The Institution of Structural Engineers

Membership Examination Part 3

3 APRIL 1992

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.

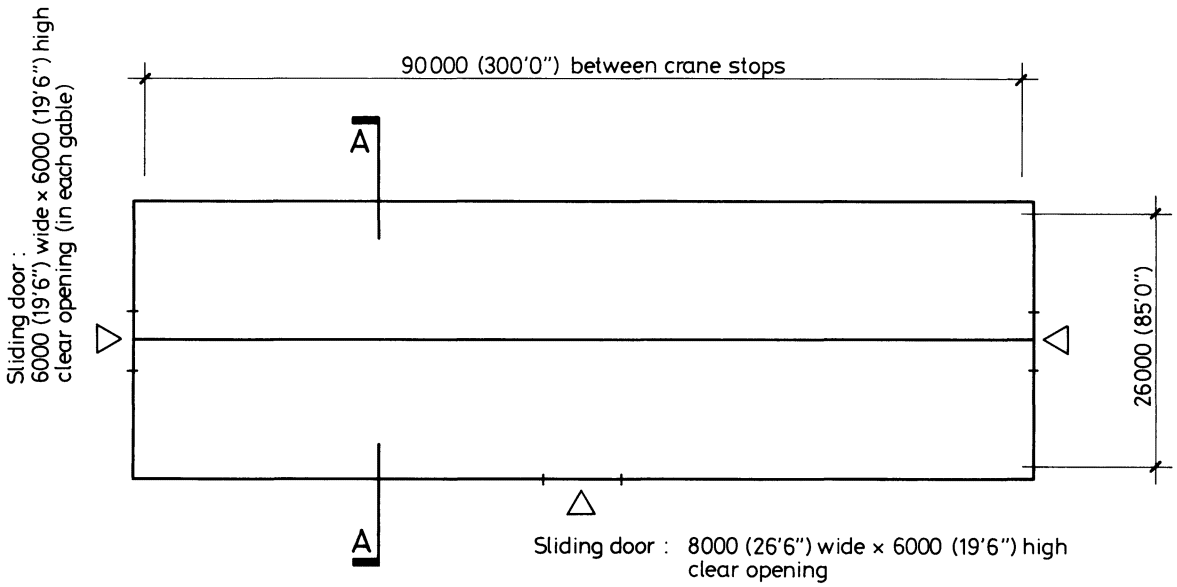
In selecting and developing your design you should also remember the guidance given in the Institution's report, 'Aims of Structural Design', and in particular:

(1) 'the structure must be safe',

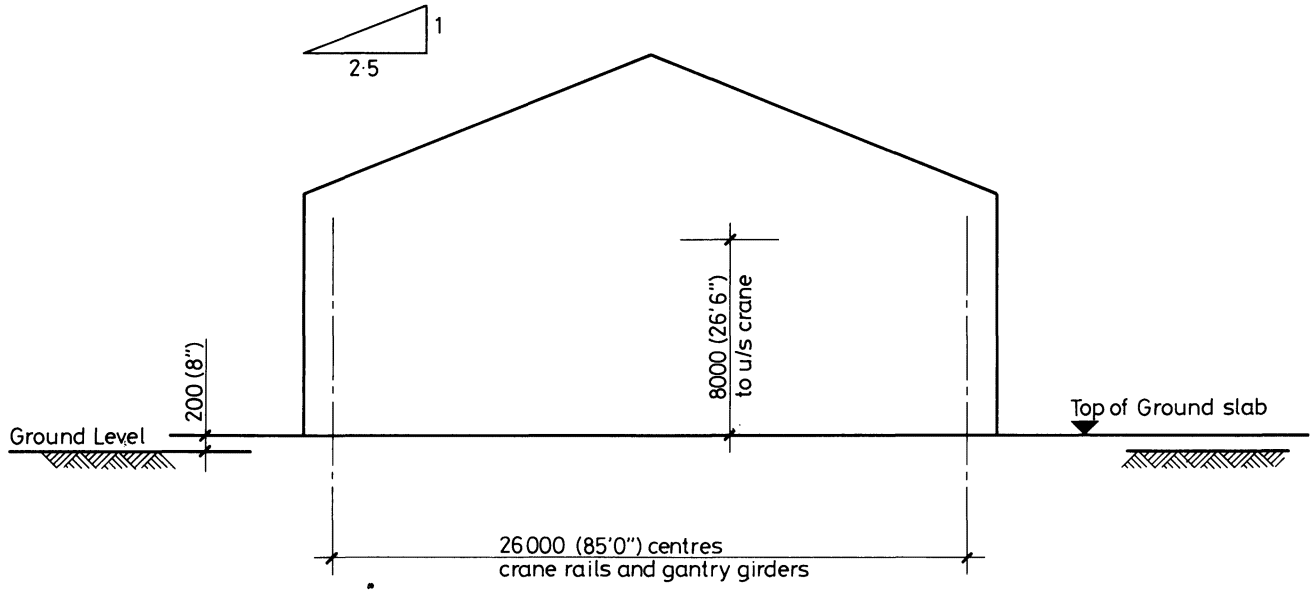
(2) 'a good design has certain typical features – simplicity, unity and necessity',

(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.



ROOF PLAN



SECTION A-A

Note. Dimensions are in millimetres (feet and inches)

FIGURE Q1

Question 1
Single Storey Workshop

Client's requirements

1. A single storey workshop building suitable for fabrication work. See Figure Q1
2. The building is to contain a single, pendant controlled, overhead travelling crane of 25 Tonnes (25 tonf) capacity with 8.0m (26′-6″) clearance from floor level to the underside of the crane structure. See 8 below for operational details and dimensions.
3. Apart from personnel access doors there is to be a main sliding door on one side and a smaller sliding door in each gable end.
4. Wall cladding to comprise a 1.0m (3′-4″) high dwarf wall with lightweight profiled sheeting above. Similar sheeting to roof but with 20% of roof area single glazed.
5. Appropriate thermal insulation to be provided to roof and walls. Finish to roof and wall cladding to be suitable for the environment specified.
6. Accurately laid, smooth finished ground floor slab providing a strong durable working floor surface requiring minimum maintenance and cleaning.

Imposed loadings

7. Roof (access for maintenance only)	0.60kN/m^2	(12lbf/ft^2)
Services in roof	0.25kN/m^2	(5lbf/ft^2)
Ground floor	7.50kN/m^2	(150lbf/ft^2)

Crane details, static loads and dimensions

8. Safe working load	25 tonnes	(25 tonf)
Crane self weight (excluding crab)	24 tonnes	(24 tonf)
Crab self weight	4 tonnes	(4 tonf)
Minimum end hook approach	1.5m	(5′-0″)
End carriage wheel centres (2 wheels per carriage)	5.0m	(16′-6″)
Minimum end clearance:		
centre line of gantry girder to near face of column roof leg	0.25m	(10″)
Minimum operating clear height:		
underside of crane structure to underside of roof structure	2.125m	(7′-0″)

Site conditions

9. The building is situated in countryside with some trees and occasional buildings. Basic wind speed is 43m/s (95 mile/h).
10. The ground is made up of 0.3m (1′-0″) of sandy clay topsoil over 0.9m (3′-0″) of firm sandy clay over 13.8m (46′-0″) of firm sandy gravel with an allowable bearing pressure of 150 kN/m^2 (1.5 tonf/ft^2). Water is struck at 1.8m (6′-0″) depth.

Omit from consideration

11. Design of crab, crane and end carriages.

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 received and approved in principle your recommended solution, the Client proposes replacing the overhead crane with 3 no. 5 Tonnes (5 tonf) capacity longitudinal runway beams running the full length of the building and supported at the quarter points of the spanning roof structure (ie at about 7.0m (23′-0″) centres).

Prepare a letter to the Client outlining the structural and financial implications of the proposal.

Part 2 (60 marks)

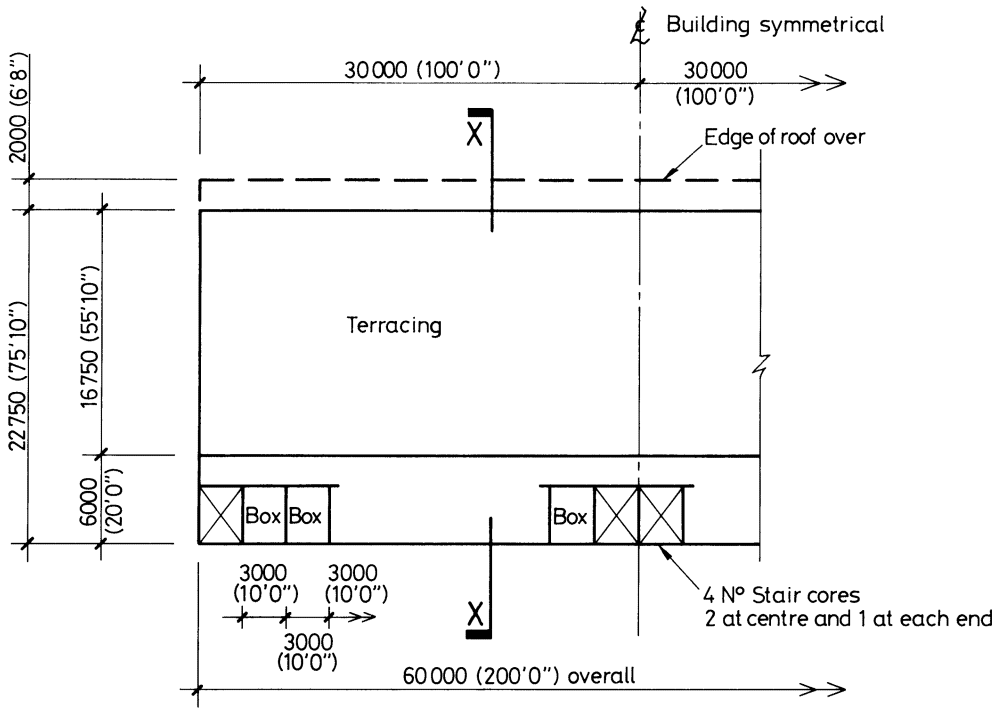
For the solution recommended in Part 1(a):

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

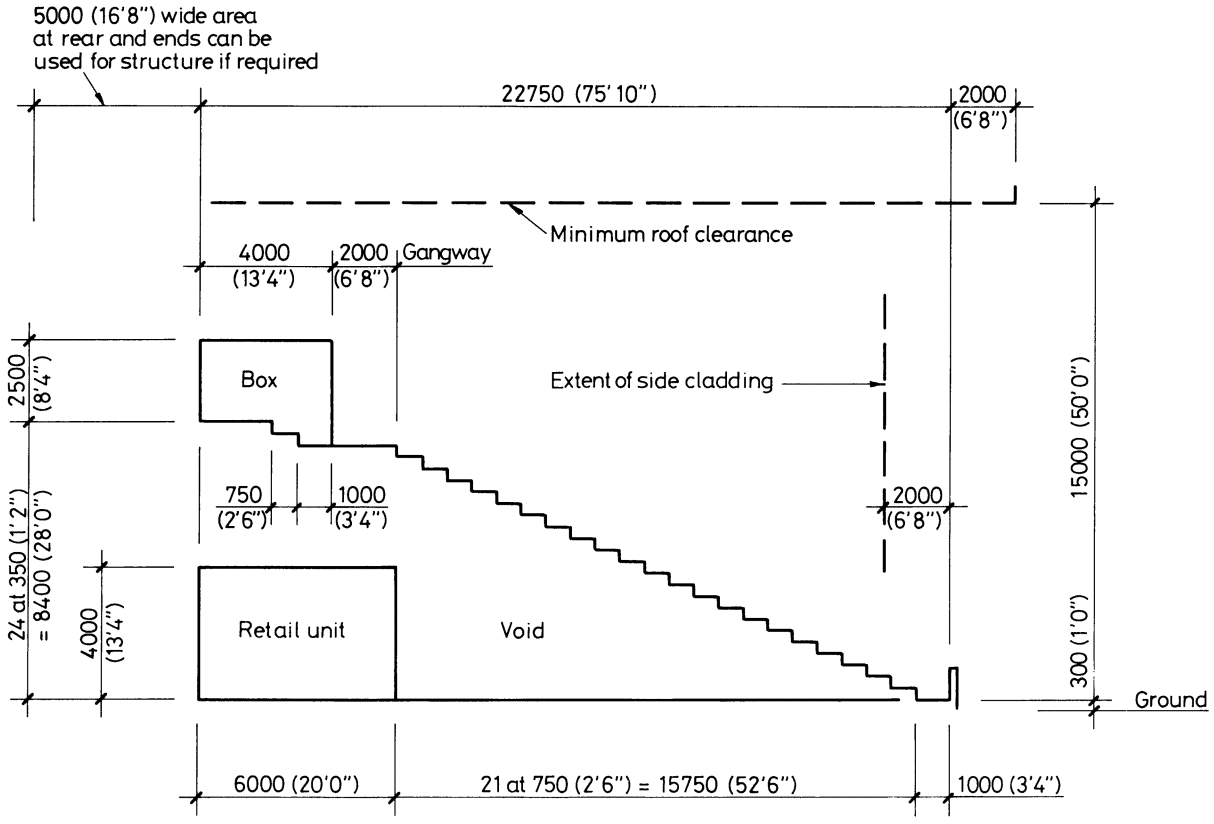
d. Prepare general arrangement plans, sections and elevations, giving the dimensions, layout, disposition and sizes of structural elements, including the ground floor slab, as required for estimating purposes.

e. Prepare clearly annotated sketches to illustrate details of:
   (i) Connection of crane gantry girder to supporting column.
   (ii) Column base and slab edge/wall support.
   (iii) Crane gantry girder end stop.

f. Explain clearly how you will specify and control the materials and construction of the ground floor slab in order to meet the requirements detailed by the Client.



PLAN



SECTION X-X

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

FIGURE Q2

Question 2
Sports Stand

Client's requirements

1. A covered sports stand for seated spectators, with individual viewing boxes. (See figure Q2).
2. Columns will not be allowed along the front edge of the stand or within the terraced seating area.
3. Roof and ends to be clad using a lightweight cladding which, together with its supporting structure, is to be aesthetically pleasing.
4. Viewing boxes to be 3.0m (10′-0″) long with a glazed screen, incorporating access, to the front.
5. Retail units 6.0m (20′-0″) square are required under the boxes with access at the rear. The remainder of the space under the terrace, other than that required for structural framing purposes, is to be a void with maintenance access only.

Imposed loadings

6. Roof $0.60kN/m^2$ $(12lbf/ft^2)$
   Services in roof $0.25kN/m^2$ $(5lbf/ft^2)$
   Terracing, boxes and gangways $5.00kN/m^2$ $(100lbf/ft^2)$
   Floors in retail units $7.50kN/m^2$ $(150lbf/ft^2)$

Site conditions

7. The sports ground is sited on the outskirts of a city. Basic wind speed is 46m/s (102 mile/h).
8. The ground comprises 0.6m (2′-0″) of made ground over 1.8m (6′-0″) of loose gravel over 21.6m (72′-0″) of firm chalk. No ground water is present.

Omit from consideration

9. Detailed design of stair cores, but any contribution to overall stability must be identified in Part 1a.
10. Access aisles, terrace gangways and stairs other than indicated.
11. Provision of crush barriers.

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. After your recommended scheme has been approved in principle the Client raises the possibility of increasing the stand capacity by adding three more rows of terracing.
   Prepare a letter to the client indicating the likely structural and cost implications of this change.

Part 2 (60 marks)

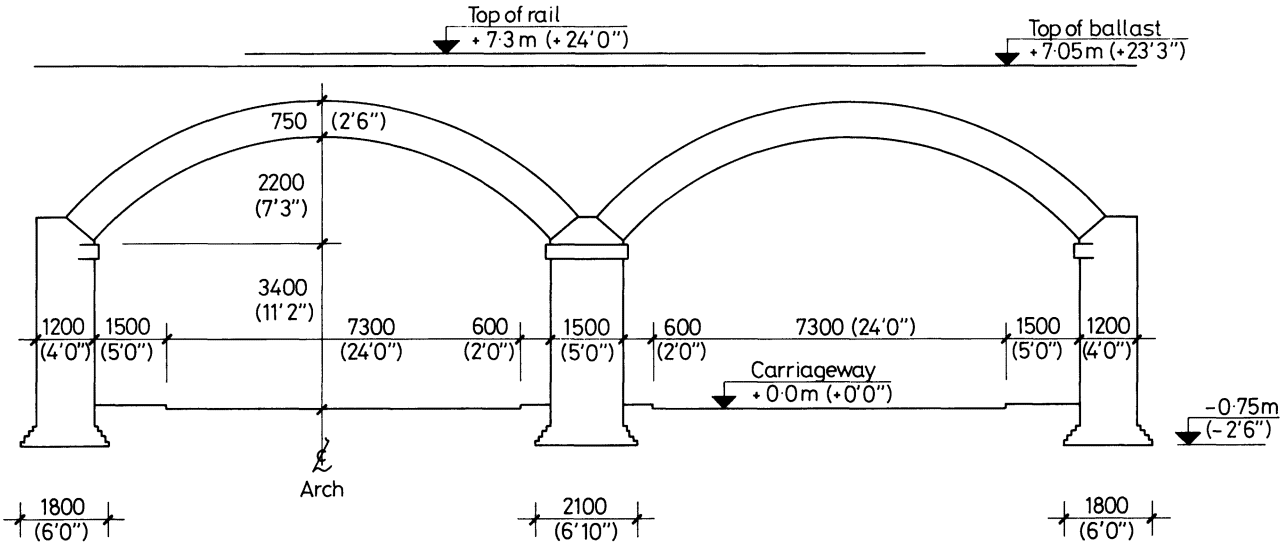
For the solution recommended in Part 1(a):

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

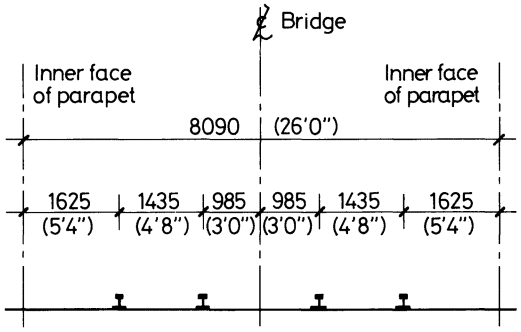
d. Prepare general arrangement plans, sections and elevations, giving the dimensions, layout, disposition and sizes of structural elements as required for estimating purposes.

e. Prepare clearly annotated sketches to illustrate details of:
   (i) Connection of a main vertical element to foundation.
   (ii) Junction of main vertical and roof elements.
   (iii) Terracing to supporting raker connection.

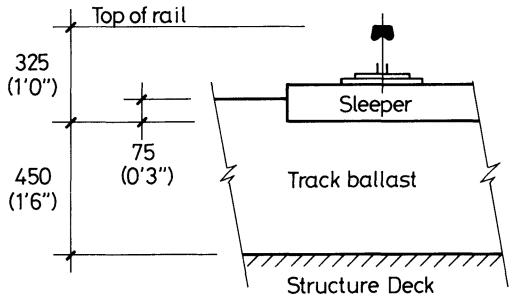
f. Prepare a simple erection schedule for the main framing identifying the sequence of work. Indicate also how temporary and permanent line and level requirements will be monitored, controlled and achieved.



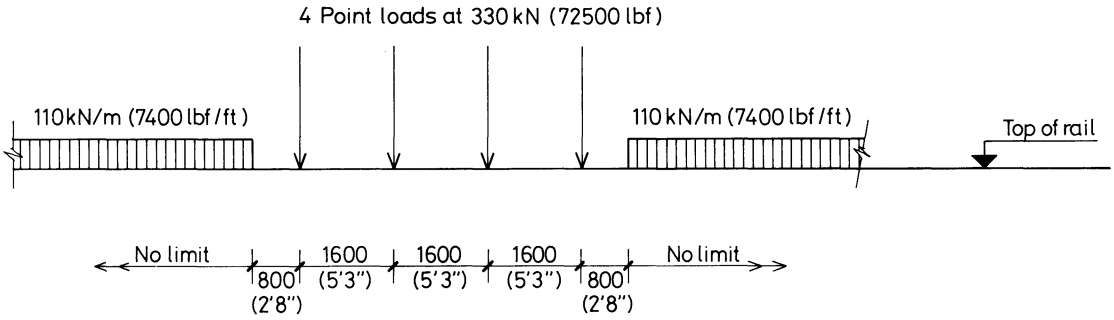
SECTIONAL ELEVATION THROUGH BRIDGE



TRACK DIMENSIONS



TRACK BALLAST DIMENSIONS FOR NEW STRUCTURE



VERTICAL LOADING FOR EACH TRACK (i.e. EACH PAIR OF RAILS)

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

FIGURE Q3

Question 3

Railway brick arch bridge replacement

An existing brick arch bridge, carrying two rail tracks over a dual two-lane highway, provides sub-standard clearance to the arch soffit. Due to the presence of a large number of services in the highway, it is considered uneconomic to lower the level of the carriageways, and it has been decided to demolish the arches and provide a new deck structure, retaining the existing pier, abutments and abutment wing walls which are splayed back at 45° from the abutment face.

Client's requirements

1. The new deck is to maintain the existing rail levels, clearance dimensions between the rails and parapets, and overall depth of ballast as shown in Figure Q3.
2. The new deck construction is to provide a **minimum** clearance between the carriageways and the soffit of 5.3m (17′-5″) across the **full width** of the carriageways.
3. Total or partial closures of the railway and highway are restricted to the following:
   Railway : total closure for a period of 9 days (22.00 Friday to 06.00 Monday, 9 days later).
   Highway : total closure only permitted during first 2 days of the railway closure (22.00 Friday to 06.00 Monday, 2 days later).
   : closure of one carriageway with two-way single-lane working on the other carriageway is permitted at other times during the railway closure and for prior preparatory work.
4. The work is to be complete, allowing unrestricted use of the railway and highway, by the end of the railway closure (06.00 on the second Monday).
5. A preliminary investigation of the existing brick pier, abutments and spread footings has shown these to be in an adequate condition for re-use in the scheme, although detailed load capacity calculations have yet to be carried out.

Imposed loading

6. The nominal vertical loading for each track (ie. each pair of rails) is shown in Figure Q3, and includes vertical dynamic effects. In addition to these loads, a nominal longitudinal load (braking/traction) of 275 kN (60,000 lbf) shall be applied to each track, acting horizontally at top of rail level.
7. These track loads can be equally divided between the two rails forming the track, but are to be applied to each of the two tracks simultaneously.

Site conditions

8. Founding material beneath pier and abutments
   – Sand, N = 30.
   Embankment Backfill to Abutments
   – Granular Material (well-drained), $\varnothing = 34°$
9. Design temperature range 50C°.

Omit from consideration

10. Accidental impact on bridge supports and parapets.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two distinct and viable solutions for the new structure. Identify in each case the type and details of construction, together with the means of overall stability and articulation.
   Your appraisal should include a description of any works on the remaining pier and abutments necessitated by your solutions, and a brief statement on a single method of achieving the demolition of the existing arches.
   Identify the solution you recommend, giving reasons for your choice.

b. Your Client queries, at a late stage in the design process, whether it would also be possible to demolish the central pier and adopt a single span structure between the modified existing abutments. Respond in the form of a letter, identifying the effects this would have on your recommended solution.

Part 2 (60 marks)

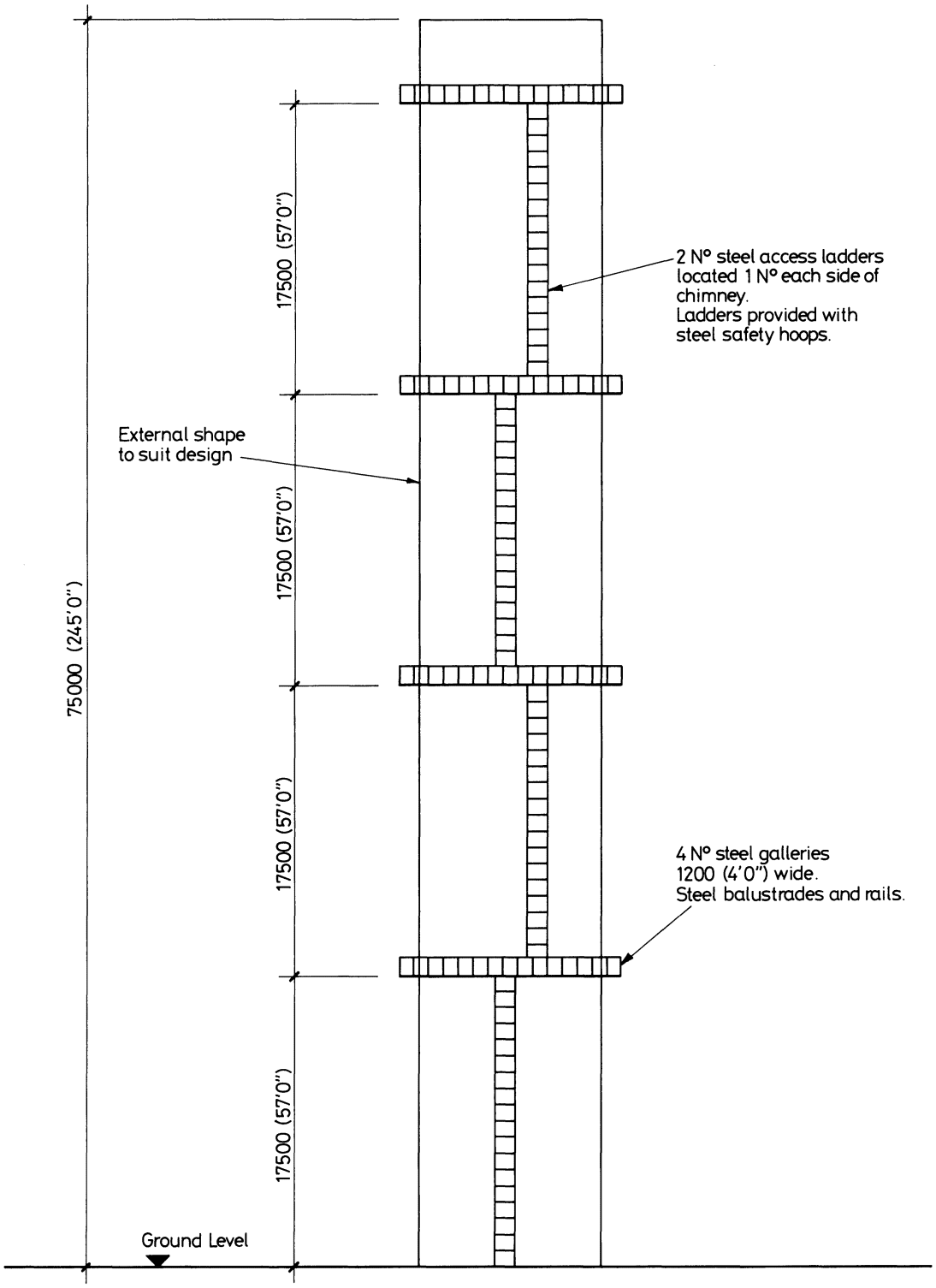
For the solution recommended in Part 1(a):

c. Prepare sufficient design calculations to establish the form and size of all principal structural elements of the new structure. This should include an outline assessment of the adequacy of the retained pier and abutments.

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

e. Prepare clearly annotated sketches to illustrate details of:
   (i) top of central pier, to include pier head and bearings;
   (ii) abutment bearing shelf and bearings;
   (iii) deck expansion joints at 'pinned' and 'free' ends of the deck spans.

f. Prepare an outline 'major activities' programme for the critical 9 day period, to illustrate that the Client's constraints can be met.



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

FIGURE Q4

Question 4
Chimney to power station

Client's requirements

1. A free standing chimney to an oil burning power station is to be provided (see Fig. Q4) of height 75.0m (245′-0″) measured above ground level and with a minimum internal working diameter of 4.0m (13′-0″).
2. A full height lining of refractory brickwork 115mm (4½″) thick is to be provided. It must be supported at suitable intervals on corbels with a ventilated cavity.
3. The flue gas inlet from the boiler is to be 3.0m (10′-0″) wide and 4.0m (13′-0″) high, with its centre located 8.5m (27′-9″) above ground level. The maximum temperature of the flue gases is 160°C.
4. Two external steel access ladders and four galleries are to be provided, as shown.

Site conditions

5. The power station is located on a level coastal site.
6. Basic wind speed = 42m/s (94 mile/h).
7. A trial pit indicates 4.0m (13′-0″) of loose overburden to sound rock with a safe bearing capacity of 500 kN/m^2 (5 tonf/ft^2).
8. Water table varies according to the tide, highest level 3.0m (10′-0″) below ground level.

Omit from consideration

9. Detailed design of the access ladders and galleries, but their effects must be considered.
10. Detailed dynamic wind analysis, but basic wind effects and influence on design and construction must be considered.
11. Design of the boiler flue and its connection to the chimney.

Part 1 (40 marks)

a. Prepare an illustrated design appraisal indicating two alternative solutions for the chimney.
   Identify clearly the stability, load transfer and construction details of each scheme.
   Identify the solution you recommend, giving reasons for your choice.

b. After approval in principle of your recommended solution the Client expresses concern about the lack of information relating to assessment and control of accuracy, strength and quality with respect to your proposed method and sequence of construction.
   Prepare a letter to him setting out details of the procedures you will adopt in order to ensure compliance with the standards laid down in the contract documents.

Part 2 (60 marks)

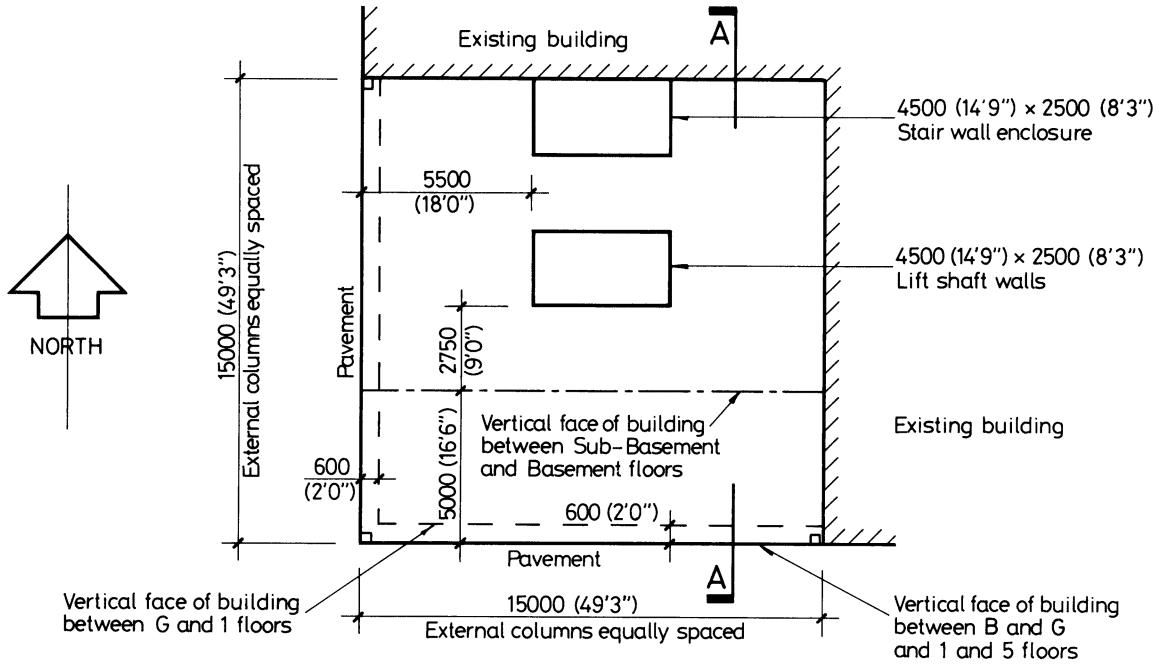
For the solution recommended in Part 1(a):

c. Prepare sufficient design calculations for the chimney to establish wall thickness, reinforcement (if any), foundation details and the effects of wind and temperature.

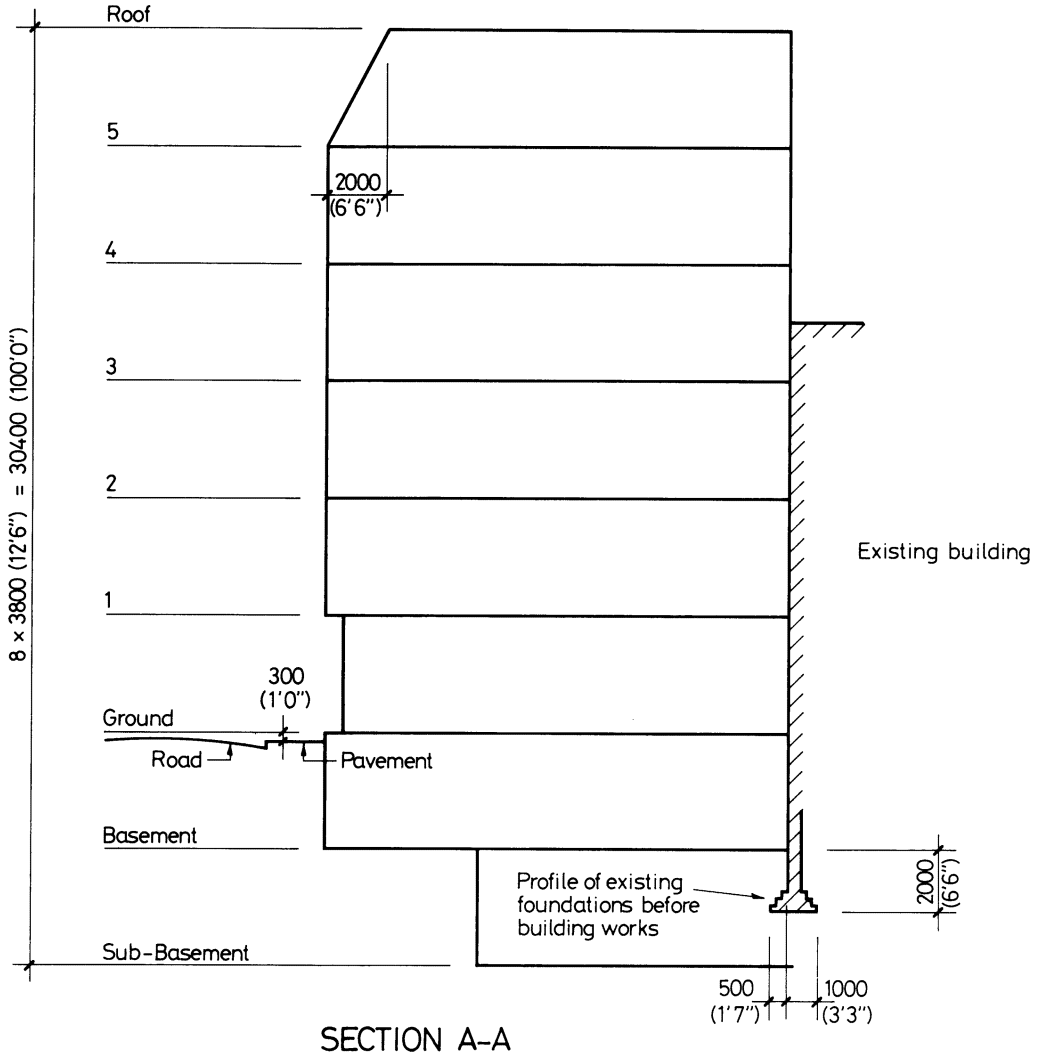
d. Prepare a detailed general arrangement drawing with sections and plans at appropriate intervals to sufficient scale to indicate all principal dimensions and details.

e. Prepare neat annotated sketches to show:
   (i) The detail at the flue inlet, including the treatment inside the chimney.
   (ii) A detail at the support of the lining.
   (iii) A detail at the cap of the chimney.

f. Prepare a programme for the construction work, identifying the various activities with times.



PLAN



SECTION A-A

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

FIGURE Q5

Question 5
City centre office development

Client's requirements

1. A new six storey fully air conditioned office building with a basement and sub-basement (See Figure Q5). Plant is to be located in the sub-basement, and the roof is to be profiled as shown. Stairs and lifts as shown to serve all floors.
2. No internal columns are permitted above ground floor level.
3. The maximum depth of structure permitted is 500mm (1′-8″) for the first floor and 400mm (1′-4″) for the other floors.
4. Fire resistance of 1½ hours is to be provided below ground floor level and 1 hour above.
5. The external cladding is to be of cavity wall construction, 265mm (11″) thick, of brick outer leaf and blockwork inner leaf, with insulated cavity, supported at each floor level. The structure should not be exposed.

Imposed loading

6. Office floors (including partitions)	5.0kN/m^2	(100lbf/ft^2)
Plant room	7.5kN/m^2	(150lbf/ft^2)
Roof	0.75kN/m^2	(15lbf/ft^2)

Site conditions

7. Level city centre site situated on a corner with adjacent buildings. Basic wind speed 36m/s (82 mile/h).
8. Ground conditions from pavement level are as follows:
   0-3.0m (10′-0″) made ground
   3.0m (10′-0″)-4.5m (15′-0″) soft silty clay
   4.5m (15′-0″)-30.0m (100′-0″) stiff clay, average c = 200kN/m^2 (4,000lbf/ft^2)
   Ground water was struck at 10.0m (33′-0″).
9. The adjacent buildings both contain basements with foundations as shown, the wall profile to East and North being as shown on Figure Q5.
   Both flank walls are in sound stable condition but the existing buildings cannot be assumed capable of contributing to either the stability of the office development or to vertical load transfer.

Omit from consideration

10. Detail design of stairs.

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. After approval in principle of your recommended solution the Client suggests enlarging the sub-basement to occupy the full below ground plan site area.
   Write a letter to him explaining the effect of his proposal upon your design.

Part 2 (60 marks)

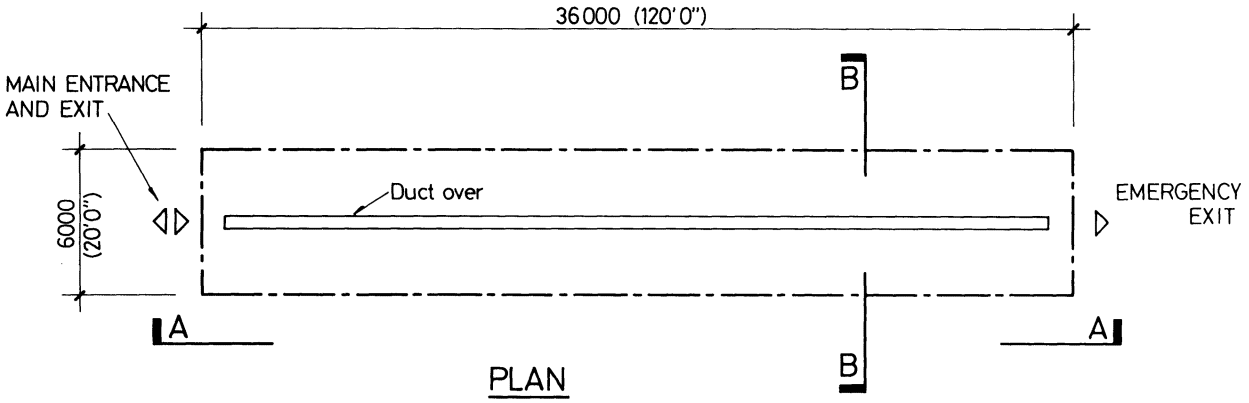
For the solution recommended in Part 1(a):

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

d. Prepare a general arrangement drawing containing plans, elevations and sections as 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 construction adjacent to one of the existing buildings below ground floor level.
   (ii) The connection at first floor level between an external ground floor column, the first floor construction and the offset column above.
   (iii) The method of supporting the external wall at a typical floor.

f. Discuss briefly, with the aid of sketches, the temporary works required during the construction of the substructure works.



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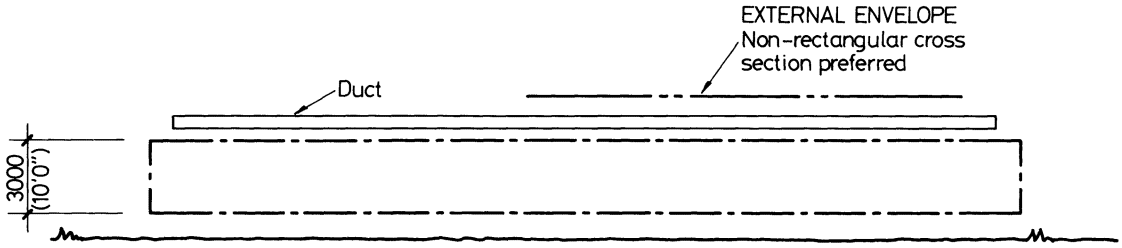
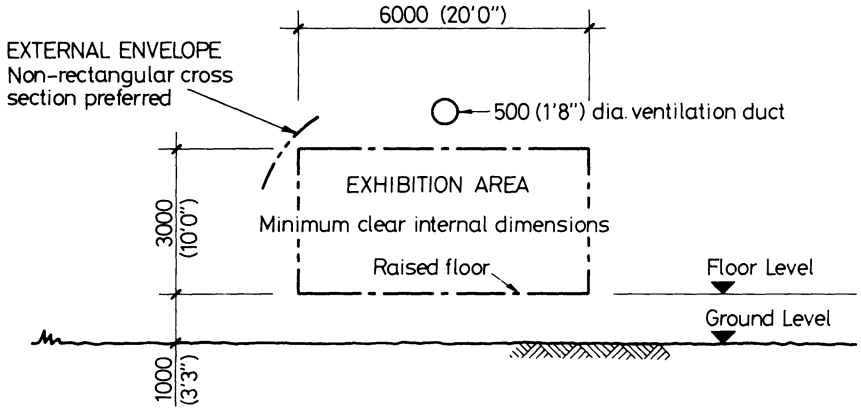


ELEVATION A-A



SECTION B-B

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

FIGURE Q6

Question 6
Demountable Exhibition Building

Client's requirements

1. A single storey demountable temporary exhibition building to accommodate a travelling exhibition of modern furniture manufactured by the Client's company. Minimum clear internal dimensions are shown in Figure Q6. The building envelope is to be mainly translucent above floor level and externally a non-rectangular cross section is preferred.
2. The Client requires a building of distinctive appearance which reflects his company's commitment to design quality.
3. Exposed structural members and their connections should be neat and unobtrusive. Wherever possible electrical cabling above floor level should be concealed by the building structure.
4. The building elements will be transported to various different locations by road. All components and elements should be suitable for regular storage and transit with assembly and dismantling being rapid and easy.

Imposed loading

5. Longitudinal duct 0.60kN/m (40lbf/ft)
   Exhibition floor 5.00kN/m^2 (100lbf/ft^2)

Site conditions

6. A prepared level site capable of supporting an allowable bearing pressure beneath isolated footings of 50kN/m^2 (0.5 tonf/ft^2) will be provided at each exhibition location.
7. Exhibition locations are sited in open spaces near the centres of large cities. Most onerous basic wind speed 50m/s (112 mile/h).

Omit from consideration

8. Accommodation for mechanical and electrical plant, which will be housed separately.

Part 1 (40 marks)

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

b. At a late stage it is discovered that the prepared site at one of the proposed locations is capable of supporting a reduced allowable bearing pressure beneath footings of only 25kN/m^2 (0.25 tonf/ft^2).
   Prepare a letter to the Client proposing possible options to modify either the building structure or the prepared site to overcome this problem.

Part 2 (60 marks)

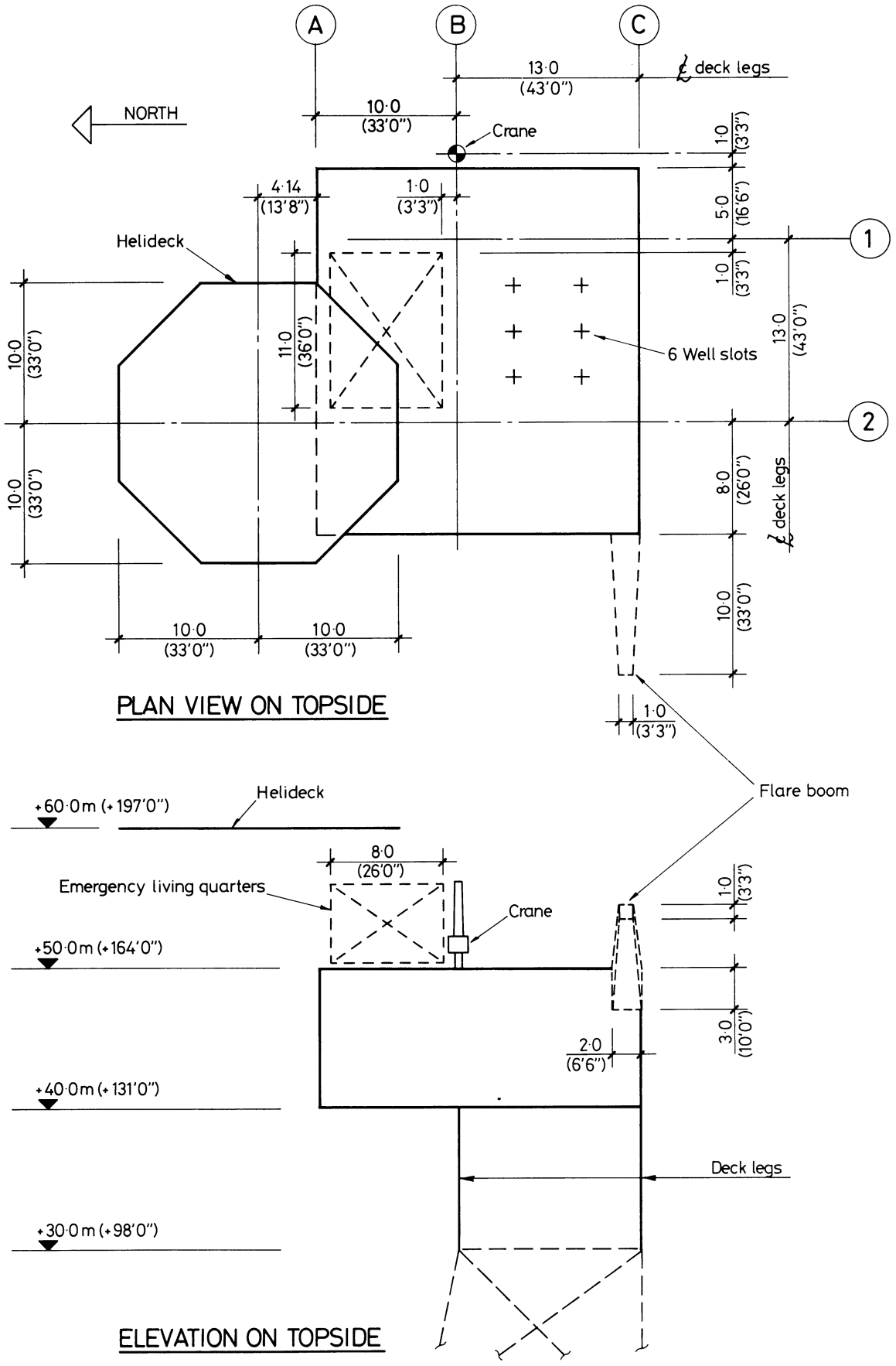
For the solution recommended in Part 1(a):

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

d. Prepare general arrangement plans, elevations and sections giving the dimensions, layout, disposition, sizes and materials of the structural elements as required for estimating purposes.

e. Prepare clearly annotated sketches of the following connections:
   (i) External wall structure to floor structure.
   (ii) Main structural support member to foundation.
   (iii) Cladding to structure.

f. Prepare a method statement describing how the building is assembled, dismantled and handled whilst in transit. Identify any temporary support required.



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

FIGURE Q7

Question 7
Topside Structure

Client's requirements

1. A topside structure for a four legged unmanned shallow water platform in the Northern Temperate Zone.
2. The topside profile is shown in Figure Q7.
3. An emergency living quarters is to be situated between grid-lines A and B, 1 and 2 under the helideck on the main deck at the +50.0m (+164′-0″) level.
4. A crane is to be located on the east face of the platform on grid-line B.
5. A flare-boom is to be located on the west face of the platform near grid-line C.
6. A helideck on the north side of the platform designed for a "Bell 214" helicopter.
7. The topside is to be installed in a single lift offshore, maximum lift weight 3,000 tonnes (3,000 tonf).

Imposed loading

8. The topside deck is to support
   (i) a helideck of total inclusive load 100 tonnes (100 tonf) (including helicopter total weight 8 tonnes (8 tonf)).
   (ii) An emergency living quarters of total inclusive load 80 tonnes (80 tonf).
9. The equipment topside loading south of grid-line B (shared equally between levels) is 1,000 tonnes (1,000 tonf).
10. Stairs, access ways around emergency living quarters, S.W.L. = 10kN/m^2 (200 lbf/ft^2).
11. The lattice flare boom on the south/west corner of the deck has a 5° elevation to horizontal and a 200mm (8″) diameter flare line running tip to root. The boom unit has a total inclusive structural self weight of 35 tonnes (35 tonf).
12. The crane has a total self weight of 30 tonnes (30 tonf) and a maximum safe working load of 25 tonnes (25 tonf) at 10.0m (33′-0″) radius.

Site conditions

13. Basic wind speed is 50m/s (112 mile/h).

Omit from consideration

14. Design of flare boom and crane.
15. Dynamic and fatigue checks.
16. Sea fastening, installation aids other than padeyes/padears.
17. Access between deck levels.

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 proposes to move the helideck southwards and centre it over Grid line B to reduce the over-turning moment. Write to him explaining the effects of his suggestion on your recommended solution.

Part 2 (60 marks)

For the solution recommended in Part 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 lifting points;
   (ii) Deck legs – locating points during loadout;
   (iii) Typical helideck to main deck connections.

f. Prepare a method statement for loadout in the form of an itemized list.