The Institution of Structural Engineers

Membership Examination Part 3

6 APRIL 1990

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 top 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.

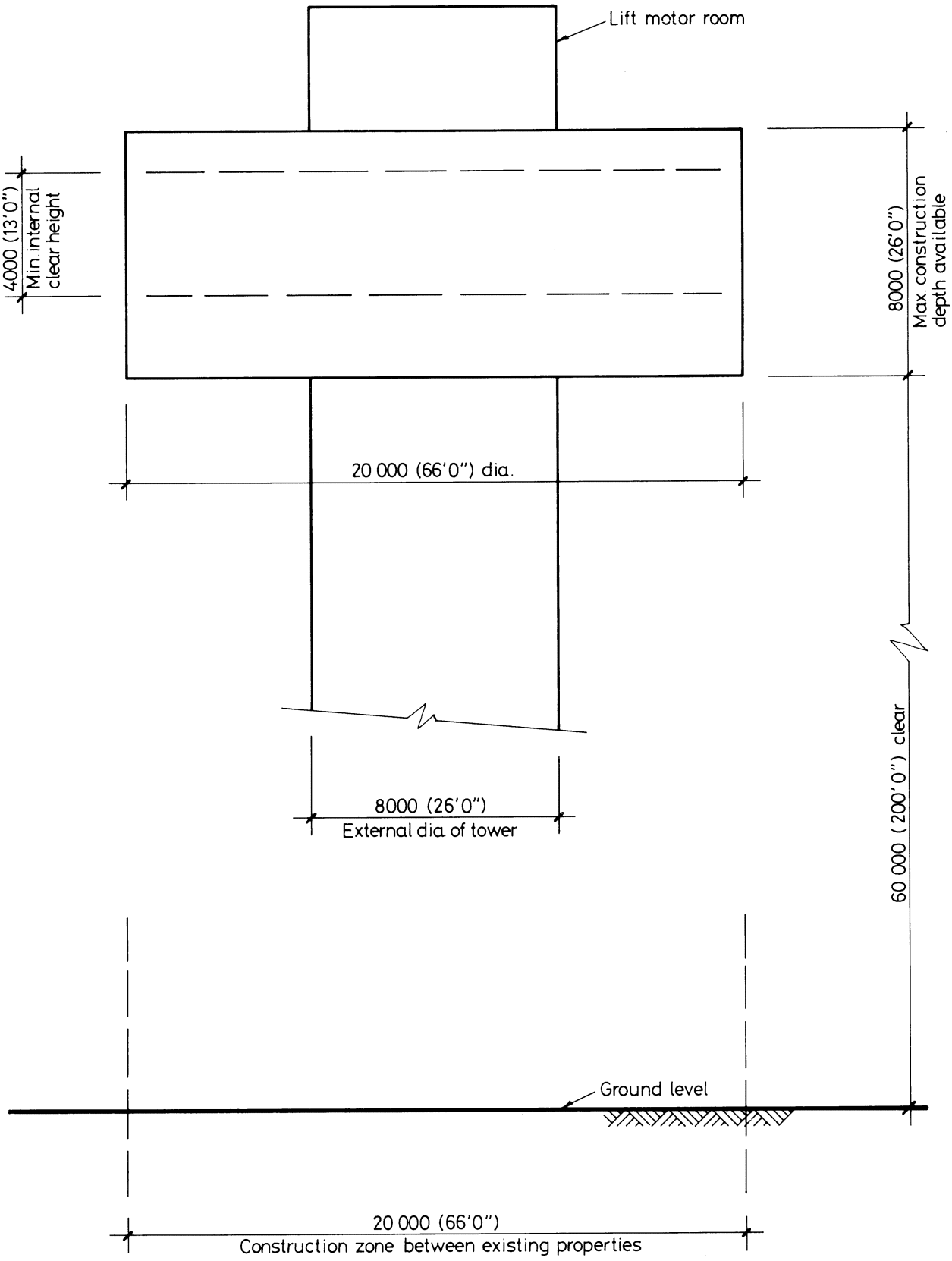
In selecting and developing your design you should also remember the guidance given in the Institution's report, 'Aims of Structural Design', and in particular:

(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.



Note. Dimensions are in millimetres (feet and inches)

FIGURE Q1

Question 1
Open plan elevated restaurant

Client's requirements

1. An open plan elevated restaurant, circular on plan, set around the top of a slip formed concrete radio tower. See Figure Q1
2. The restaurant structure must be located within the zone specified in Figure Q1. The slip formed concrete core may be terminated at the level most convenient for the proposed restaurant design.
3. The restaurant floor area between the centre core and the outer perimeter to be free of columns, and a minimum internal clear height of 4m (13′0″) must be maintained throughout the restaurant area.
4. Perimeter walling to be glazed full height.

Imposed loadings

5. Vertical loads

roof	0.75kN/m^2 (15lbf/ft^2)
plant hung from restaurant roof	1.00kN/m^2 (20lbf/ft^2)
floor	5.00kN/m^2 (100lbf/ft^2)

Site conditions

6. Basic wind speed 46m/s (102 mile/h)
7. Ground conditions

0 – 0.5m (0 – 1′8″)	made ground
0.5m – 3.5m (1′8″ – 11′6″)	silty gravel (N values vary linearly from 8 at 1.0m (3′3″) to 23 at 3.0m (10′0″)
3.5m – 60.0m (11′6″ – 200′0″)	limestone massively bedded.

Omit from consideration

8. Detailed design of concrete tower, foundations, motor room, stairs, lifts and services.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the restaurant. Identify 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 advising him of the scope and extent of the temporary works for the safe and efficient construction of the restaurant, and how the construction of your recommended scheme may affect adjacent owners and tenants.

Part 2 (60 marks)

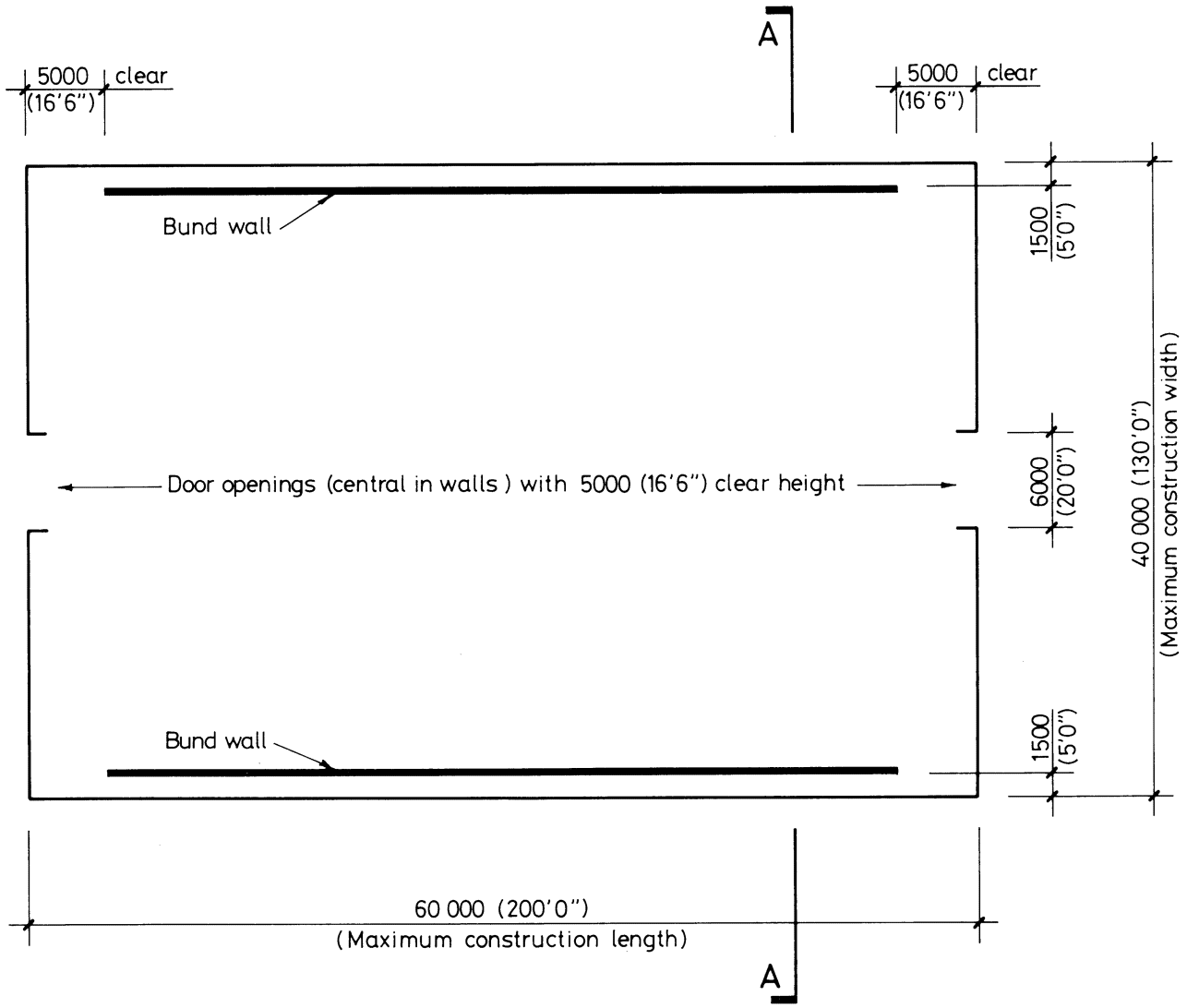
For your recommended solution in 1(a):

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

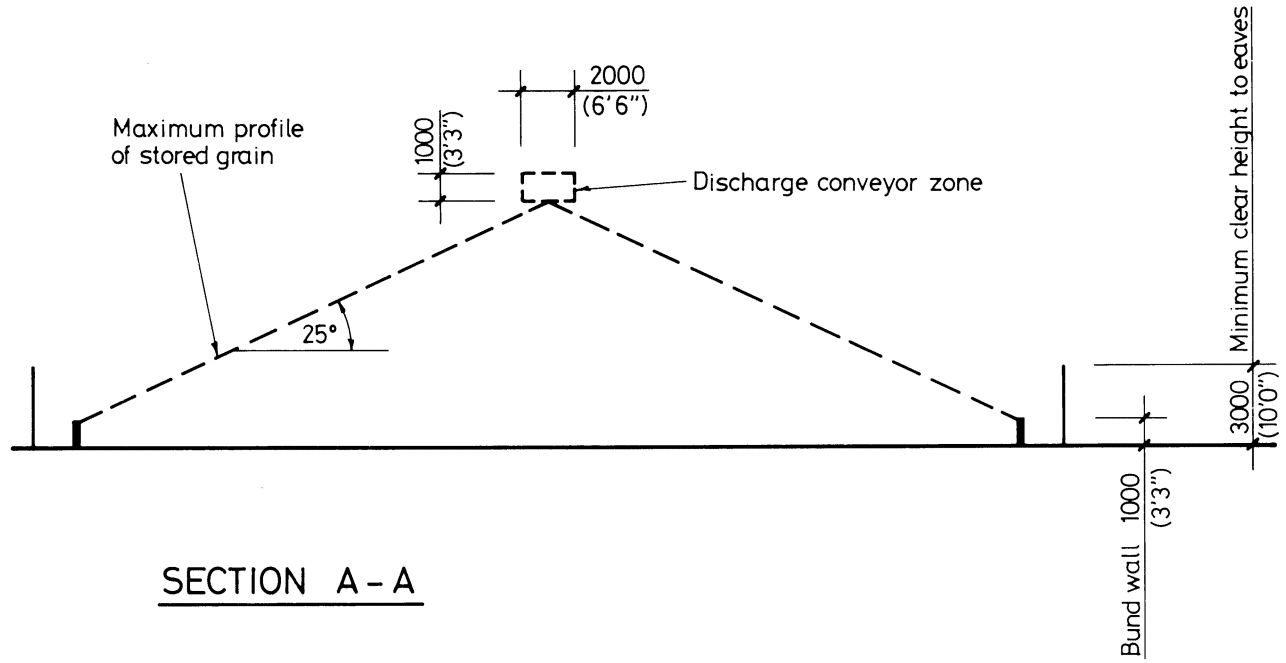
d. Prepare a general arrangement drawing containing plans, sections and elevations, showing the dimensions, size, layout and disposition of the structural elements, as required for estimating purposes.

e. Prepare clear annotated sketches to illustrate the details of:
   (i) Roof to central support connection.
   (ii) Floor to central core connection.
   (iii) Connection of vertical perimeter elements to floor and roof.

f. Prepare a statement outlining the various factors to be considered in selecting the most appropriate form and construction method for the tower foundations.



PLAN



SECTION A-A

Note. Dimensions are in millimetres (feet and inches)

FIGURE Q2

Question 2
Demountable bulk grain store

Client's requirements

1. A demountable bulk grain store having a single site location life of five to seven years. See Figure Q2.
2. The building to be free of any internal columns.
3. The roof and side cladding to be of lightweight construction but well insulated.
4. Access openings to be provided in both ends as indicated, and minimum framing height to eaves on both sides 3m (10′0″).

Imposed loadings:

5.	ground floor	six axle 400kN(40tonf) vehicle or stored grain.
	roof (on plan area)	0.75kN/m^2 (15lbf/ft^2) 0.25kN/m^2 (5lbf/ft^2) services and plant
	roof central conveyor zone	6.0kN/m^2 (120lbf/ft^2)
	grain	(specific weight) 7.0kN/m^3 (44lbf/ft^3) angle of repose 25 degrees angle of internal friction 25 degrees

Site conditions

6.	Basic wind speed	50m/s (112 mile/h)
7.	Ground conditions	
	0 – 0.30m (0 – 1′0″)	made ground
	0.30m – 1.75m (1′0″ – 5′9″)	soft silty clay
	1.75m – 35.0m (5′9″ – 115′0″)	stiff clay undrained shear strength 90kN/m^2 (1800lbf/ft^2)
	35.0m down (115′0″ down)	chalk water struck at 0.5m (1′6″).

Omit from Consideration

Detailed door design, natural lighting provision.

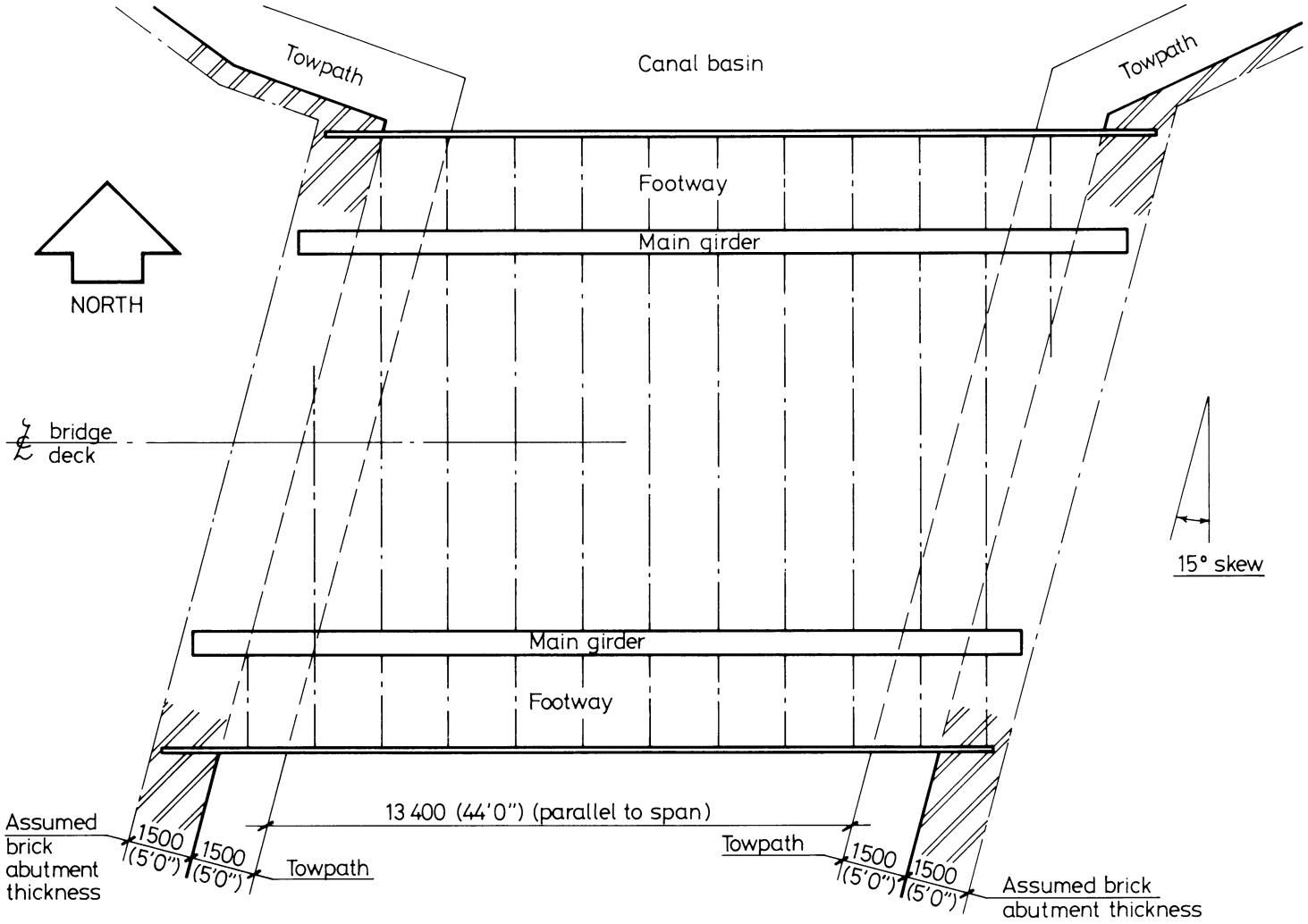
Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable 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. Prepare a letter to the client to justify your choice of ground floor construction.

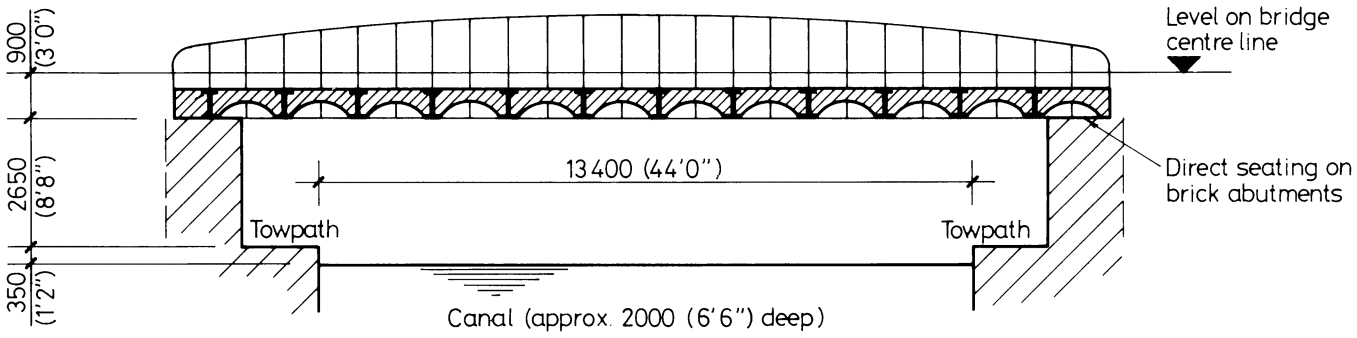
Part 2 (60 marks)

For your recommended solution in 1(a):

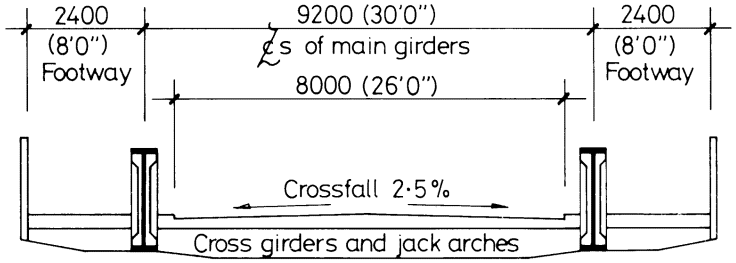
c. Prepare sufficient design calculations to establish the size and form of all significant elements including foundations.
d. Prepare a general arrangement drawing containing plans, sections and elevations showing the dimensions, size, layout and disposition of the structural elements, as required for estimating purposes.
e. Prepare clear annotated sketches to illustrate the details of:
   (i) Main frame construction.
   (ii) Main frame to foundation connection.
   (iii) Main frame to gable post connection.
f. Prepare a method statement outlining the sequence of work for dismantling the building for re-use elsewhere indicating any major plant or temporary work requirements.



PLAN ON EXISTING BRIDGE



TYPICAL SECTIONAL ELEVATION THROUGH EXISTING BRIDGE



EXISTING DECK CROSS SECTION

Note. Dimensions are in millimetres (feet and inches)

FIGURE Q3

Question 3
Road bridge replacement

An existing iron bridge (main girders, cross-girders and brick infill jack-arches) crossing a canal is in an extremely poor state of repair. The structural form of the existing bridge is shown in Figure Q3.
The Client has decided to replace this single two-lane superstructure with a new wider single four-lane deck to provide an increased highway capacity.

Client's requirements

1. The completed new bridge is to comprise four traffic lanes (two in each direction) of 3.2m (10′6″) width, with a footway at each side of 2.0m (6′6″). Parapets 1.0m (3′3″) high are to be incorporated at the deck edges.
2. A revised vertical alignment for the highway gives a road centre-line level over the new structure 0.3m (1ft) higher than the existing structure. Normal crossfall of 2.5% is to be provided from the centre-line to each kerb.
3. Immediately to the north of the bridge the canal widens out into a large canal basin.
4. Due to alignment restrictions on the bridge approaches the centre-line of the new bridge deck may not be further than 4.0m (13ft) southward of the existing centre-line, nor may any operational permanent or temporary traffic lanes extend more than 10.4m (34ft) southward of the existing centre-line.
5. The existing bridge is to be replaced in such a manner that single line traffic, with a minimum lane width of 3.2m (10′6″), is maintained at all times in each direction. During replacement, a single footway of 2.0m (6′6″) width is to be provided.
6. Road closures are to be avoided, or kept to the minimum practicable number and of minimum duration.
7. Apart from occasional short closures, the canal must remain in operation.
8. Headroom over the canal water level may be reduced to 2.0m (6′6″) during the construction contract, but the original headroom must be reinstated in the permanent works.
9. Each towpath may be reduced, if necessary, to a minimum width of 0.6m (2ft) during the contract.

Imposed loading

10. Traffic loading 8kN/m^2 (160lbf/ft^2), with an alternative loading for local element design of a 100kN (22,000lbf) wheel load on a 0.3m × 0.3m (1ft × 1ft) square contact area.
11. Footway loading 4kN/m^2 (80lbf/ft^2).
12. Wind loading 2kN/m^2 (40lbf/ft^2) on exposed area for which a vehicle height of 2.5m (8ft) may be assumed.

Site conditions

13. Design temperature range 50C°.
14. Early investigations show that the brick abutments continue southwards at a minimum thickness of 1.5m (5ft), but that they do not extend northwards beyond the pedestrian parapet of the existing bridge.
    These investigations further confirm that the existing abutments, foundations and substrata are capable of carrying the modified loading imposed by the new bridge.

Omit from consideration

15. Detailed consideration of the demolition of the existing superstructure.

Question 3 continued on page 11

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the construction of the new bridge. Identify in each case the type and details of construction together with the means of overall stability and articulation.
Your appraisal should include a brief explanation of how stability and traffic requirements are met during the replacement phase (i.e. both temporary and permanent conditions should be outlined).
Identify the solution you recommend, giving reasons for your choice.

b. Your Client queries whether the existing substructure is capable of carrying the new bridge deck. Respond in the form of a letter, identifying the aspects that you would have investigated and considered in the appraisal of the abutments, foundations and ground conditions.

Part 2 (60 marks)

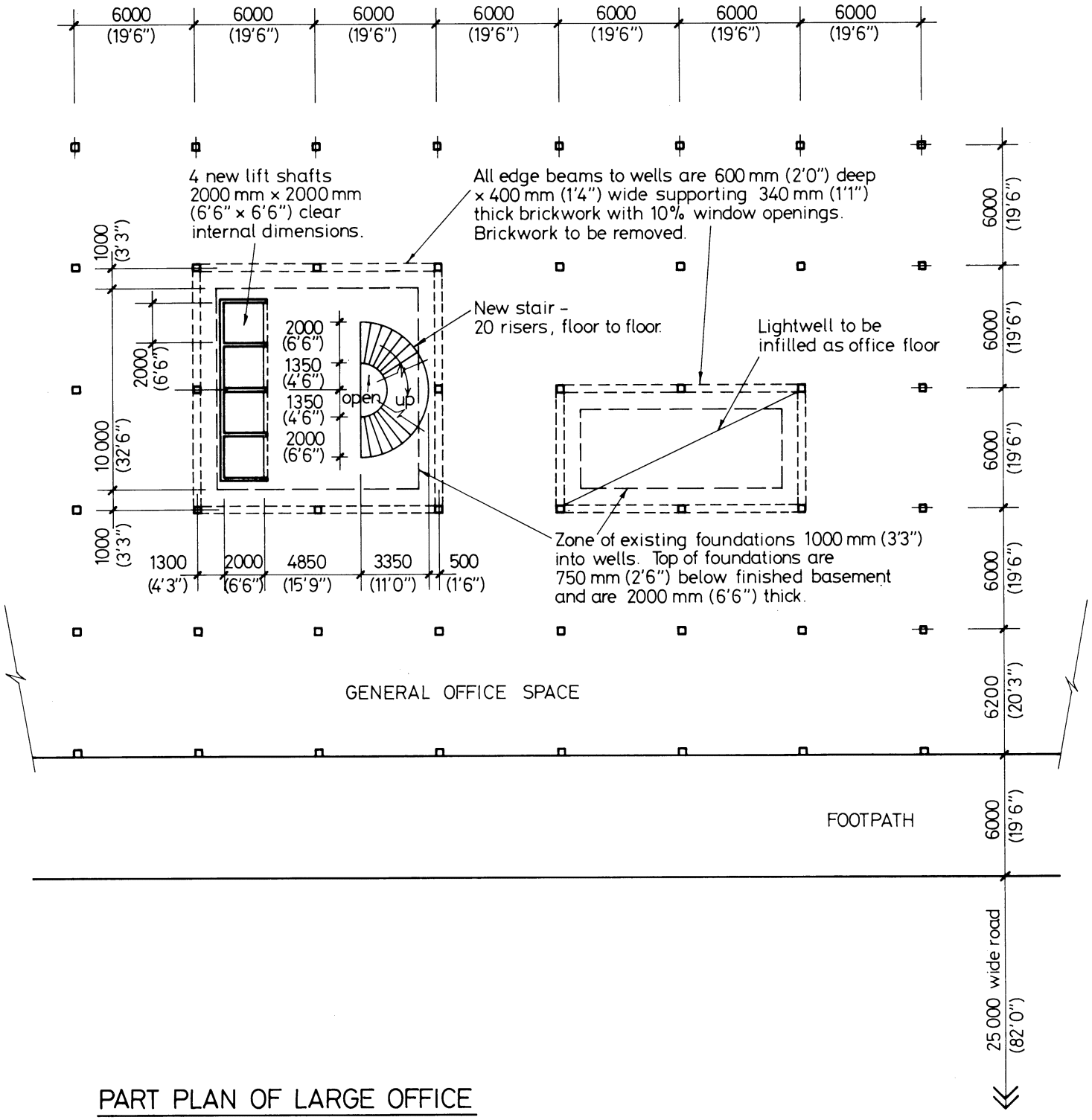
For the solution recommended in 1(a):

c. Prepare sufficient design calculations for the bridge superstructure to establish sizes of all significant structural elements in the completed new bridge.
Outline consideration should be given to any major items of temporary works necessary to maintain stability during the construction phase of the works.

d. Prepare to suitable scales a general arrangement drawing of the new bridge, with plan, elevation and sections necessary to show size and layout of structural elements, as required for estimating purposes.

e. Prepare neat annotated sketches of:
(i) Details of the end support to the new bridge, showing bearings, expansion arrangements and any necessary works to the existing abutment.
(ii) A cross-section through the deck(s) during the construction phase to show how the traffic requirements are met, and any major items of temporary works.

f. Prepare a brief method statement for the bridge replacement contract.



PART PLAN OF LARGE OFFICE

Note. Dimensions are in millimetres (feet and inches).

FIGURE Q4

Question 4
Infill existing office building lightwells

Client's requirements

1. Infill two lightwells of an existing office building, one with a lift/stair complex and the other with new office space (See Fig. Q4). The building has a basement, ground, six upper floors and a flat roof. Floor to floor heights throughout are 3.4m (11′3″).
2. Rapid construction, with noisy work to be carried out at night or weekends when the building is unoccupied.
3. Two hours fire resistance to match existing construction.
4. Plant room to be located over the lift/stair complex, and a glazed roof over the small office floor infill area.
5. Existing foundations must not be interfered with or subjected to *additional* load, but any new vertical supports are to be located either adjacent to the existing columns or around the outer periphery of the new stair. Refer to Fig. Q4 for existing foundation locations.
6. The existing brick walls around the lightwells are to be removed to open up the office area and for access to the new stair and lifts. The load thus removed from the supporting beams can be replaced, but not exceeded, by some of that from the new construction. Refer to Fig. Q4 for details of walls.

Imposed loading

7. 5.0kN/m^2 (100 lbf/ft^2) for office and access areas including finishes and partitions.
   7.5kN/m^2 (150 lbf/ft^2) for plant room floor.

Site conditions

8. Level city centre site.
9. Pavement gantry permissible.
10. The adjacent road is multi lane one way.
11. Ground conditions from basement level in one lightwell found to be as follows:

0	–	0.4m (1′4″) Unreinforced concrete slab
0.4m (1′4″)	–	2.0m (6′6″) Made ground
below 2.0m (6′6″)	–	Stiff grey clay, average c = 150kN/m^2 (3000 lbf/ft^2) $\varnothing$ = 0

Sulphates 0.15% by weight. No ground water.

Omit from consideration

12. Detailed design of plantroom.
13. Detailed design of glazed roof over small office floor infill area.

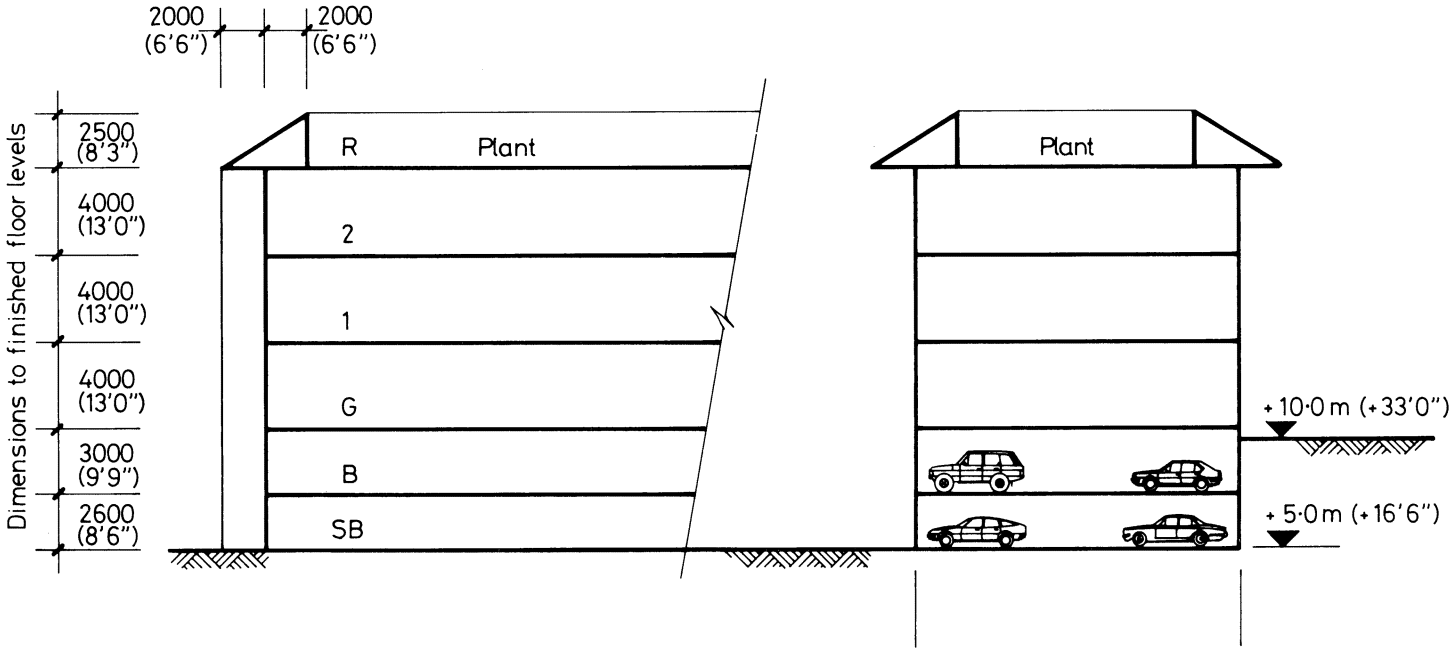
Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the proposed infilling of the lightwells. Identify clearly the functional framing, stability and load transfer aspects of each scheme.
   Identify the solution you recommend, giving reasons for your choice.
b. In a letter to the Architect, prepare a method statement setting out the sequence of construction for your recommended solution with special regard to the implications on the tenants.

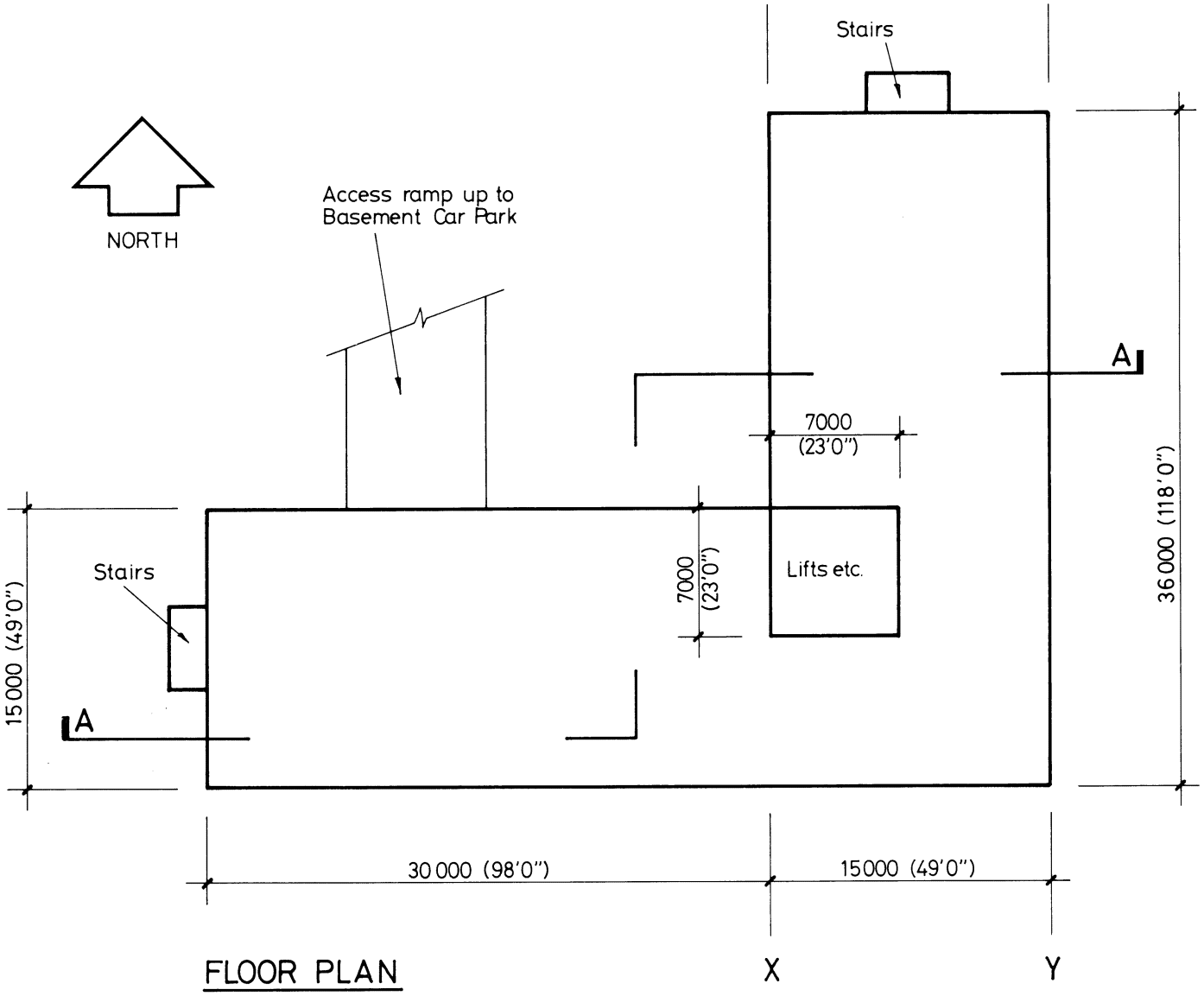
Part 2 (60 marks)

For your recommended solution in 1(a):

c. Prepare sufficient design calculations to establish the form and size of all major structural elements including the foundations.
d. Prepare a general arrangement drawing comprising plans, elevations and sections necessary to show dimensions, layout and disposition of the structural elements.
e. Prepare neat annotated sketches to show details of:
   (i) The junction beteen the new and existing construction at a typical floor level.
   (ii) The construction of the staircase.
   (iii) New foundations in relation to the existing.
f. Describe, with the aid of sketches, a feature glazed roof for the small infill lightwell, emphasising the structural form and members.



SECTION A-A



FLOOR PLAN

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

FIGURE Q5

Question 5

Multi storey building with integral car parking

Client's requirements

1. A new five storey building, with car parking in the sub-basement and basement, and offices on the ground, first and second floors (See fig Q5). Plant is to be located on the flat roof, screened by false mansards.
2. The maximum depth of structure permitted for the roof, first and second floors is 450mm (1′6″), for the ground floor 650mm (2′2″) and for the basement floor 350mm (1′2″). One line of internal columns is permitted in each wing of the offices. In the basement and sub-basement, columns are to be placed to suit car parking requirements.
3. Fire resistance of two hours is to be provided.
4. External cavity walls to office areas are to be 265mm (11″) thick of brick outer leaf and blockwork inner leaf.

Imposed loading

5. For offices — 5.0kN/m^2 (100 lbf/ft^2)
   For car parking — 2.5kN/m^2 (50 lbf/ft^2)
   For plant — 7.5kN/m^2 (150 lbf/ft^2)

Site conditions

6. Ground to the east of line Y is level at +10.0m (+33′0″). The ground to the west of line X is level at +5.0m (16′6″) and there is a uniform slope between the two.
7. The site is located on the outskirts of a large city. Basic wind speed 40m/s (90 mile/h).
8. Boreholes revealed the following information:
   Ground East of Line Y
   0 – 250mm (10″) top soil
   250mm (10″) – 2.4m (8′0″) loose gravel with water seepage
   below 2.4m (8′0″) stiff grey clay, average c = 150 kN/m^2 (3000 lbf/ft^2) $\varnothing$ = 0, pH = 5.2
   Ground West of Line X
   0 – 250mm (10″) top soil
   below 250mm (10″) stiff grey clay, average c = 150kN/m^2 (3000 lbf/ft^2) $\varnothing$ = 0, pH = 5.2

Omit from consideration

9. Detail design of mansards.
10. Detail design of access ramp to basement car park.
11. Detail design of staircases and lift shafts, although their contribution (if any) to overall stability and load transfer must be stated in Part 1(a).

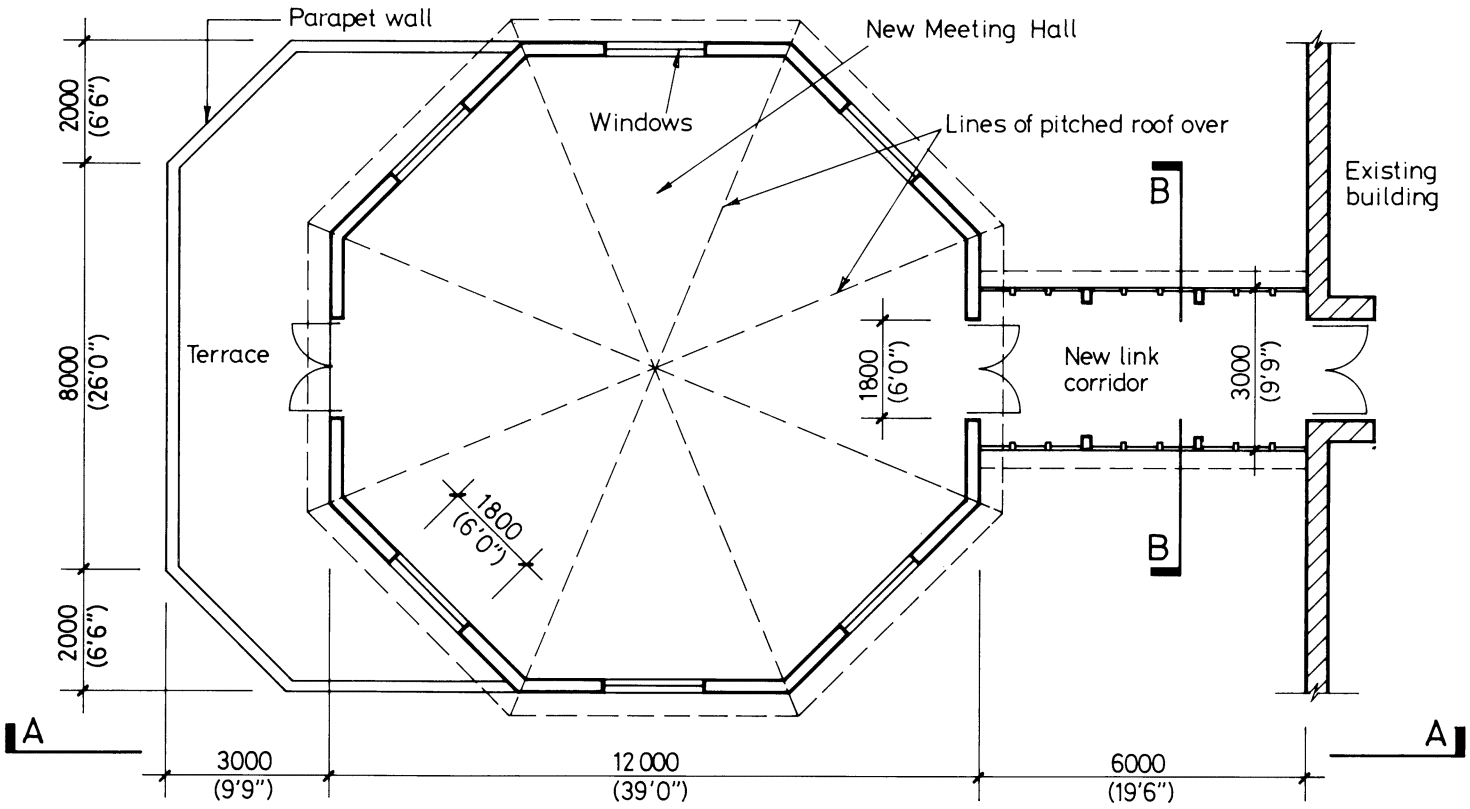
Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the building. Identify clearly the functional framing, stability and load transfer aspects of each scheme.
   Identify the solution you recommend giving reasons for your choice.
b. In a letter to the client explain the effect of clay heave and how you would accommodate it in your design.

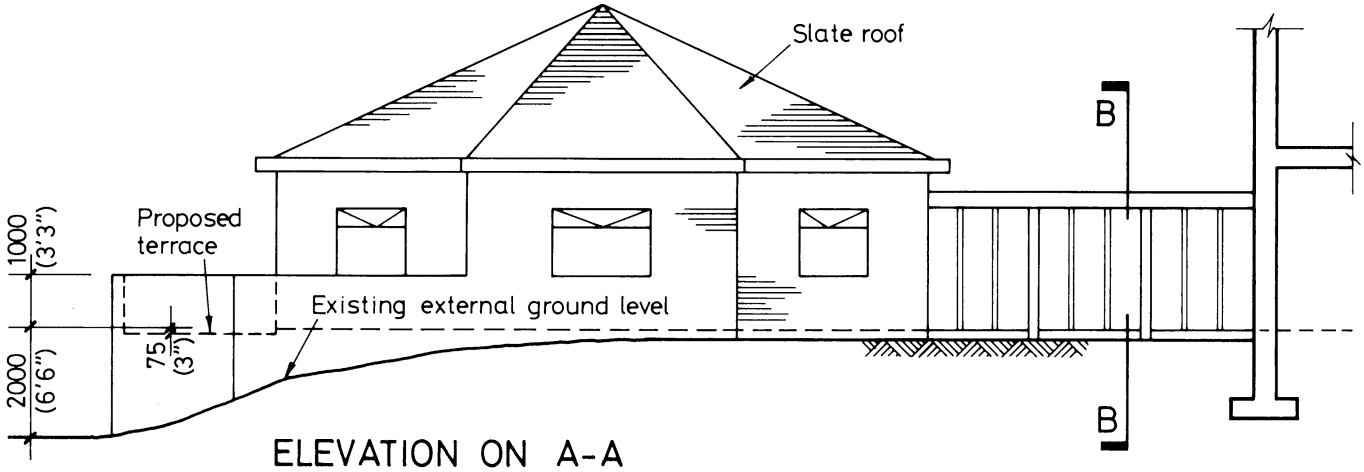
Part 2 (60 marks)

For the solution recommended in 1(a):

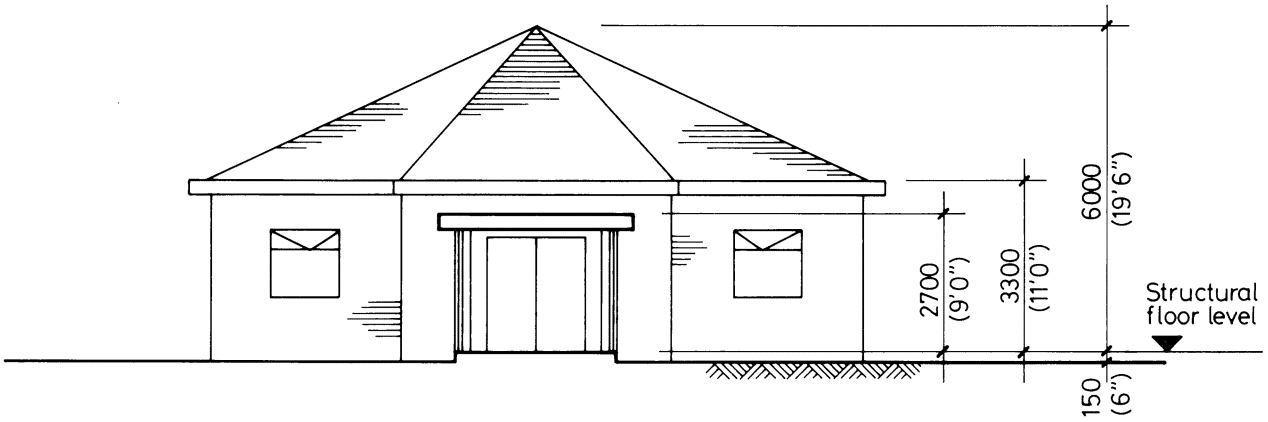
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including foundations.
d. Prepare a general arrangement drawing containing plans, elevations and sections necessary to show dimensions, layout and disposition of the structural elements as required for estimating purposes.
e. Prepare neat annotated sketches to show details of:
   (i) The junction between the sub-basement slab and the retaining wall on Line Y.
   (ii) A beam to internal column junction at ground floor level.
   (iii) A section through the roof slab showing a method of waterproofing which allows for installation of plant at a later date.
f. Describe the effects which the sloping site has on the means of construction. Write a brief method statement to indicate how the main problems are overcome.



PLAN



ELEVATION ON A-A



SECTION B-B

Note. Dimensions are in millimetres (feet and inches)

FIGURE Q6

Question 6

Octagonal meeting hall extension to residential home

Client's requirements

1. The construction of a new octagonal meeting hall and link corridor extension to an existing elderly persons residential home. See Fig. Q6.
2. A pitched, slated roof structure is to be used for the hall which is to be timber board clad on the soffit of the pitched members to express fully the roof height and shape internally. No separate horizontal ceiling rafters, ties or internal columns are permitted.
3. External masonry walls to be faced in brickwork externally and finished internally with fair-faced blockwork. A raised external terrace with a brick faced parapet is required at the rear of the hall.
4. The link structure is to have fully glazed external walls and a flat roof.
5. 1 hour minimum fire protection is required for all structural members.

Imposed loadings

6. Pitched roof – 0.75 kN/m^2 (15 lbf/ft^2) on plan
   Ground floor
   (Corridor, Hall & Terrace) – 4.0 kN/m^2 (80 lbf/ft^2)

Site conditions

7. Trial pits reveal that the existing building is founded in dry soft sandy clay at 1m (3′3″) depth on 600m (2′0″) wide concrete strip footings.
8. The site slopes down at the rear. Sub-soil conditions established from trial pits at the top of the slope are:
   0 – 0.3m (0 – 1′0″) grass and top soil
   0.3m – 0.6m (1′0″ – 2′0″) fill materials
   below 0.6m (2′0″) – soft sandy clay, with ground water table at 3.5m (11′6″) depth.
   Safe bearing pressure in soft sandy clay is 100 kN/m^2 (1 Tonf/ft^2).
9. Basic Wind Speed = 50 m/s (112 mile/h).

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable structural solutions for the proposed extension. Identify 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 your client describing an alternative, and more economical, structure for the same pitched roof if a horizontal ceiling were permitted in the main hall.

Part 2 (60 marks)

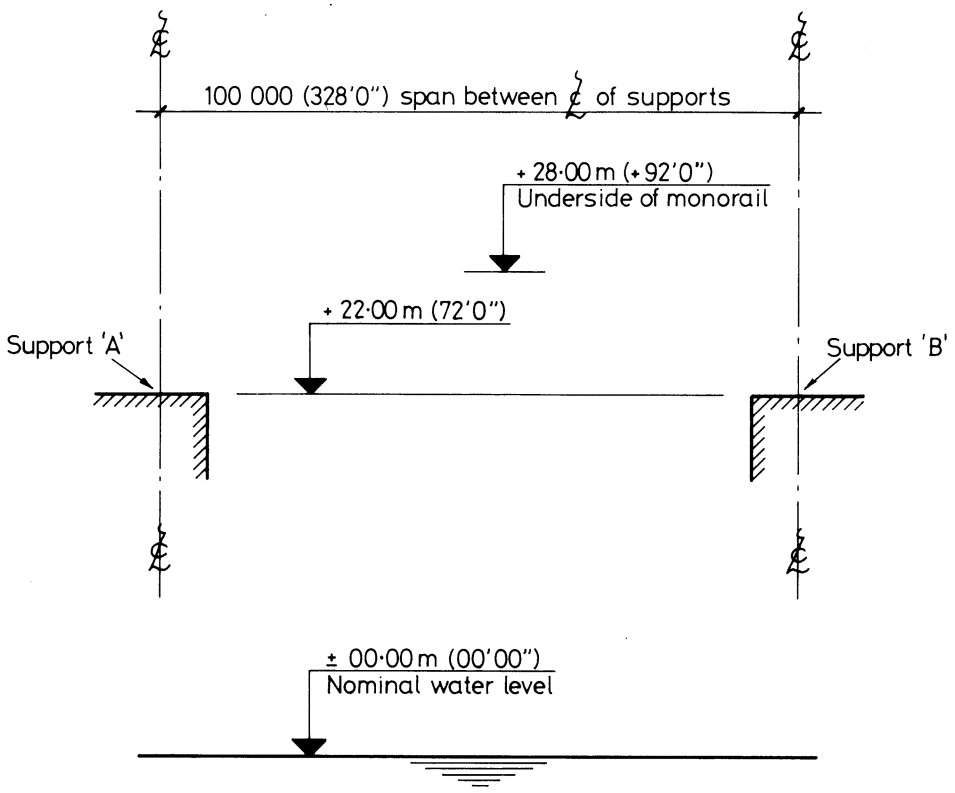
For the solution recommended in 1(a):

c. Prepare sufficient design calculations to establish the size and form of the principal structural members including foundations and retaining walls.

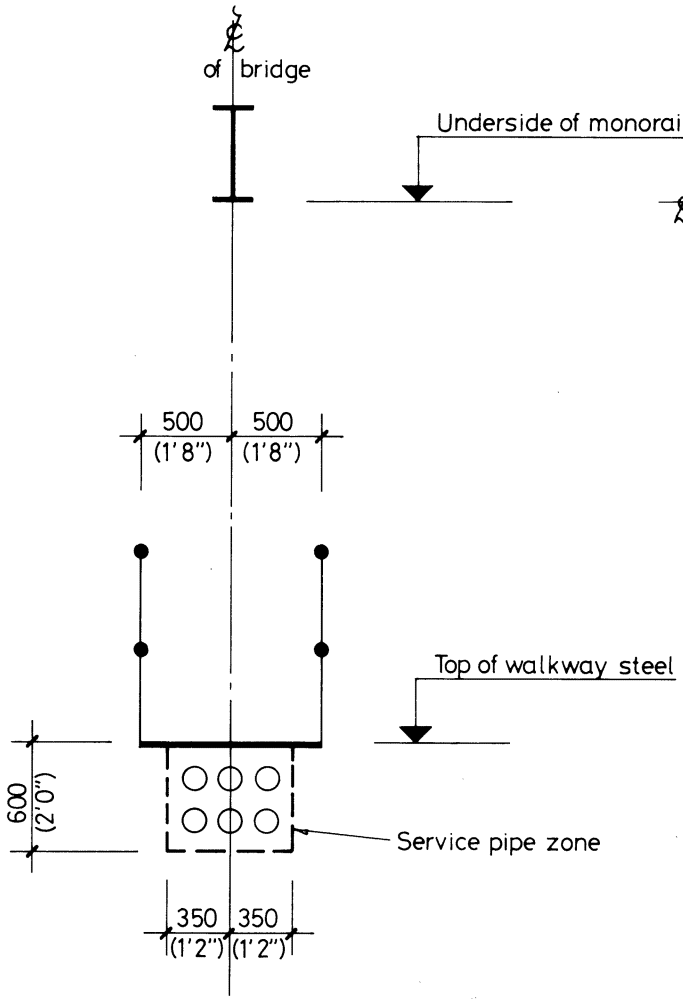
d. Prepare to a suitable scale general arrangement drawings with plans, elevations and sections showing clearly the dimensions, sizes and layout of the structural elements, as required for estimating purposes.

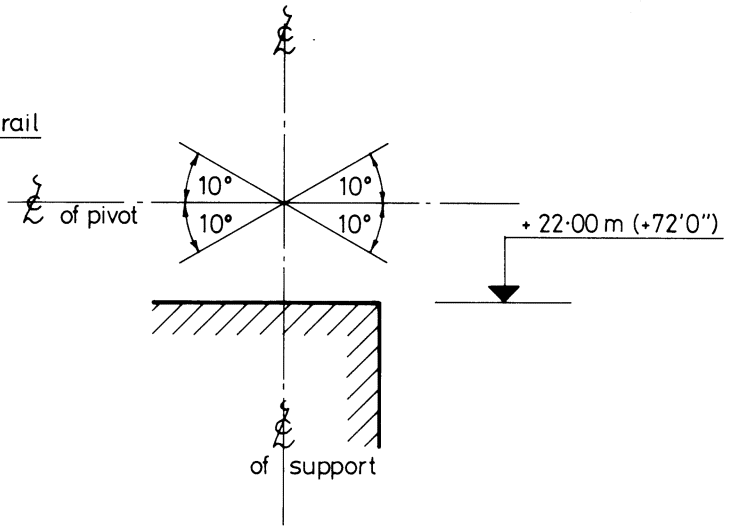
e. Prepare neat annotated sketches indicating details of:
   (i) A section through the terrace retaining wall and proposed terrace construction.
   (ii) A section through an external wall of the main hall showing wall to foundations/ground slab details and wall to roof/eaves details.
   (iii) The principal member joint at the roof apex.

f. Prepare a method statement outlining the sequence of construction envisaged, and identify any temporary works including propping and/or scaffolding that you consider necessary.



GENERAL ARRANGEMENT





TYPICAL SUPPORT SHOWING VERTICAL ROTATION ALLOWANCE

Note. Not to scale.
All levels are in metres (feet and inches)
Other dimensions are in millimetres (feet and inches)

SECTION THROUGH BRIDGE

FIGURE Q7

Question 7
Link bridge

Client's requirements

1. An open bridge spanning between two existing Southern North Sea Offshore platforms.
2. The connections of the bridge are to be at locations (A) and (B) as shown in Fig Q7. There is to be allowance for 300mm (1ft) horizontal movement in line with the bridge at connection (B) and, at both (A) and (B), an allowance for a rotation of plus or minus 10° about an axis perpendicular to the span direction of the bridge.
3. The bridge is to be installed in a single lift offshore.
4. The bridge is to have a 40 year design life.

Imposed loading

5. The bridge is to carry six 100mm (4in) diameter services, supported at 2m centres longitudinally as indicated in Figure Q7. The services have a total operating weight including live load of 10kN/m run of bridge (670lbf/ft run).
6. The bridge is to provide 1m (3'4") wide personnel access from one platform to another and carry a mono-rail with a safe working load of 20kN (2tonf) which includes the weight of the lifting appliance.

Site conditions

7. Basic wind speed 40m/s (90 mile/h).
8. Extreme ice thickness 50mm (2in) of density 900kg/m^3 (55lb/ft^3).

Omit from consideration

9. Dynamic and fatigue checks.
10. Seafastenings.
11. Installation aids other than padeyes/padears.
12. Design consideration of 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 increase the service loading to 20kN/m run (1,340lbf/ft run) by the introduction of six additional services. Write to him explaining the effects of his suggestion on your recommended solution.

Part 2 (60 marks)

For the solution recommended in 1(a):

c. Prepare sufficient design calculations to establish the size and form of all significant elements for both temporary and permanent conditions.

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

e. Prepare neat annotated sketches to illustrate the details of:
   (i) Typical top boom node point connection.
   (ii) Typical lifting point.
   (iii) Supports points (A) & (B).

f. Prepare a method statement outlining a suitable inspection and maintenance procedure for the bridge.