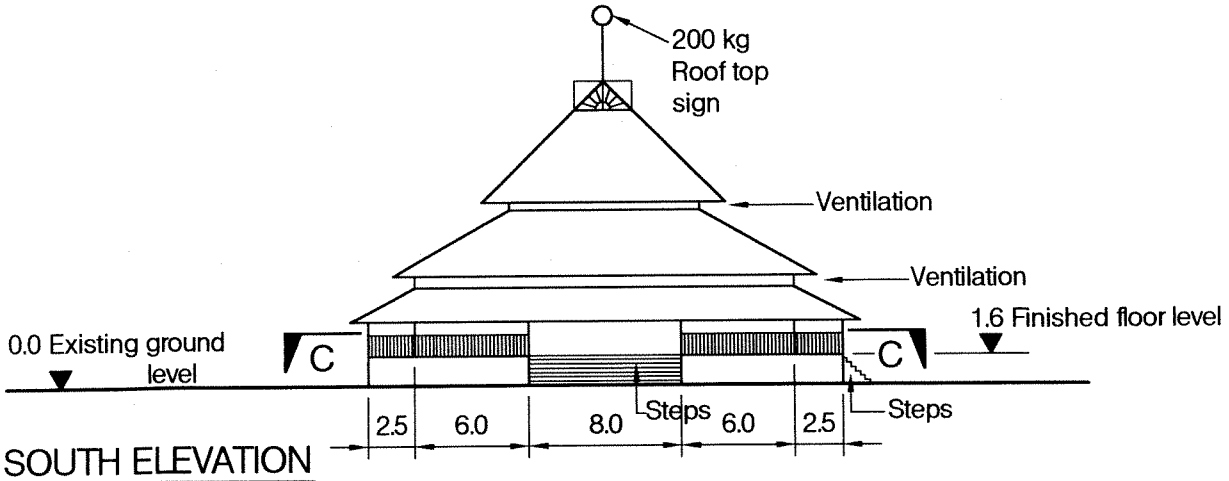
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

e. Prepare a detailed method statement for the safe construction of the building. With the aid of fully annotated sketches, describe any temporary works required. (10 marks)

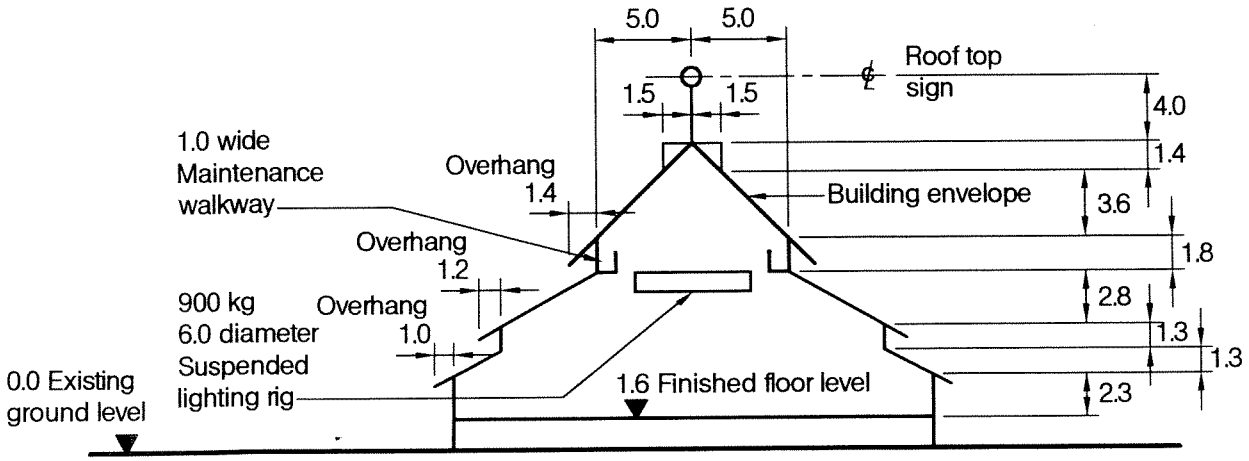


SECTIONAL PLAN C-C



SOUTH ELEVATION

EAST ELEVATION SIMILAR
(NORTH & WEST ELEVATIONS SIMILAR BUT NO STEPS)



SECTION A-A

SECTION B-B SIMILAR
(STEPS NOT SHOWN)

Question 7
Offshore wind farm

Client's requirements

1. A steel structure to support a wind turbine generator unit at an elevation of 85.0 m above sea level at an offshore site with a water depth of 45.0 m. See Figure Q7. The wind farm will comprise 80 such structures.

Imposed Loading

2. Weight of turbine unit — 330 tonnes.
   Wind load on turbine and blades — 2.2 MN (The wind turbine generator unit and blades rotate about the vertical yaw axis shown on Figure Q7 so that they point into the wind).
   Wave loading (See Figure Q7) — 25D kN/m at an elevation of 10.0 m above mean sea level reducing to 10D kN/m at sea bed level. Where D is the diameter (in metres) of each tubular member in the wave zone.

Site Conditions

3. Ground conditions:

Sea bed level - 1.0 m	Loose Sand. N = 5.
Below 1.0 m	Hard to very hard Clay. C = 300 kN/m^2.

Omit from consideration

4. Design of the blades, turbine generator unit, access platforms and power cable supports.
5. Any additional wind loading acting on the structure (i.e. only consider the wind loading specified in 2, above).

SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After completion of your design, the client requests that the turbine unit be raised to a height of 95.0 m above mean sea level. Write a letter to the client explaining the effect that this would have on the design of the structure and the installation of the generator unit. (10 marks)

SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

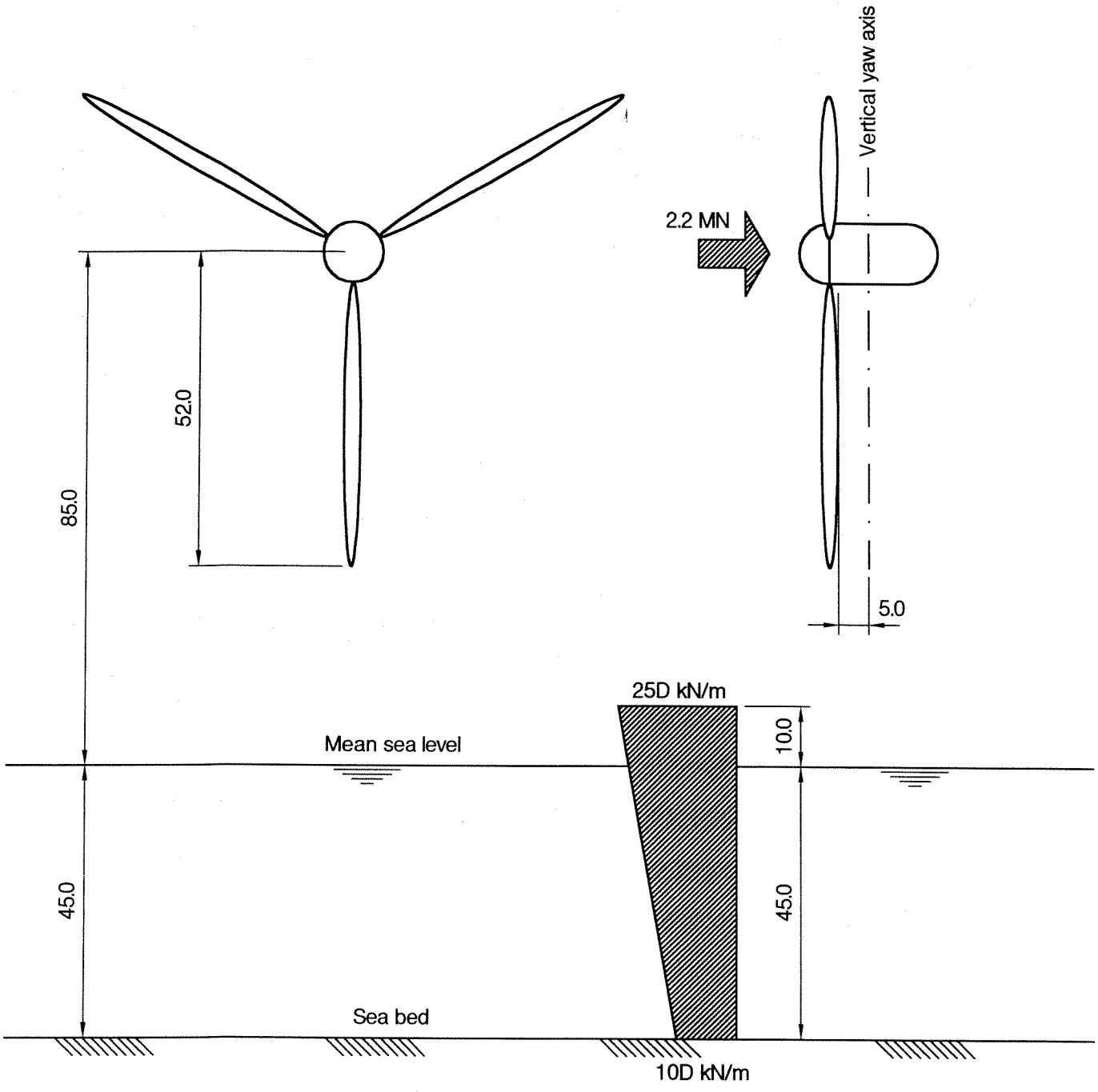
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

e. With the aid of fully annotated sketches, describe the installation procedure for the support structure, turbine unit and blades. (10 marks)

FRONT VIEW OF TURBINE GENERATOR UNIT AND BLADES

SIDE VIEW OF TURBINE GENERATOR UNIT AND BLADES



WAVE LOAD PROFILE