The Institution of Structural Engineers

Membership Examination Part 3

2 APRIL 1993

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.

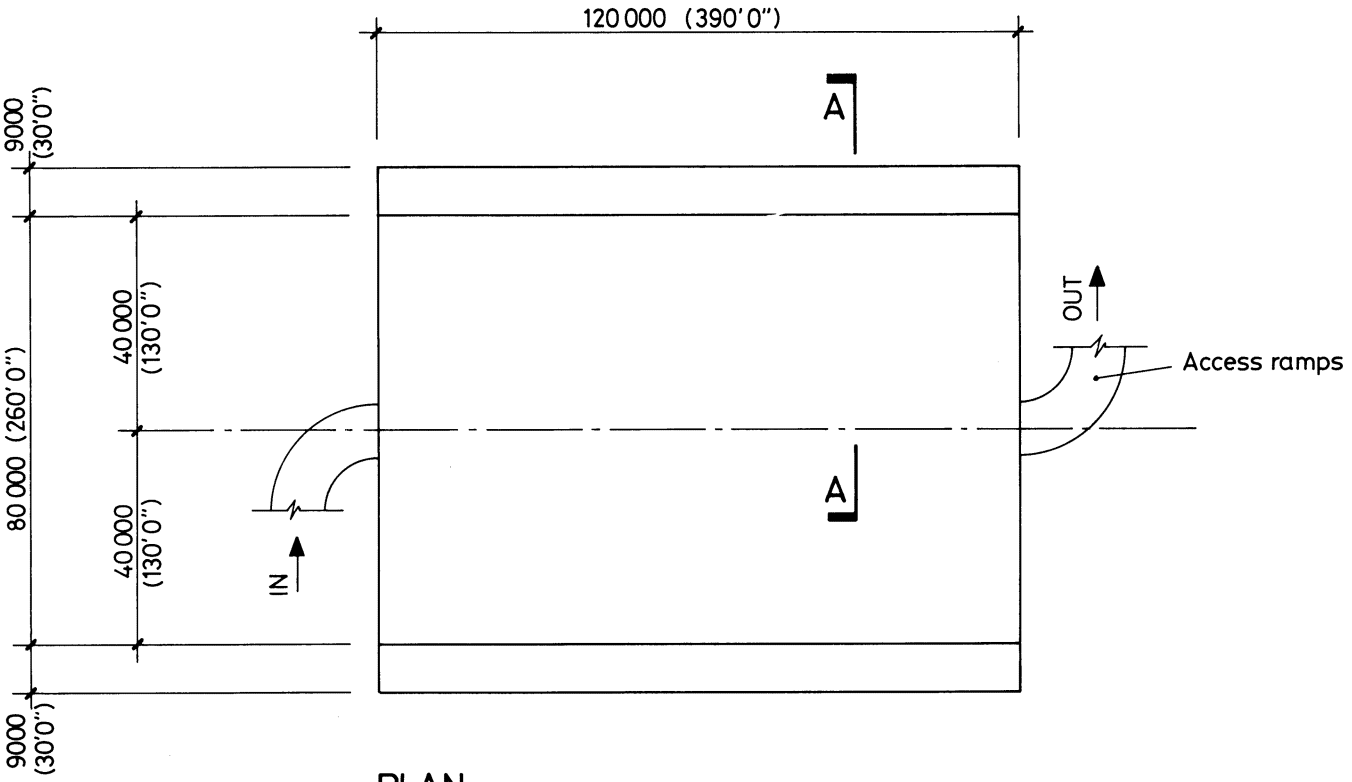
In selecting and developing your design you should also remember the guidance given in the Institution's report, 'Aims of Structural Design', and in particular:

(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, (overleaf). 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.



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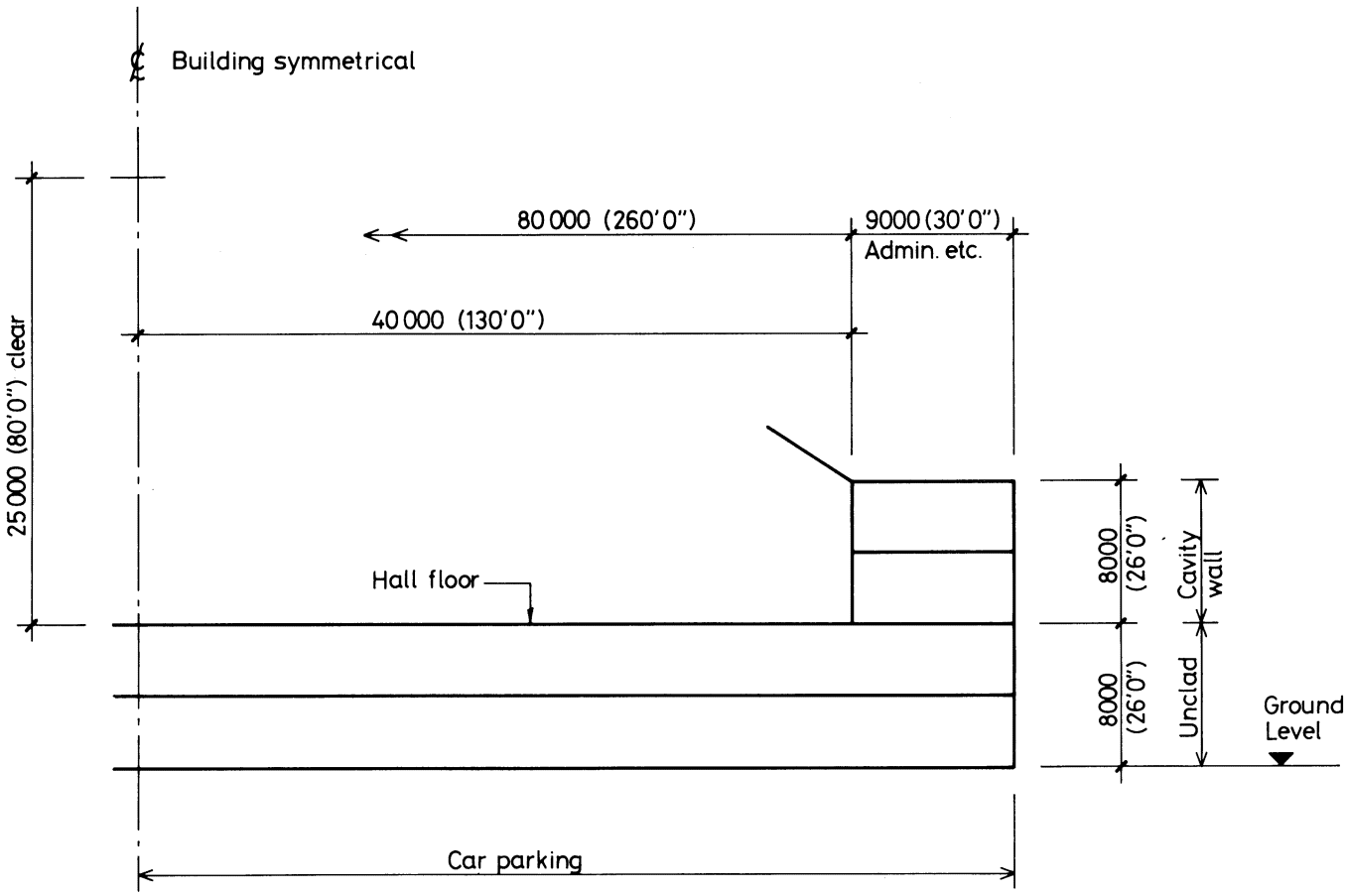


SECTION A-A

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

FIGURE Q1

Question 1
Exhibition Hall

Client's requirements

1. An exhibition hall 80m (260′-0″) wide and 120m (390′-0″) long free of internal columns and with a clear height of not less than 8m (26′-0″) at the sides and 25m (80′-0″) at the longitudinal centre line. See Figure Q1.
2. Administration, retail and restaurant areas to be accommodated in two-storey structures on each side of the hall.
3. The area below is to accommodate two levels of car parking with entry and exit ramps provided externally.
4. The roof covering the exhibition hall is to be insulated profiled metal cladding without allowance for natural lighting apart from a fully glazed rooflight along the longitudinal centre line 5m (16′-6″) wide and 2m (6′-6″) high.
5. External cladding to the two-storey structures is to be of brick/block cavity wall construction. Glazed screens are to be provided between the exhibition hall and the two-storey side structures.
6. Specified fire resistances are one hour to the administration, retail and restaurant areas and half hour to the parking areas.
7. The roof structure is to be aesthetically pleasing.

Imposed loading

8.

Roof (access for maintenance only)	0.6kN/m^2	(12lbf/ft^2)
Services in roof	0.3kN/m^2	(6lbf/ft^2)
Hall floor	30.0kN/m^2	(600lbf/ft^2)
Administration, retail, restaurant area floors	5.0kN/m^2	(100lbf/ft^2)
Car park floors	2.5kN/m^2	(50lbf/ft^2)

Site conditions

9. The building is situated in a city environment. Basic wind speed is 38m/s (84 mile/h).
10. The site is level and the ground comprises:

Ground level to −0.4m (1′-3″)	Sandy top soil
−0.4m (1′-3″) to −2.0m (6′-6″)	Sand and gravel, N=5
−2.0m (6′-6″) and below	Gravel, N=25

No ground water is present.

Omit from consideration

11. Stairs, lift cores and access ramps.
12. Detailed design of the gable end elements.
13. Parking layout.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the building. 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 work on foundations has started, the Client wishes to consider using the volume, previously designated for parking, for storage. The upper car parking floor would be deleted but the floor loading at ground level increased to 7.5kN/m^2 (150lbf/ft^2).

Prepare a letter to the Client outlining the structural and financial implications of this proposed change.

Part 2 (60 marks)

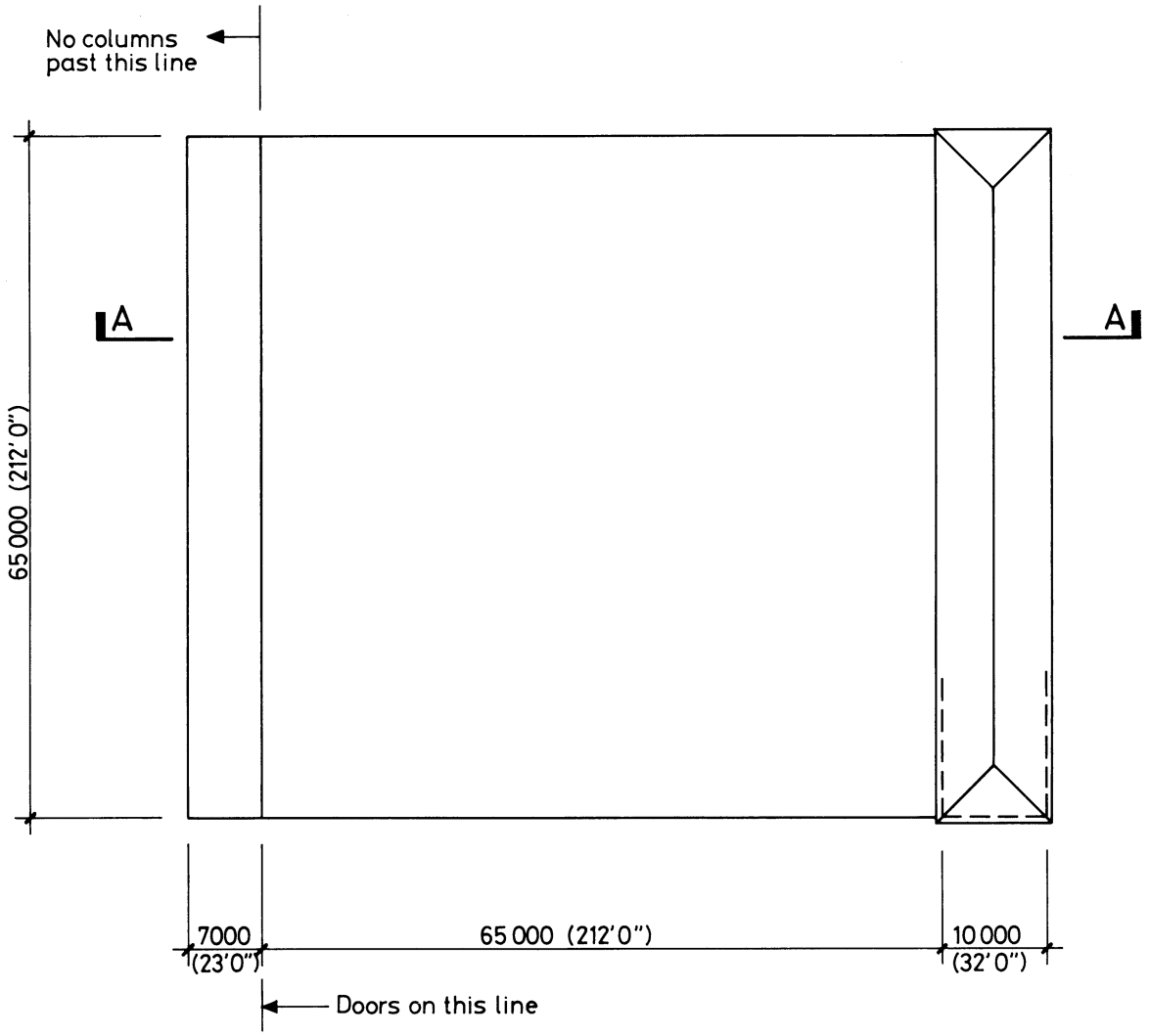
For the solution recommended in Part 1(a):

c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including foundations and the ground floor slab.

d. Prepare general arrangement plans, sections and elevations necessary to show the dimensions and layout of the structural elements as required for estimating purposes.

e. Prepare clearly annotated sketches to illustrate details of:
   (i) Connection of main roof element to support structure.
   (ii) Connection of main column to foundation.
   (iii) Connection of major floor beam to column.

f. Prepare an outline method statement for the construction of the superstructure and describe any major temporary works which might be required.



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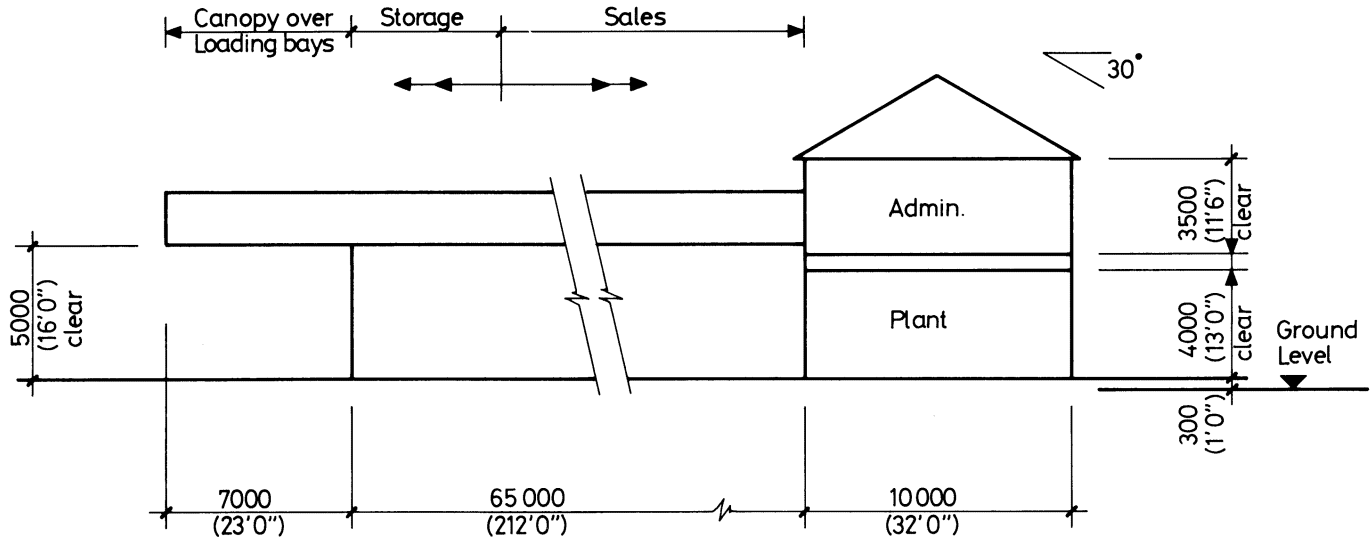


SECTION A-A

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

FIGURE Q2

Question 2
Retail Store

Client's requirements

1. A retail store with a 65m (212′-0″) square main floor which can be divided into sales and storage areas to suit future requirements. See figure Q2.
2. In order to give a maximum clear floor area no more than four internal columns are acceptable. The loading bays must be column free.
3. The main roof is to be of flat construction with suitable insulation.
4. External elevations are generally to be of brick/block cavity wall construction. However, at the loading bays full height sliding folding doors are required to suit twelve 4m (13′-0″) wide bays with an 8.5m (28′-0″) bay at each end. Columns are allowable between bays.
5. A two-storey administration/plant room block is required with a slated and insulated pitched roof. The wall between the plant room and the sales area is to be of rendered blockwork.

Imposed loadings

6.

Roofs (access for maintenance only)	0.6kN/m^2	(12lbf/ft^2)
Ground floor	10.0kN/m^2	(200lbf/ft^2)
Store and sales ceiling and services	0.45kN/m^2	(9lbf/ft^2)
Administration/plant room ceiling and services	0.25kN/m^2	(5lbf/ft^2)
Administration floor	4.5kN/m^2	(90lbf/ft^2)

Site conditions

7. The building is situated in the countryside with some trees and occasional buildings. Basic wind speed is 40m/s (90 mile/h).
8. The site is level and the ground comprises:

ground level to −0.3m (1′-0″)	fill
−0.3 (1′-0″) to −3.0m (10′-0″)	clayey silt
−3.0m (10′-0″) and below	firm chalk

Ground water is not present.

Omit from consideration

9. Access stairs in the two-storey block.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the building. Identify clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend giving reasons for your choice.

b. Having completed the design and obtained budget prices, you are asked by the client to consider the effects of a future need to provide some customer parking on the roof. Prepare a letter to the client suggesting how this might be achieved, giving the structural and financial implications.

Part 2 (60 marks)

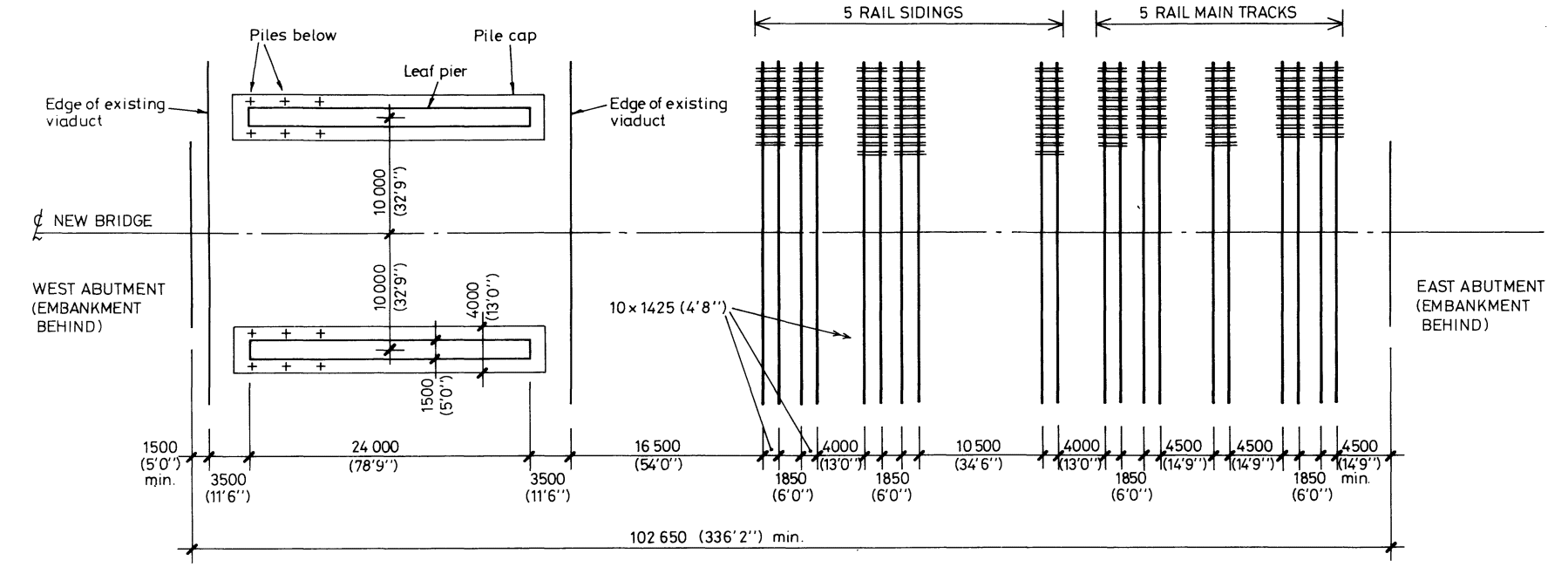
For the solution recommended in Part 1(a):

c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including foundations and the ground floor slab.

d. Prepare general arrangement plans, sections and elevations necessary to show the dimensions and layout of the structural elements as required for estimating purposes.

e. Prepare clear annotated sketches to illustrate details of:
   (i) The connection between the canopy support structure and the structure above an 8.5m (28′-0″) wide loading bay door.
   (ii) The slated roof and its junction with the supporting structure.
   (iii) The connection of the main roof members with an internal column.

f. Indicate alternative ways in which a one hour fire resistance can be achieved for the two-storey building.



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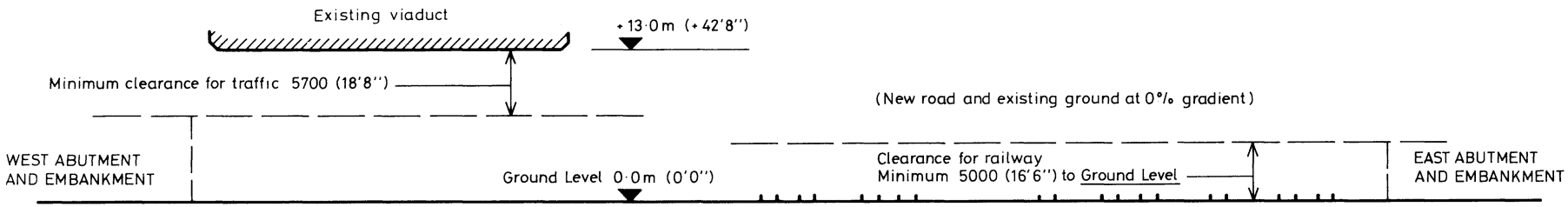
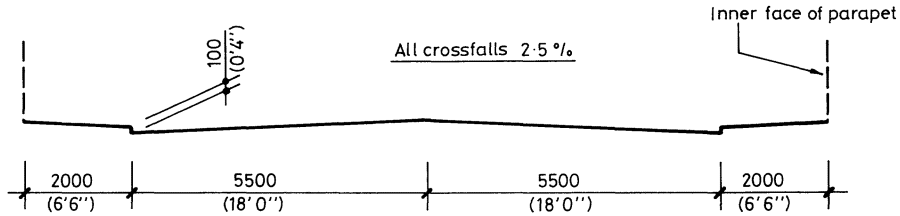


SECTIONAL ELEVATION

NOTE. All dimensions are in millimetres (feet and inches) except levels, which are in metres (feet and inches).



SECTION THROUGH NEW BRIDGE DECK

FIGURE Q3

Question 3

New Highway Bridge

A bridge is required to carry a new three-lane highway across a series of rail tracks and sidings. The vertical alignment of the new highway is constrained by the clearances required above the railway, and by the presence of an existing highway viaduct which the new highway has to pass beneath. The horizontal alignment of the new highway bridge is fixed due to the close proximity of two leaf piers supporting the existing viaduct, which the new road has to pass between. These constraints are illustrated in Figure Q3. Both the new road and the existing ground are at a gradient of 0%.

Client's requirements

1. The completed new bridge is to comprise three traffic lanes with a total width between kerbs of 11.0m (36′-0″). In addition, a footway of 2.0m (6′-6″) width is to be provided at each side of the highway.
2. The required minimum clearance to the overhead viaduct must be achieved for the completed bridge; the minimum clearance to the railway must be achieved at all times during construction and for the completed bridge.
3. Erection of the main superstructure elements for the spans over the railway must take place during rail possessions. Once these elements have been erected further work on the bridge superstructure over the rail tracks and sidings can be carried out at any time, provided that full protection is provided to prevent any items of the works or plant falling onto the tracks.
4. Rail track possessions can be allowed as follows:
   Main Tracks : Any weekend, between 22.00 Saturday evening and 14.00 Sunday afternoon.
   Sidings : Any weekend, between 20.00 Friday evening and 07.00 Monday morning. In addition, closures of the sidings can be arranged (if necessary) for two non-consecutive periods each of two weeks duration.
5. A minimum horizontal clearance of 4.5m (14′-9″) shall be provided between any rail and the face of any piers or abutments to the new bridge above ground level, to avoid the need to design these elements for accidental impact.

Imposed loading

6. Traffic loading 10kN/m^2 (200lbf/ft^2), with an alternative loading for local element design of a 100kN (22,000lbf) wheel load on a 0.3m × 0.3m (1′-0″ × 1′-0″) square contact area.
7. Footway loading 5kN/m^2 (100lbf/ft^2).
8. Wind loading 2kN/m^2 (40lbf/ft^2) on exposed area for which a vehicle height of 2.5m (8′-0″) may be assumed.

Site conditions

9. Design temperature range 50C°.
10. Ground conditions:
    0-2.0m (6′-6″) made ground
    2.0m (6′-6″) – 7.0m (23′0″) alluvium
    7.0m (23′-0″) – 12.0m (37′-6″) weak clay
    12.0m (37′-6″) and below stiff clay with an undrained shear strength of 75kN/m^2 (1500lbf/ft^2).

Omit from consideration

11. Accidental impact on bridge supports.
12. Detailed design of the end abutments and wing-walls.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the bridge, including practical implications of the different types of foundations which might be adopted. Identify in each case the span arrangement, type and details of construction, together with the means of overall stability and articulation. Identify the solution you recommend, giving reasons for your choice.

b. The Client believes that a possible economy can be achieved by moving the West Abutment to the east of the existing viaduct (i.e. between the viaduct and the rail sidings), and adopting a single-span structure. In this case the new highway would be carried beneath the existing viaduct on embankment.
   Prepare a letter to the Client outlining the feasibility of this proposal, and the effect that it would have on the existing viaduct and on the proposed form of the new bridge.

Part 2 (60 marks)

For your recommended solution in Part 1(a):

c. Prepare sufficient design calculations for the new bridge superstructure, piers and pier substructures to establish the form and size of these principal structural elements.

d. Prepare general arrangement plans, sections and elevations necessary to show the dimensions and layout of structural elements, as required for estimating purposes.

e. Prepare clearly annotated sketches to illustrate details of:
   (i) An expansion joint, showing the deck construction, abutment shelf and bearings.
   (ii) A cross-section through an edge of the bridge deck, parapet and barrier, to show the structural elements required to transmit the barrier loads to the superstructure.

f. Prepare a brief method statement for the structural site works, to include a description of the utilisation of available railway possessions.

Question 4
Water Tower

Client's requirements (No figure)

1. A roofed over two compartment water tower on a central support (which need not be of constant cross section) with a total capacity of 2,000 cu m (70,000 cu ft). Each compartment is to hold at least 800 cu m (28,000 cu ft) and is to be capable of being emptied for maintenance whilst the other remains full.
2. The lowest part of the compartment is to be 25m (80′-0″) above ground level.
3. The tower is located in a prominent position on the edge of a town and it is important that it is of attractive appearance and proportions.
4. Maintenance access is to be by a staircase within the central support structure and thence by manholes through the roof.

Site conditions

5. On gently rising ground.
6. Basic wind speed is 35m/s (78 mile/h).
7. Ground conditions:
   0-0.150m (6″) topsoil
   0.150m (6″)-1.50m (5′-0″) soft silty clay
   Below 1.50m (5′-0″) dense gravel N=40
   Water struck at 5.0m (15′-0″) below ground level.

Omit from consideration

8. Pipework and pipe entry points.
9. Detailed design of access stairs and manholes.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal 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.

b. Prepare a letter to the Client explaining what maintenance provision you would recommend to ensure the continuing visual attractiveness of the structure.

Part 2 (60 marks)

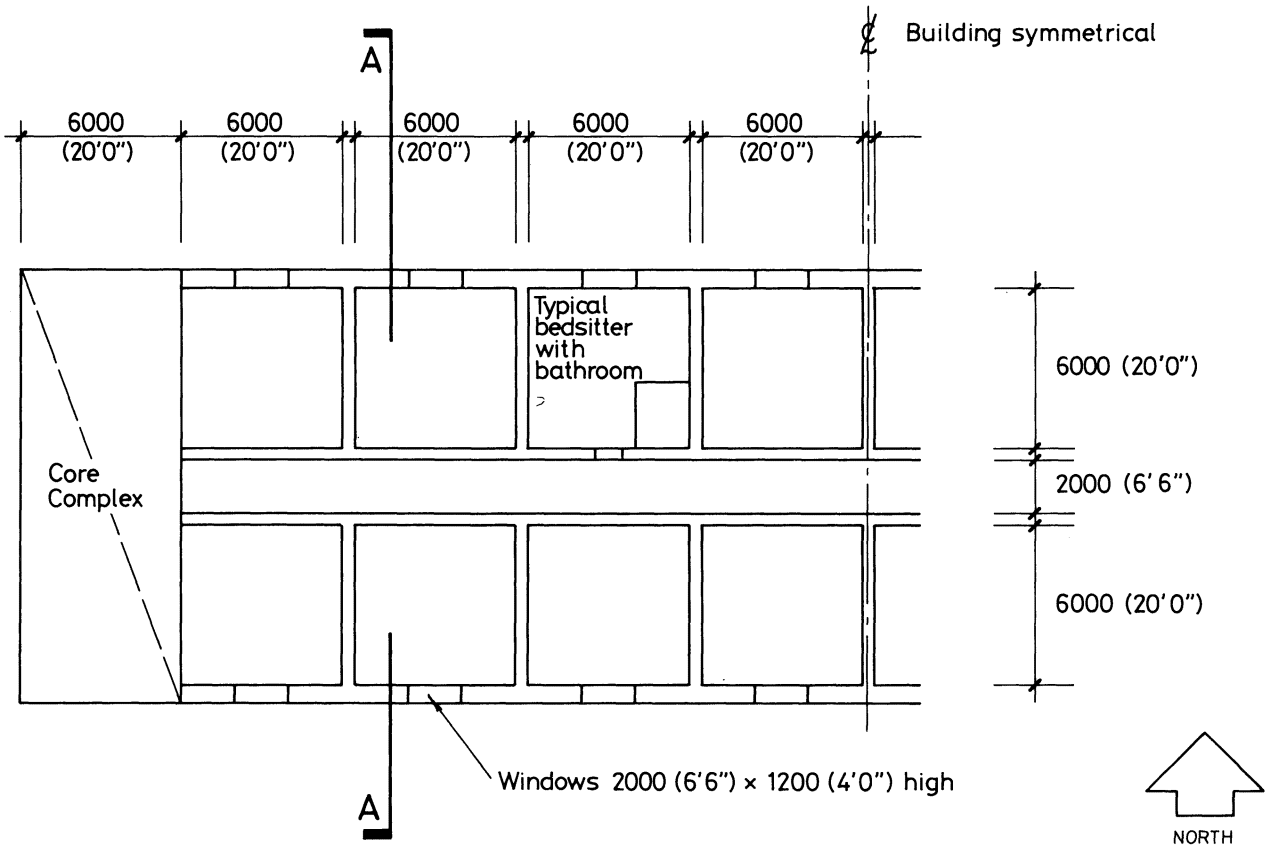
For the solution recommended in Part 1(a):

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

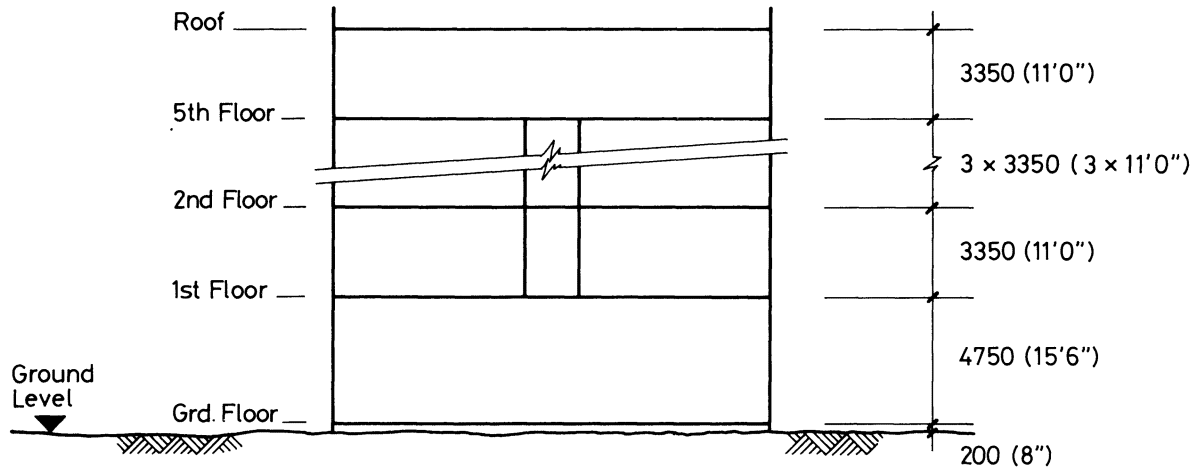
d. Prepare general arrangement plans, elevations and sections necessary to show the dimensions and layout of the structural elements as required for estimating purposes.

e. Prepare neat annotated sketches to illustrate details of:
   (i) The junction of the central support and the floor of the compartments.
   (ii) The junction of the central support and the foundation.
   (iii) The junction of the roof and the perimeter of the compartments.

f. Prepare an outline method statement for the construction of the structure, emphasising those aspects which require special attention during the works.



PART PLAN - RESIDENTIAL FLOOR



SECTION A-A

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

FIGURE Q5

Question 5
Nurses Hall of Residence

Client's requirements

1. A six storey flat roofed residential building with elevations of brickwork and blockwork with cavity walls above first floor and full height glazing at ground floor. The 1st to 5th floors inclusive accommodate single bed/sitting rooms off a central corridor. See Fig. Q5.
2. Stairs, lift and service ducts, together with communal kitchens and laundry rooms are to be provided in cores at each end of the building.
3. All horizontal services are to be provided in a 600mm (2′-0″) deep clear ceiling void over the corridor.
4. The clear height in the bed/sitting rooms is to be at least 2.45m (8′-0″) and in the corridors 2.15m (7′-0″).
5. The ground floor between the end cores is to provide common rooms, restaurant and bookshop, and, to allow for flexibility of planning, is to be clear of internal supports.
6. The shape of the perimeter columns from Ground to 1st floor is to be chosen to present a slender face on the external elevations.
7. The fire resistance of the structure is to be 1 hour.

Site conditions

8. The site is level in a town centre.
9. Basic wind speed is 35m/sec (78 mile/h)
10. Ground conditions:
    0-3.0m (10′-0″) loose fill
    3.0m (10′-0″)–6.0m (20′-0″) medium dense gravel N=25
    6.0m (20′-0″)–30.0m (100′-0″) very stiff fissured clay, average C = 100kN/m^2 (1 ton/sq ft)
    Water table at 5.5m (18′-0″) below ground level.

Omit from consideration

11. Detail arrangement and design of the cores.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the building. Indicate 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 scheme has been approved in principle the Client raises the possibility of introducing a 4m (13′-0″) deep basement for storage under the western half of the building. Prepare a letter to the Client indicating the likely structural and cost implications of this change.

Part 2 (60 marks)

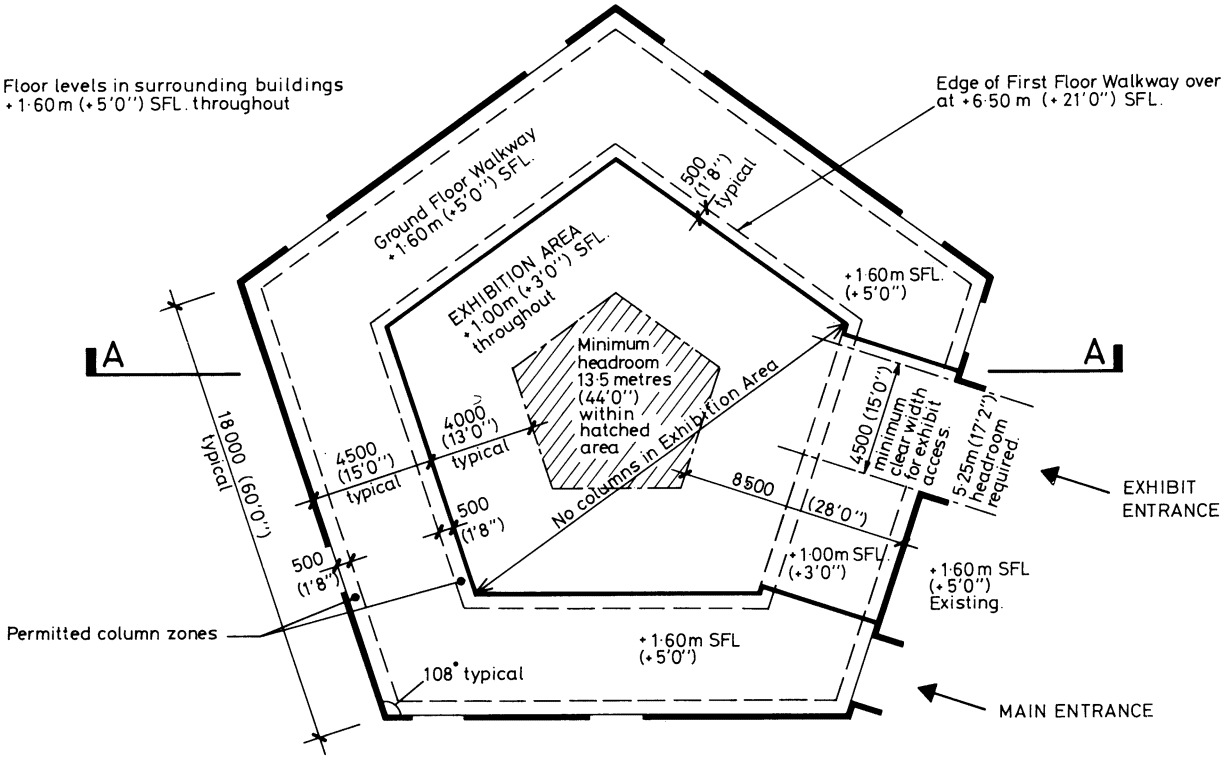
For the solution recommended in Part 1(a):

c. Prepare sufficient design calculations to establish the form and size of all principal structural elements, including the foundations.

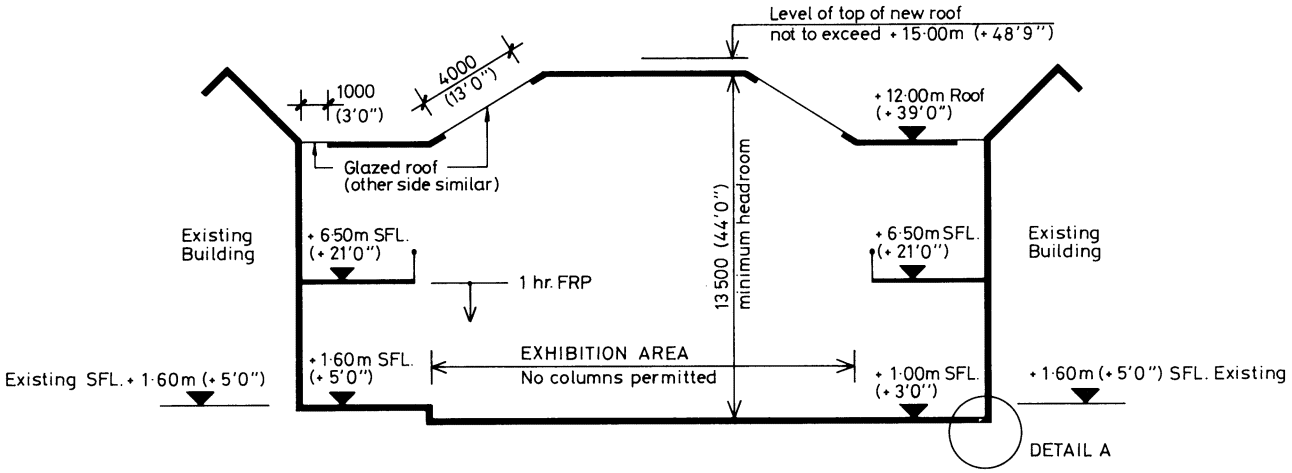
d. Prepare general arrangement plans, elevations and sections necessary to show the dimensions and layout of the structural elements as required for estimating purposes.

e. Prepare neat annotated sketches to illustrate the detail of:
   (i) A beam and column connection at first floor level.
   (ii) A column and foundation connection.
   (iii) The support system for the external cavity walls.

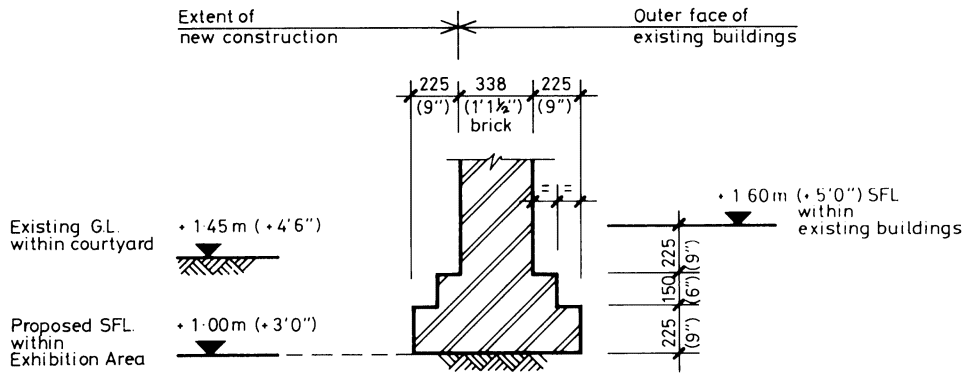
f. Prepare two alternative specifications for the roof finishes, giving the merits and disadvantages of each.



GROUND FLOOR PLAN



SECTION A-A



DETAIL A

EXISTING DIMENSIONS ARE CONJECTURAL

NOTE. All dimensions are in millimetres (feet and inches) except levels, which are in metres (feet and inches).

FIGURE Q6

Question 6
Courtyard Infill

Client's requirements

1. An extension to a small boat museum involving construction of a new infill building within an existing courtyard. See Figure Q6.
2. A column-free Exhibition Area is required surrounded by walkways at ground and first floor levels. Structural supports are permitted within the zones indicated around the walkways.
3. Fire resistance of 1 hour is to be provided in structural members up to and including first floor level.
4. The new infill building fills the courtyard area. Access to adjacent buildings is provided at a number of points around the perimeter.
5. Approximately half of the roof area is to be double glazed with the remainder clad in slate and lead. Structural members are permitted in glazed areas.
6. Loads from the new infill structure should not be transmitted to the surrounding buildings.

Imposed loading

7. Exhibition Area	7.5kN/m^2	(150lbf/ft^2)
Walkways, etc	5.0kN/m^2	(100lbf/ft^2)
Services and ceilings	0.5kN/m^2	(10lbf/ft^2)

Site conditions

8. The site is located near the sea front in a coastal town. Basic wind speed 42 m/s (94 mile/h).
9. The site is underlain by 0.4m (1′-4″) of made ground followed by deep sands and gravels with allowable bearing capacity 100kN/m^2 (1 tonf/ft^2). Ground water level varies according to the tide, highest level 2.5m (8′-4″) below the courtyard level.

Omit from consideration

10. Requirements within the surrounding buildings.
11. Handrails and ballustrades.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the building. Identify clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend giving reasons for your choice.

b. The client has asked for advice on whether the existing museum, which is housed in the buildings around the courtyard, can remain open during construction activities in the courtyard. Prepare a letter to the client setting out possible advantages and disadvantages of permitting this to happen.

Part 2 (60 marks)

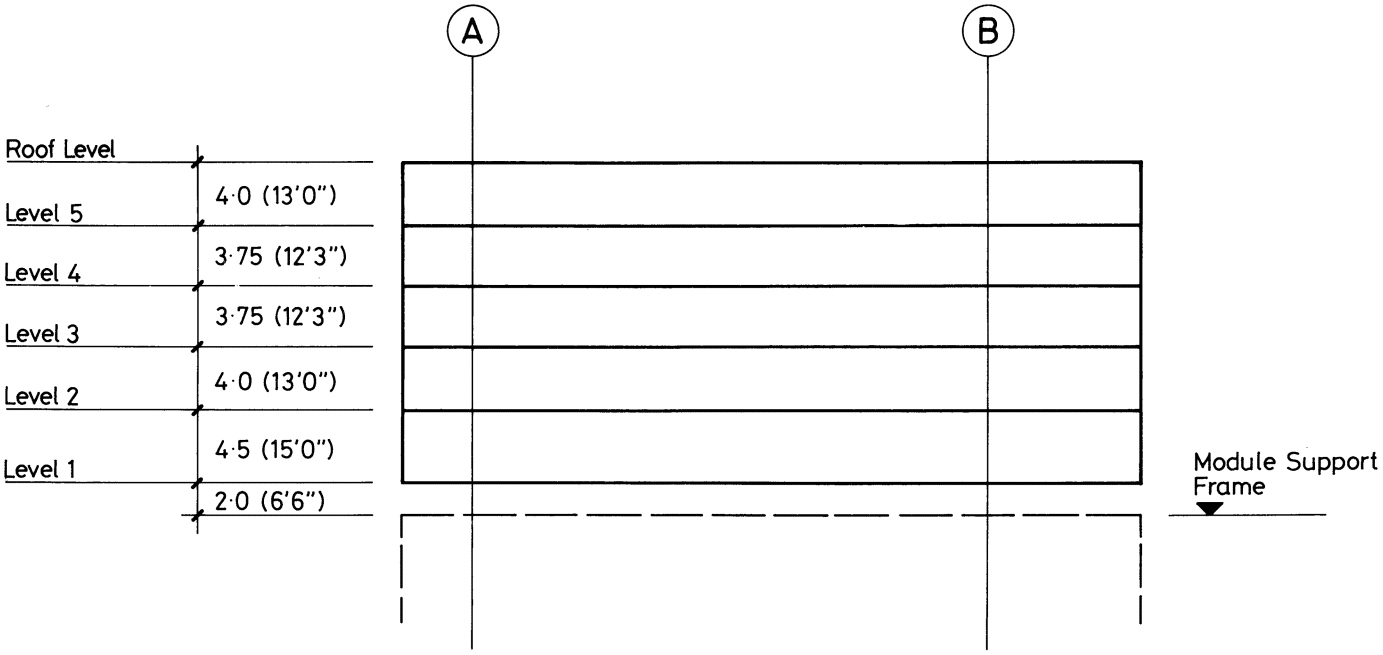
For the solution recommended in Part 1(a):

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

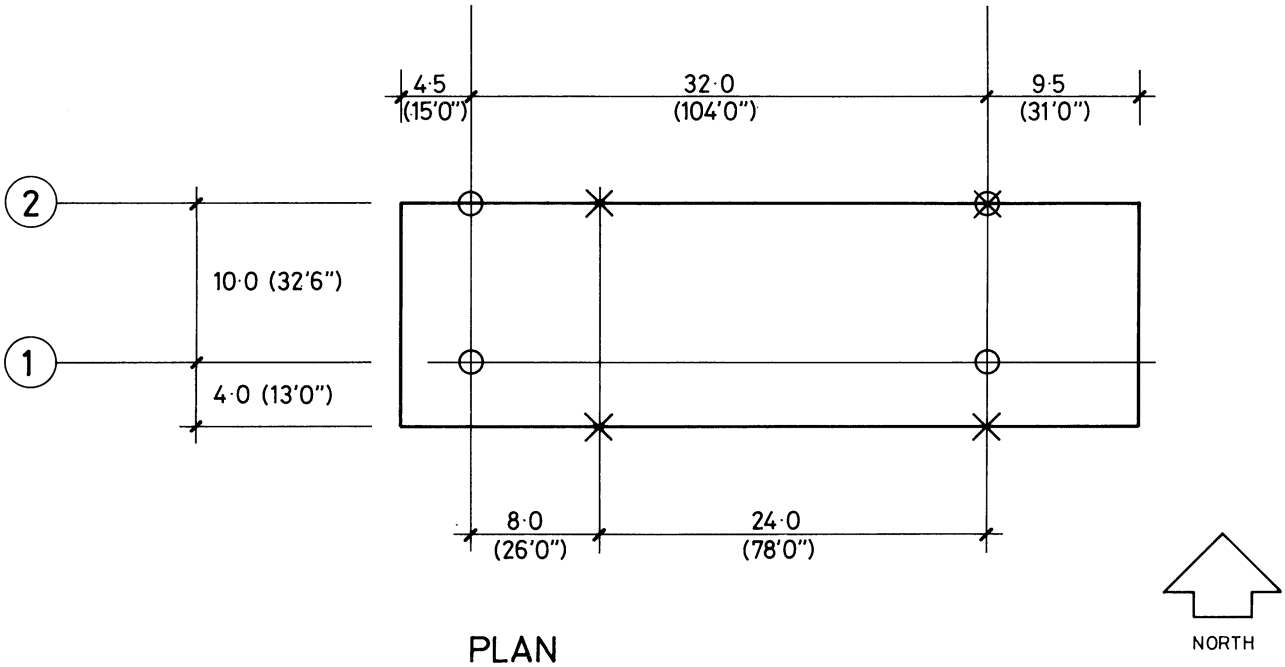
d. Prepare general arrangement plans, elevations and sections necessary to show the dimensions, layout and materials of the structural elements as required for estimating purposes.

e. Prepare clearly annotated detail sketches to show details of the structure at the following locations:
   (i) Roof structure to internal column.
   (ii) First floor structure to upper column and lower column.
   (iii) Ground floor slab edge to existing wall in the vicinity of Detail A.

f. Prepare a method statement describing investigations to be carried out to establish whether any special precautions are required along the length of courtyard wall where the proposed new ground floor within the courtyard lies below ground floor levels in the surrounding buildings.



ELEVATION



PLAN

○ Module supported at A1 B1 A2 B2

× Module lift points at 8·0 m (26'0") East of Grid Line A on Grid Line 2.
4·0 m (13'0") South of Grid Line 1, 8·0 m (26'0") East of Grid Line A.
Intersection of Grid Lines B and 2.
4·0 m (13'0") South of Grid Line 1 on Grid Line B.

Note. Dimensions given on Plan are to the centre lines of structural elements.

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

FIGURE Q7

Question 7
Accommodation Module

Client's requirements

1. A 150 man accommodation module for a manned platform in the northern North Sea.
2. The profile is shown in Figure Q7.
3. The structure is supported at 4 points.
4. The structure is to be installed by a single crane lift.
5. Secondary framing is only acceptable at the ends of the module and on grid lines A and B. Clear spans are required elsewhere.
6. A minimum clear height of 3.0m (10′-0″) must be maintained at each Level. To allow for outfitting the space between the support elevation and Level 1 may be used.
7. The lifting attachments are to be left in place to provide for possible future use.
8. Maximum lift weight must not exceed 2,600 tonnes (2,600 tonf).

Imposed loadings

9.

Roof	=	10.0kN/m^2	(200lbf/ft^2)
Level 5	=	5.0kN/m^2	(100lbf/ft^2)
Level 4	=	5.0kN/m^2	(100lbf/ft^2)
Level 3	=	5.0kN/m^2	(100lbf/ft^2)
Level 2	=	5.0kN/m^2	(100lbf/ft^2)
Level 1	=	7.5kN/m^2	(150lbf/ft^2)

Site conditions

10. Basic wind speed is 54m/s (119 mile/h).

Omit from consideration

11. Architectural outfitting.
12. Blast loadings.
13. Loadout details.
14. Sea fastening.
15. Internal staircases.
16. Mechanical services.
17. Installation aids other than padears/padeyes.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the proposed work including the 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. In the early stages of design your client wishes to reposition the accommodation unit.
It is to be cantilevered off the end of the module support frame.
The unit is to be supported at Grid lines A and B at Level 1 and Level 3.
Level 3 is to have the same elevation as the top of the module support frame.
Prepare a letter to your client explaining the overall effects that this suggestion is likely to have on your proposal for the accommodation module and on the support frame.

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.

d. Prepare general arrangement plans, elevations and sections necessary to show the dimensions and layout of the structural elements and lifting points as required for estimating purposes.

e. Prepare clearly annotated sketches to illustrate details of:
(i) A permanent lifting point.
(ii) A module support point.
(iii) The connection of a vertical structural element with a floor support element and a floor edge trimming element.

f. It is a requirement of the fabrication specification that on completion all decks are to be level at mid span within a tolerance of ±5mm (0.2″) of the stated top of steel elevation.
What fabrication processes remedial or otherwise are available to you as the engineer to ensure that the stated tolerance limits may be achieved? Briefly explain any procedures stated.