

The Institution of Structural Engineers

Membership Examination

Part 3



12 APRIL 1996

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 luncheon 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 drawings must bear the candidate's index 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, ie bending, shear, deflection, etc.
3. In all questions 40 marks are allocated to Part 1 and 60 marks to Part 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 battery 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. This paper is set in SI Units, together with an alternative set of numerical data in British Imperial Units in parentheses. Candidates may use either set of data and may work in either system of units but should note that the two sets of data do not necessarily correspond. This is in order to avoid complicated arithmetic in one set of units.

Now read 'Reminder' on Page 3 

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 clear and logical way.

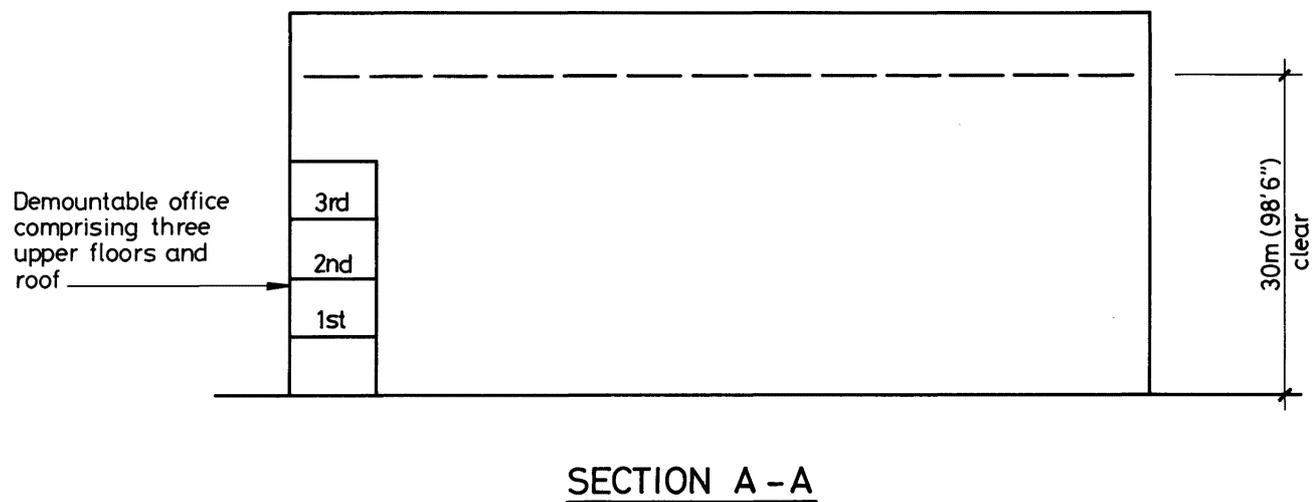
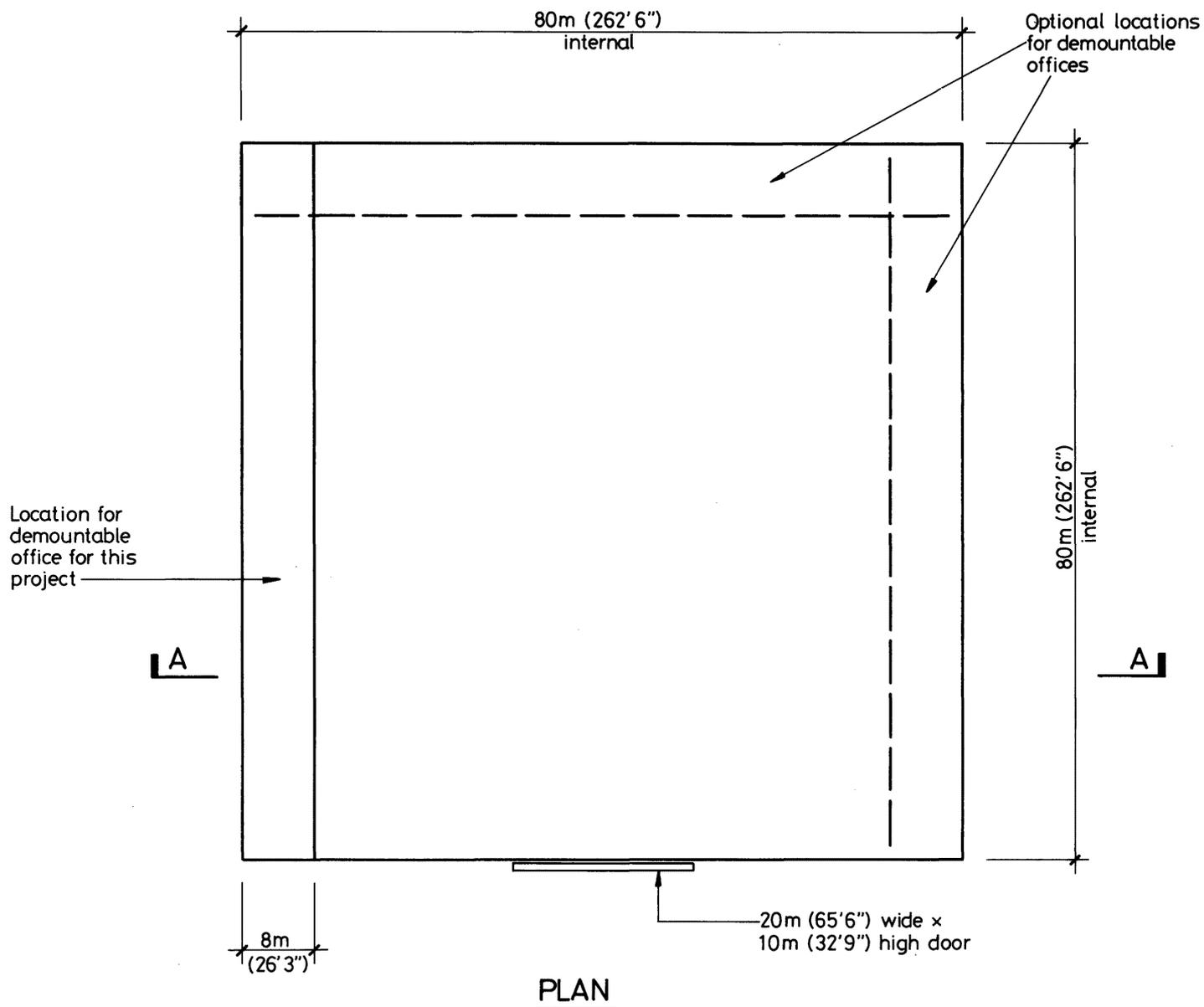
The unusual requirement of the examination is that you must demonstrate the validity of the training and experience that you have acquired in recent years. The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of a structural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

A Chartered Structural Engineer must have an ability to design and a facility to communicate his 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 design 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.



NOTE All dimensions are in metres (feet and inches)

FIGURE Q1

Question 1

Research Building

Client's requirements

1. A single storey building for letting to outside organisations for research; see Figure Q1.
2. The headroom required to the underside of the roof structure is 30m (98'-6"). The building height should be kept as small as possible consistent with an economic design.
3. A demountable office is required along one side of the building. The office structure should be capable of being dismantled and installed on any of the three sides of the building. The office will have a minimum period of 18 months in any location. The structure of the main building may be used to support the office. Three upper floors and the ground floor are required with a minimum floor to ceiling height of 3.5m (11'-6").
4. The elevations and roof are to be of profiled metal. Windows are required in each elevation which might accommodate offices.
5. A double concertina sliding door is required in the front elevation. The door is to be 10m (32'-9") high and 20m (65'-6") wide.

Imposed loadings

6. Main roof:	Snow loading	0.6kN/m ² (12.5lbf/ft ²)
	Services	1.0kN/m ² (20lbf/ft ²)
Office floors:	Imposed	2.5kN/m ² (50lbf/ft ²)
	Services	1.0kN/m ² (20lbf/ft ²)
Internal pressure:	±0.3kN/m ² (6lbf/ft ²)	
Ground floor:	35kN/m ² (730lbf/ft ²)	

Site conditions

7. The site is situated in open country. Basic wind speed is 45m/s (100 mile/h).

Ground conditions

8. Ground level to 1.6m (5'-3")	Topsoil and loose fill
1.6m (5'-3") to 3.6m (11'-9")	Gravel. N = 10.
Below 3.6m (11'-9") Chalk to depth	Safe bearing pressure 300kN/m ² (2.75 ton/ft ²)

Omit from consideration

9. Detailed design of cladding, office stairs and walls.

Part 1

(40 marks)

- a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the building, foundations and floors. Identify the functional framing, the load transfer and stability aspects of each scheme. Identify the scheme you recommend giving reasons for your choice.
- b. Foundation construction is complete and steelwork fabricated but not delivered to site. The client asks for the demountable offices to be located permanently in the position shown in figure Q1, but with an increased imposed floor loading of 5kN/m² (100lbf/ft²).

Write a letter to the client explaining the implications of this request, and describe how it might be achieved structurally.

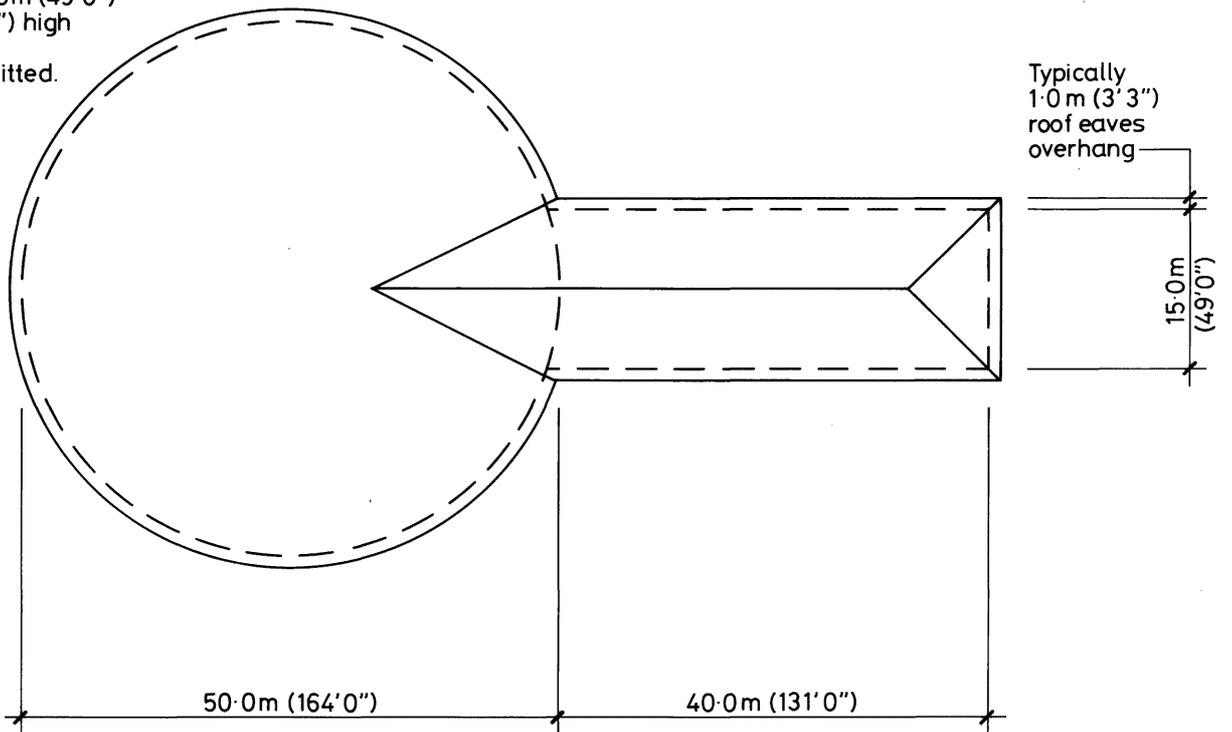
Part 2

(60 marks)

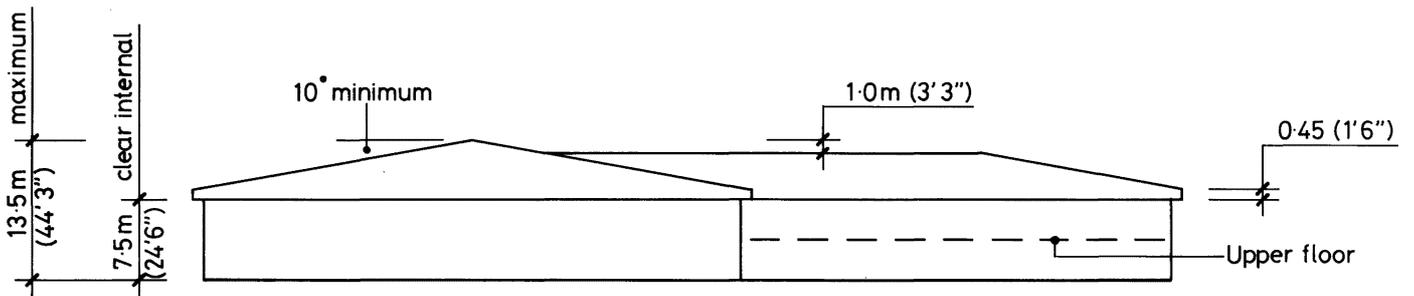
For the solution identified in part 1(a).

- c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the ground slab, foundations, demountable offices and superstructure.
- d. Prepare general arrangement plans, sections and elevations necessary to show the dimensions, layout and disposition of the structural elements as required for estimating purposes.
- e. Prepare clearly annotated sketches to illustrate details of:
 - (i) The connection of the demountable office structure to a main column.
 - (ii) The connection of a main column to a principal roof member.
 - (iii) A detail through the roof/wall junction showing provision for drainage and the arrangement of the roof/wall cladding.
- f. Provide a method statement for the safe dismantling and re-erection of the demountable office, together with a simple bar chart programming the main activities.

Main entrance 15.0m (49'0") wide x 5.0m (16'4") high glazed area.
One column permitted.



ROOF PLAN SHOWING BUILDING OUTLINE (BROKEN LINE)



ELEVATION

NOTE All dimensions are in metres (feet and inches).

FIGURE Q2

Question 2

Exhibition and Function Building

Client's requirements

1. A single storey circular building for exhibitions and functions with an adjoining two storey office; see Figure Q2.
2. The clear headroom required in the exhibition area is 7.5m (24'-8"). Elevations are to be brickwork with windows. The roof is to be clad with specialist metal cladding and is to have a minimum slope of 10 degrees. The height of the roof is to be as low as possible consistent with economic design. The total height of the building must not exceed 13.5m (44'-3"). A 1.0m (3'-3") eaves overhang is required.
3. The entrance to the exhibition room is via a glazed door and window area 15m (49'-0") wide and 5.0m (16'-4") high. One column is permitted within the entrance.
4. The adjoining office block is to have brickwork elevations and a roof to match the exhibition centre. Clear floor to ceiling heights of 3.0m (9'-9") are required. Columns are permitted in the external elevations with a single line of columns internally, offset by 0.75m (2'-6") from the centreline of the building to provide a central corridor. The ridge of the roof should be 1.0m (3'-3") below the apex of the exhibition hall roof and a 1.0m (3'-3") eaves overhang is required.
5. Windows are required in all elevations of the office block and any bracing must take account of this. Access within the office is via an unenclosed lightweight staircase.

Imposed loadings

6. Office floors:	5.0kN/m ² (100lb/ft ²)
Exhibition room floor	1.5kN/m ² (30lb/ft ²)
Exhibition room roof	1.0kN/m ² (20lb/ft ²)
Snow loading	0.6kN/m ² (12lb/ft ²)

Site conditions

7. The building is situated on a golf course on the outskirts of a small town. Basic wind speed is 42m/s (98 mile/h).
8. Ground conditions
0 to 2.0m (6'-6") Topsoil and fill.
2.0m (6'-6") – 6.0m (19'-6") Sand and gravels. N = 7 to 12
Below 6.0m (19'-6") Clay. C = 125kN/m² (2500lb/ft²)
Groundwater is present at 1.5m (5'-0") below ground level.

Omit from consideration

9. Design of the staircase.

Part 1

(40 marks)

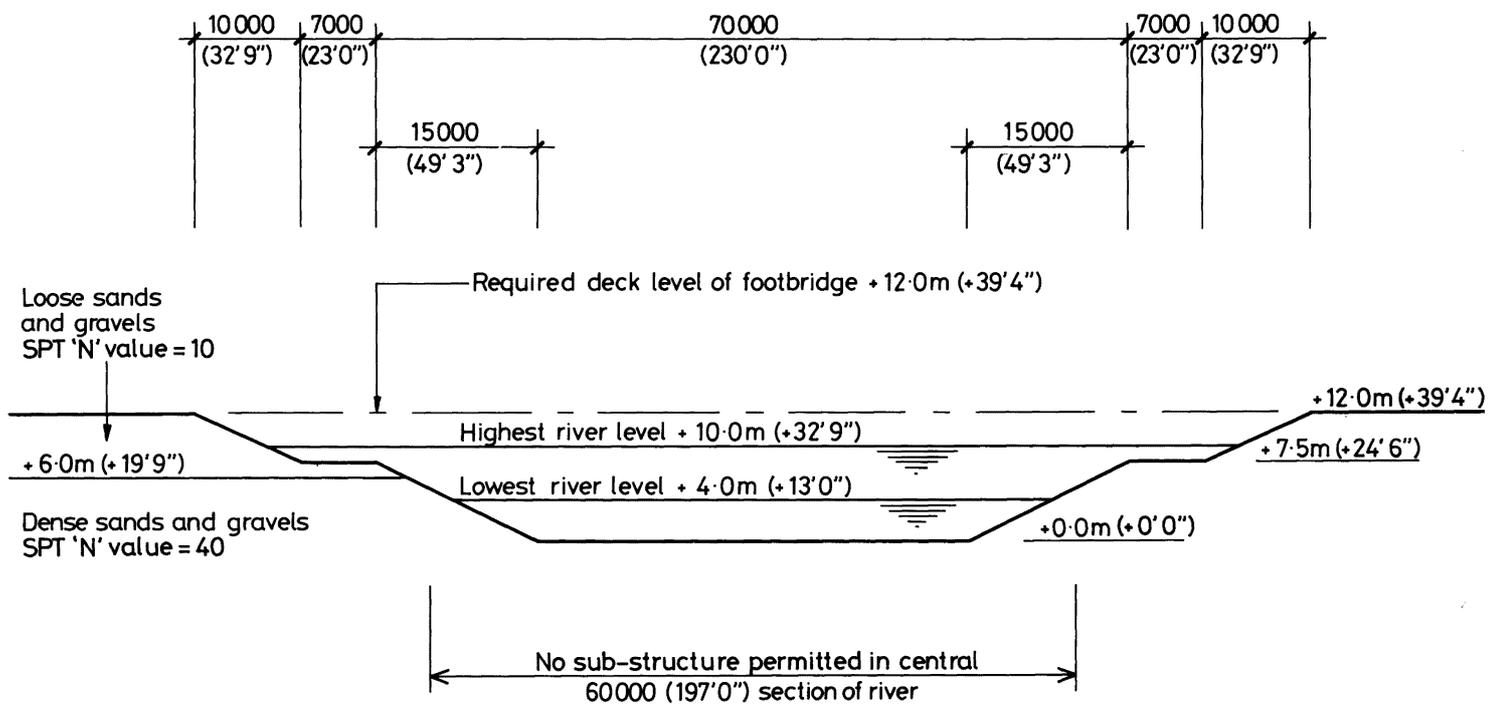
- a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the building, its foundations and floors. Identify clearly the functional framing, the load transfer and stability aspects of each scheme. Identify the solution you recommend giving reasons for your choice.
- b. Following completion of the design and fabrication of the steelwork the client asks for the ground floor office area to be made free of internal columns. Foundation work is in progress. Write a letter to the client describing how this change could be achieved.

Part 2

(60 marks)

For the solution recommended in Part 1(a):

- c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the ground floor slab and foundations.
- d. Prepare the general arrangement plans, sections and elevations necessary to show the dimensions, layout and disposition of the structural elements as required for estimating purposes.
- e. Prepare clearly annotated sketches to illustrate details of:
 - (i) The structure of the centre of the exhibition room roof.
 - (ii) The junction of the structure of the exhibition room and office roof.
 - (iii) A section through the eaves of the exhibition room roof.
- f. Provide a method statement for the safe erection of the structure, listing any abnormal risks.



Note

Ground conditions are the same on both sides of the river.

NOTE All levels are in metres (feet and inches)
All other dimensions are in millimetres (feet and inches)

FIGURE Q3

Question 3

River Footbridge

Client's requirements

1. A new footbridge is required to cross a river; see Figure Q3.
2. The new bridge must have no permanent support in the central 60m (197'-0") section of the river.
3. The footbridge must have a clear width of 2m (6'-6").
4. Guard rails 1m (3'-3") high shall be provided at the edge of the deck.
5. All parts of the main deck shall be clear of the highest river water level.

Imposed loading

6. Imposed vertical loading on the bridge shall comprise a uniformly distributed pedestrian loading of 5kN/m² (100lb/ft²).
7. Design wind speed 45 m/s (100 mile/h).

Site conditions

8. The ground conditions are as indicated in Figure Q3.

Part 1

(40 marks)

- a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the bridge construction. Identify clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice.
- b. After your recommended solution has been approved in principle, the client asks if it is possible to adapt the design to accommodate a maintenance vehicle 1.5m (5'-0") wide with a maximum weight of 50kN (5 ton) on 2 axles with a 2.5m (8'-6") wheelbase.

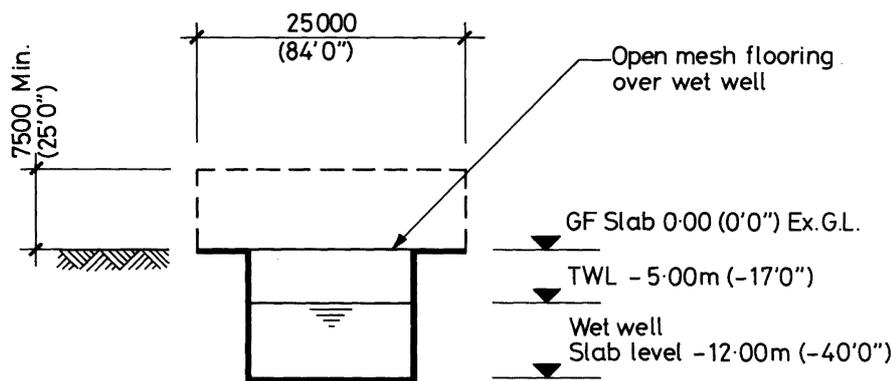
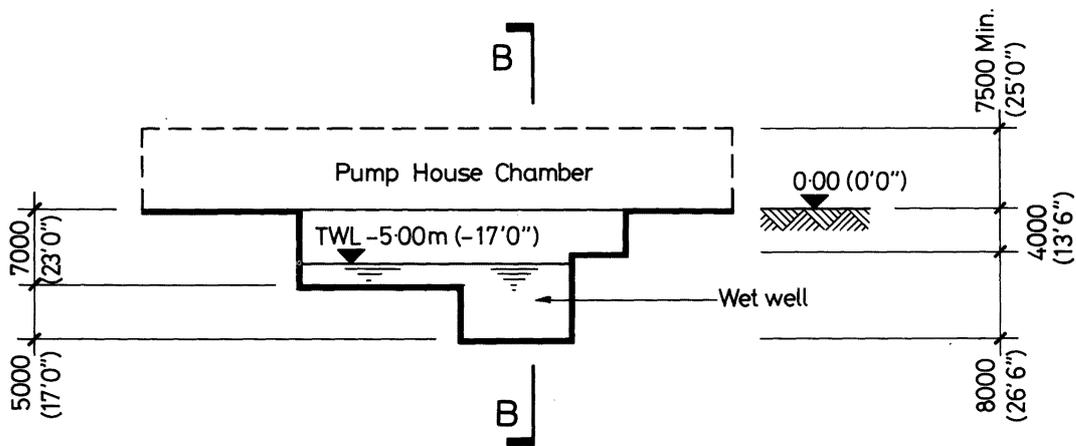
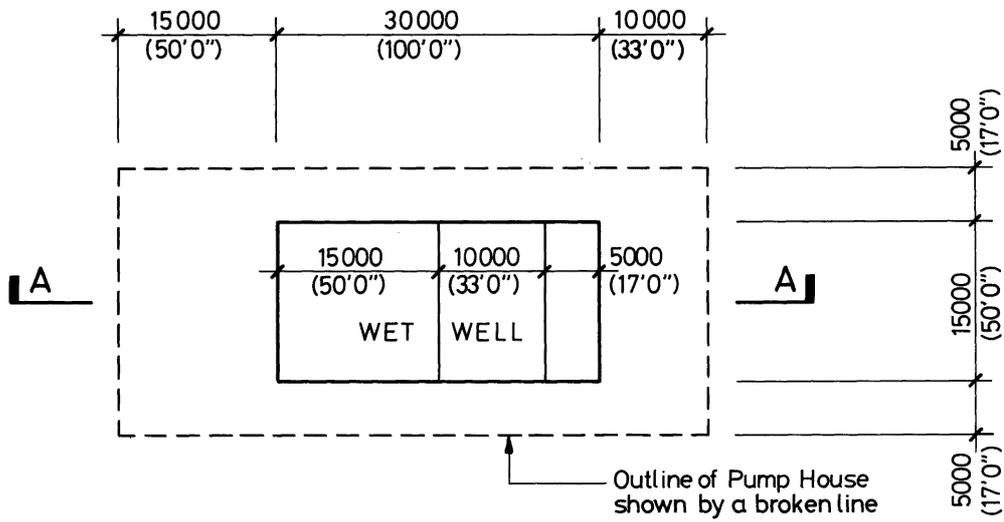
Write a letter to the client explaining the effect of this request on the design.

Part 2

(60 marks)

For the solution recommended in Part 1(a):

- c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including all foundations.
- d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes.
- e. Prepare clearly annotated sketches to illustrate details of:
 - (i) The articulation/bearing details.
 - (ii) The pedestrian guard rail and its connection to the deck.
- f. Prepare a brief method statement for the safe construction of the structure, including highlighting any temporary works required.



NOTE All levels are in metres (feet and inches)
 All other dimensions are in millimetres (feet and inches)

FIGURE Q4

Question 4

Pump House

Client's requirements

1. A new single storey pump house, suitably clad, encompassing a 30m (100'-0") long by 15m (50'-0") wide wet well containing penstock, screens, valves, pipework and pumps. See Figure Q4.
2. The minimum height to the underside of the roof in the pump house chamber is to be 7.5m (25'-0").
3. The water level in the wet well varies depending upon the operational mode at any particular time. The top water level (TWL) is as indicated on Figure Q4.

Imposed loading

- | | | |
|----------------|-------|---|
| 4. Pump house: | Floor | 5.0kN/m ² (100lbf/ft ²) |
| | Roof | 0.75kN/m ² (15lbf/ft ²). |

Site conditions

5. A level coastal site with no adjacent structures.
6. Ground conditions:

0-2m (6'-6")	Made ground
2m (6'-6") – 15m (50'-0")	Soft silty sands. N = 5
Below 15m (50'-0")	Stiff boulder clay. Average C = 200kN/m ² (4000lbf/ft ²)

Ground water was encountered at 1.5m (5'-0") below existing ground level.

Omit from consideration

7. Screens, valves, pumps and associated services.

Part 1

(40 marks)

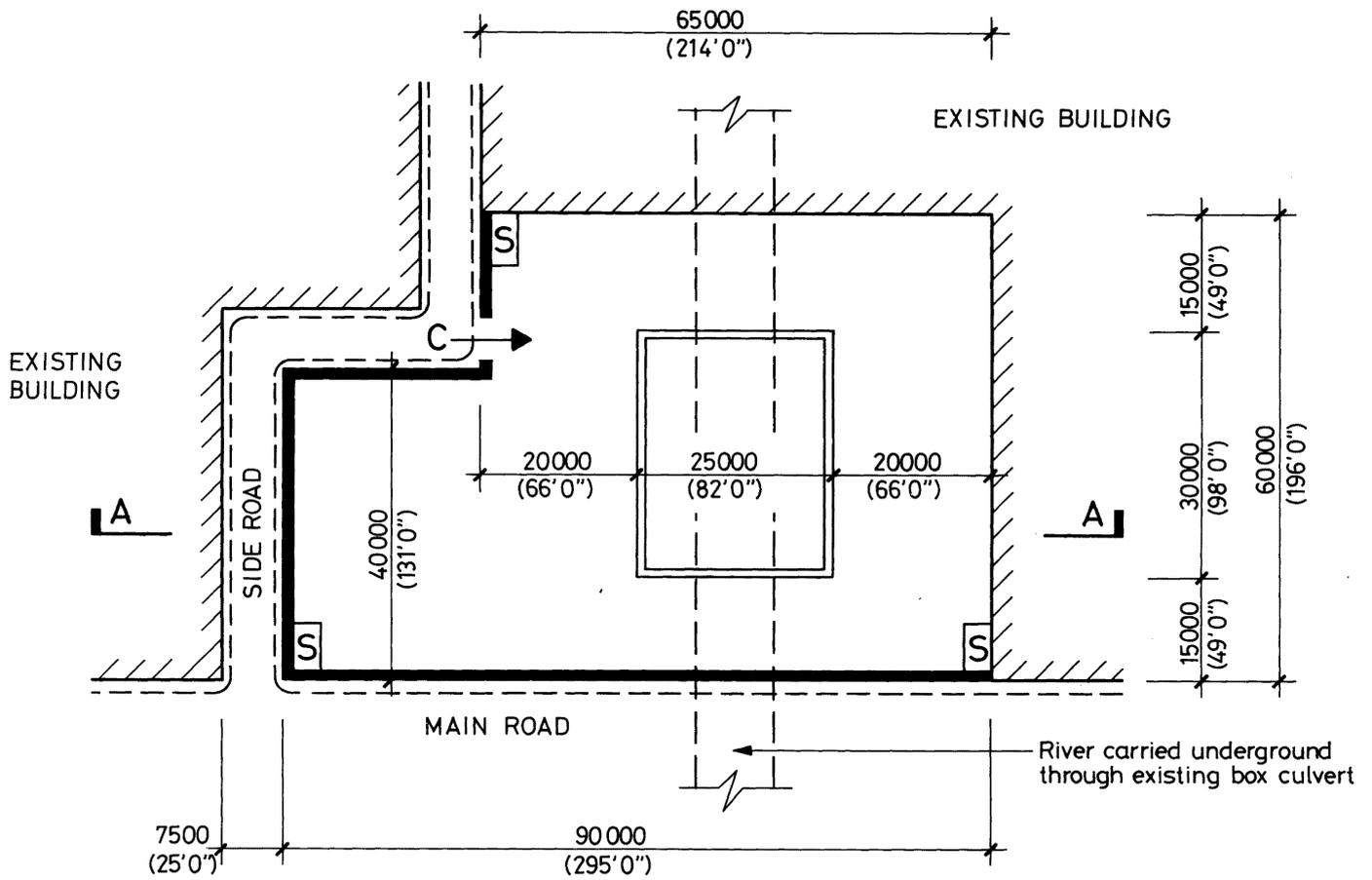
- a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the proposed structure. Identify the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice.
- b. After your recommended solution has been approved in principle the client considers adding a second storey to the pump house chamber to incorporate offices and other facilities. Write a letter to the client outlining the effects this consideration will have on your chosen solution.

Part 2

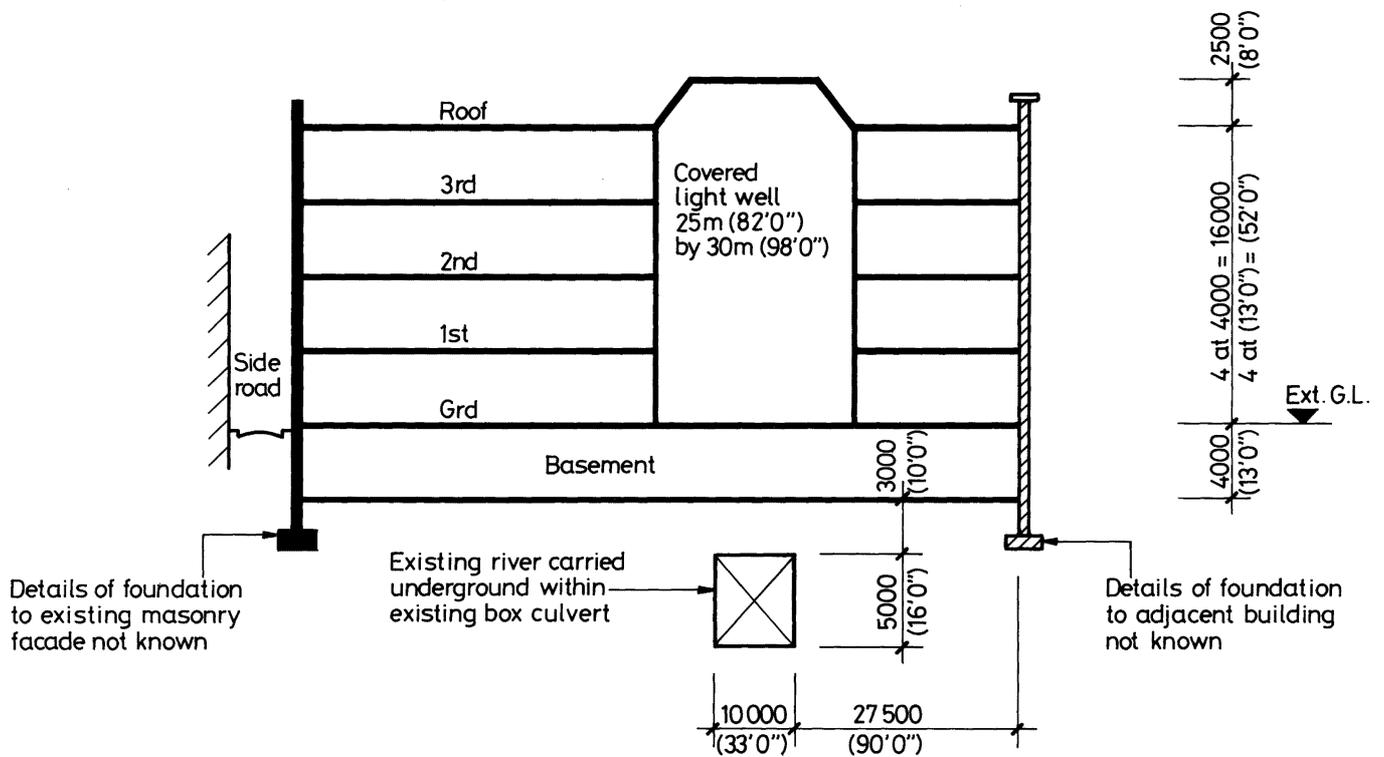
(60 marks)

For the solution recommended in part 1(a):

- c. Prepare sufficient design calculations to establish the form and size of all principal structural elements for the structure including the pump house chamber and wet well.
- d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes.
- e. Prepare clearly annotated sketches to illustrate details of:
 - (i) The connection between the wet well floor slab and the perimeter wall.
 - (ii) The connection between the column and the foundation to the pump house chamber structure.
 - (iii) The connection at the eaves level between the walls and the roof of the pump house including structural elements and finishes.
- f. Describe, using illustrations as necessary, the construction sequence for the pump house including any temporary works required for the safe construction of the works.



PLAN



SECTION A-A (Please note that vertical scale is different from horizontal)

NOTE All dimensions are in millimetres (feet and inches)

FIGURE Q5

Question 5

City Centre Office Building

Client's requirements

1. A new four storey office building with basement is to be constructed within the confines of an existing masonry facade and an adjacent building. See Figure Q5. The retained facade and the existing party wall to the adjacent building are not to be used for supporting any of the new structure.
2. A covered lightwell is to be incorporated within the new structure with fully glazed sides and roof.
3. Columns are permitted above ground floor level at not less than 10m (33'-0") centres. See also site conditions 10 below.
4. The dimensions floor to floor are as shown on section A-A. The minimum clear floor to ceiling height of 3.0m (10'-0") must be provided throughout the structure with a 400mm (1'-4") minimum ceiling void for services.
5. The fire resistance of the new structure is to be two hours.
6. Three stair/lift enclosures 6.0m (20'-0") by 3.0m (10'-0") are to be incorporated into the new structure in the three locations marked 'S' on the plan.

Imposed loading

- | | |
|------------------------------|--|
| 7. Floors including basement | 5.0kN/m ² (100lbf/ft ²) |
| Roof | 0.75kN/m ² (15lbf/ft ²) |

Site conditions

8. A level site in a city centre.
9. The contractor's access to construct the works is extremely limited and restricted via the 7.5m (25'-0") wide side road to a temporary access point indicated 'C' on the plan.
10. A river exists on the site which is carried underground through an existing box culvert. The building must not impose any additional loading on this existing structure.
11. Ground conditions from existing ground level (approx. road level):

0 – 4.0m (0' – 13'-3")	Fill
4.0m – 5.5m (13'-3" – 18'-0")	Sand and gravel. N = 6.
Below 5.5m (18'-0")	Stiff Clay. Average C = 200kN/m ² (4000lbf/ft ²)

Ground water is not present.

Omit from consideration

12. Detail design of the staircase and lift shafts, although their contribution (if any) to overall stability and load transfer must be stated in Part 1(a).
13. Temporary support to the masonry facade during construction.

Part 1

(40 marks)

- a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the proposed structure. Identify the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice.
- b. After your recommended solution has been approved in principle the client considers deleting the requirement for the covered lightwell and alternatively proposes to increase the floor plan area of the building accordingly.

Write a letter to the client outlining the possible structural advantages or disadvantages this proposed change may have on the design of the scheme together with any construction and financial implications.

Part 2

(60 marks)

For the solution recommended in Part 1(a):

- c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the roof to the covered lightwell and the basement and the new foundations.
- d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes.
- e. Prepare clearly annotated sketches to illustrate details of:
 - (i) The connection between the flat roof and the inclined covered lightwell showing structural details and finishes.
 - (ii) The connection between the existing masonry facade and upper floors of the new structure.
 - (iii) A column and foundation connection.
- f. Discuss what investigative measures are necessary in order to determine the founding level and extent of the existing foundations under the masonry facade. Summarise the measures in the form of a method statement outlining the work to be carried out by the site investigation team.

Question 6

Library Extension

Client's requirements

1. An extension to a city centre library to create a new entrance foyer, children's library, adult reading area, computer media room, administrative office and additional basement storage. The extension is to be located in the corner formed by two wings of the existing building. See Figure Q6.
2. The front elevation to the foyer is to be glazed for its full width and height above ground. The new side elevation and the front wall to the computer media store above the administrative office are to be of cavity masonry construction, using facing bricks to match the existing library.
3. A pitched, slate-clad roof is required. The full height of the roof is to be visible internally over the adults' and children's reading areas, stairs and foyer. No horizontal ceiling members, ties or internal columns are permitted within these areas. The main structural members are to be exposed to view and neatly detailed. There is to be a central glazed section of the roof.
4. The bookshelf stacks are 0.5m (1'-8") wide and arranged in rows at 2.25m (7'-6") centres. The supporting structure should be designed to provide full width aisles between bookshelves.
5. A one hour minimum fire resistance is required for all structural elements.

Imposed loading

6. Floors:	Basement:	12 kN/m ²	(240lb/ft ²)
	Office:	4 kN/m ²	(80lb/ft ²)
	Elsewhere:	5 kN/m ²	(100lb/ft ²)
Roofs:		0.6 kN/m ²	(12lb/ft ²)
Balustrades:		3 kN/m	(200lb/ft)

Site conditions

7. The site is located in the centre of a town. Basic wind speed 40m/s (90 mile/h).
8. Ground conditions established from trial pits are:
 - 0 – 0.5m (1'-8") Topsoil and clayey made ground.
 - 0.5m (1'-8") – 1.5m (5'-0") Made ground comprising ash, clay and rubble.
 - 1.5m (5'-0") – 3.0m (10'-0") Firm to stiff clay. $C = 75\text{kN/m}^2$ (1500lb/ft²)
 - below 3.0m (10'-0") Weathered mudstone. $C = 250\text{kN/m}^2$ (5000lb/ft²)Ground water was encountered at 4.0m (13'-0").
9. Trial pits dug adjacent to the existing library revealed that it has stepped brick footings with those for its basement area founded at 3.65m (12'-0") in the mudstone and those for the other areas of the library and adjacent museum founded at 2.0m (6'-6") on the firm to stiff clay.

Omit from consideration

10. Detailed design of the stairs.

Part 1

(40 marks)

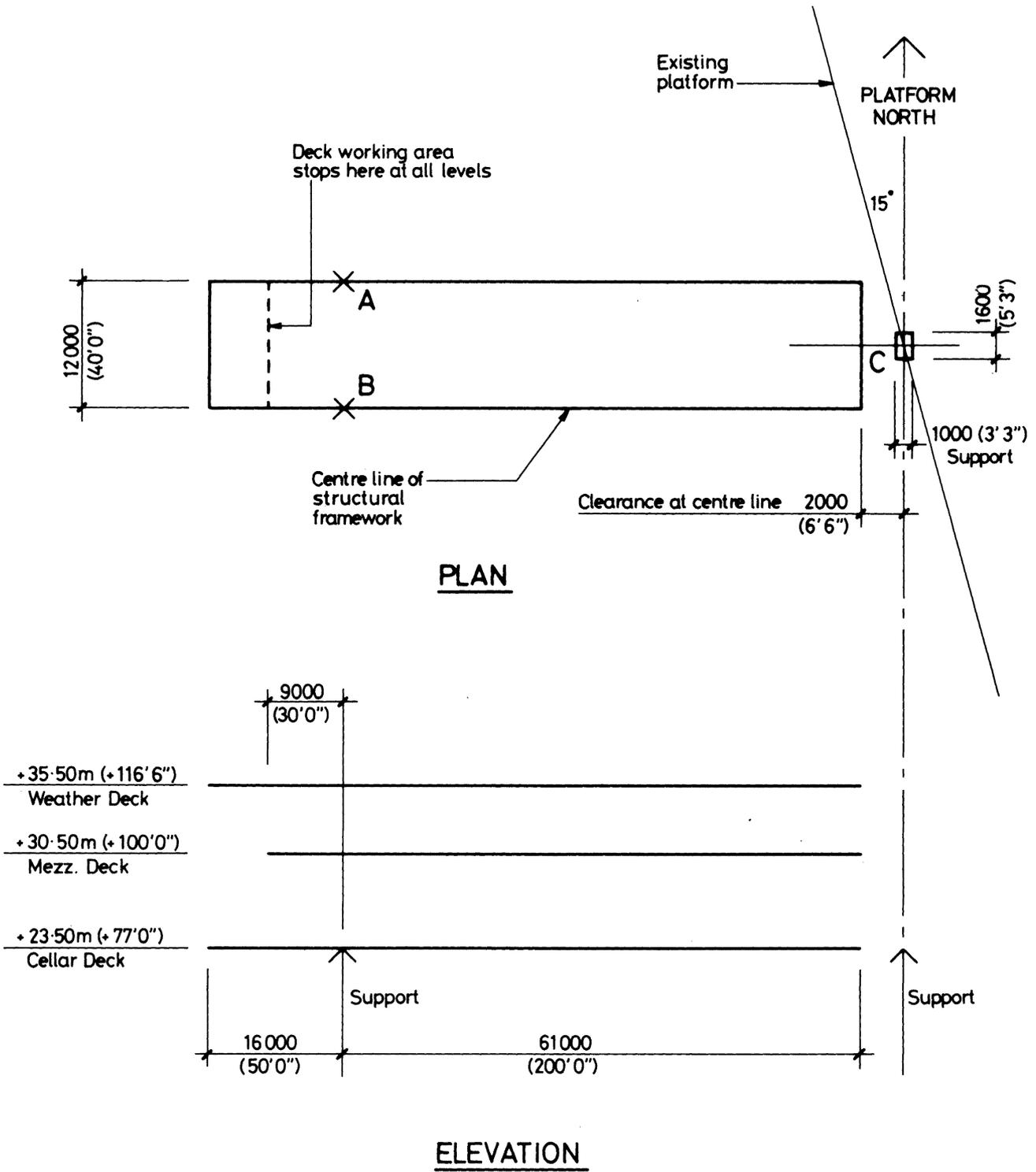
- a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the extension building. Indicate clearly the functional framing, load transfer and stability aspects, together with how the services are accommodated, for each scheme. Identify the solution you recommend, giving reasons for your choice.
- b. After your recommended solution has been approved, the client considers extending the basement storage to the maximum practical area under the whole of the extension. Write a letter to the Architect, recommending the dimensions for this extended basement, explaining the revisions necessary to the structural solution, together with the cost and programme implications.

Part 2

(60 marks)

For the solution recommended in Part 1(a):

- c. Prepare sufficient design calculations to establish the form and size of all principal structural elements, including foundations and retaining walls.
- d. Prepare general arrangement plans, sections and elevations to show the layout, dimensions and materials of the structural elements as required for estimating purposes.
- e. Prepare clearly annotated sketches to show details of the structure at the following locations:
 - (i) The foundation, basement wall and ground floor adjacent to the existing building at X.
 - (ii) The support to the roof adjacent to the existing building at Y.
 - (iii) The connection of the roof structure to the side external wall at Z.
- f. Prepare a detailed method statement for the safe preparation of the site and construction of the building, including how disruption to the existing library is to be minimised and identifying any temporary works that you consider necessary to construct the basement.



Secondary structural framing is only acceptable at the east end of the bridge and 9000 (30'0") west of supports A and B

NOTE All levels are in metres (feet and inches)
Other dimensions are in millimetres (feet and inches)

FIGURE Q7

Question 7

Link Bridge Module

Client's requirements

1. An open-sided bridge module spanning between an existing offshore platform and a mono-tower support.
2. The connections of the bridge are to be at locations A, B and C. See Figure Q7. There is to be a sliding support which allows for 300mm (12") movement in the East-West direction at the bridge connection points A and B. At A and B there is to be an allowance for a rotation of plus or minus 10 degrees about an axis perpendicular to the span of the bridge.
Support C is on an existing structure and a clearance of 2.0m (6'-6") must be maintained at the centreline of the bridge between the existing structure and the structural framework of the bridge.
3. The bridge is to be installed as a single lift and should weigh under 3,000 tonnes (3,000 tonf).
4. The bridge has a free fall life boat installed at the west end.
5. The bridge has a design life of 40 years.

Imposed loading

6. The bridge is to have a travelling gantry crane capable of lifting 25 tonne (25 tonf). The gantry must be able to travel unrestrictedly along the top elevation of the bridge from one end of the bridge to the other whilst maintaining a 6.0m (20'-0") clear head room throughout its travel.
7. Due to equipment and piping requirements the bridge is to have clear spans in the north-south direction, except where noted on the diagram.
8. Equipment-loads are

Weather deck	25kN/m ² (500lbf/ft ²)
Mezz. deck	10kN/m ² (200lbf/ft ²)
Cellar deck	15kN/m ² (300lbf/ft ²)
Piping	10kN/m ² (200lbf/ft ²)
Live load	5kN/m ² (100lbf/ft ²)

The piping is suspended from the underside of the weather deck and mezz. deck.
Equipment and piping can be assumed to cover 70 percent of the deck area throughout the bridge.

Site conditions

9. Basic wind speed is 40 m/s (90 mile/h).
10. Extreme ice thickness 50 mm (2") of density 900kg/m³ (55 lb/ft³).

Omit from consideration

11. Any dynamic and fatigue effects.
12. Sea fastening.
13. Installation aids other than padeyes and padears.
14. Design considerations of the lateral movement and horizontal rotation of the bridge supports.

Part 1

(40 marks)

- a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the proposed work including method of loadout and installation.
Indicate clearly the functional framing, load transfer and stability aspects of each scheme.
Identify the solution you recommend giving reasons for your choice.
- b. Having received your recommended design your client then proposes to delete the gantry crane and replace it with two pedestal cranes positioned so as to cover the whole deck area.
Write to your client explaining the structural implications which his requirements will have on your proposal and advise him of the best location for these cranes.

Part 2

(60 marks)

For the solution you have recommended in Part 1(a):

- c. Prepare sufficient design calculations to establish the size and form of all significant elements.
- d. Prepare a general arrangement drawing containing plans, elevations and sections necessary to show dimensions, layout and disposition of the structural elements and the lifting points as required for estimating purposes.
- e. Prepare neat annotated sketches to illustrate the details of:
 - (i) Support point C including 6.0m (20'-0") to the west.
 - (ii) A typical lifting point.
 - (iii) A typical node point connection in the structural framework of the sides.
- f. Prepare a method statement outlining a suitable inspection and maintenance procedure for the bridge.

