

# Chartered Membership Examination

Friday 10 July 2015

## Structural Engineering Design and Practice

09.30 – 13.00 and 13.30 – 17.00 (Discussion between individuals is not permitted during lunch period). A period of fifteen minutes is provided for reading the question paper, immediately before the commencement of the examination. Candidates are not permitted to write in answer sheets, or on drawing paper or to use a calculator during this time. Candidates must satisfy the Examiners in ONE question.

### Important

The written answer to the question selected and any A3 drawings must bear the candidate's number and the question number at the bottom of the page. Only the answer sheets 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. Examiners will only mark work written by hand during the examination.
3. A fair proportion of marks will be awarded for the demonstration of an understanding of fundamental engineering concepts, as distinct from calculation of member forces and sizes. NOTE: In the calculation part of all questions, establishing "form and size" is taken to mean compliance with all relevant design criteria, i.e. bending, shear, deflection, etc.
4. In all questions 50 marks are allocated to Section 1 and 50 marks to Section 2.
5. 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.
6. Any assumptions made and the design data and criteria adopted must be stated.
7. Good clear drawings and sketches are required; they should show all salient and structural features to suitable scales and should incorporate adequate details.
8. Candidates will not be allowed to include any previously prepared calculations, notes, sketches, diagrams, computer output or other similar material in their answer sheets or A3 drawings. Any previously prepared information submitted by candidates will be ignored by the examiners.
9. Candidates may not bring into the examination room any electronic devices capable of wireless communication, optical photography or scanning.  
The following devices are not permitted: Mobile phones, Laptops, notebooks or portable computers and similar devices, iPads, tablets and similar devices, E-readers (e.g. Kindle) and similar devices, Cameras, optical scanners and similar devices.  
Any candidates arriving at the examination room with such devices will be asked to switch them off and place them in a sealed bag kept by the Invigilator for the duration of the exam, which includes the lunch period.
10. This paper is set in SI Units.

**Now read 'Reminder' on page 3.**



# Chartered Membership Examination, a reminder from your Examiners

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

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

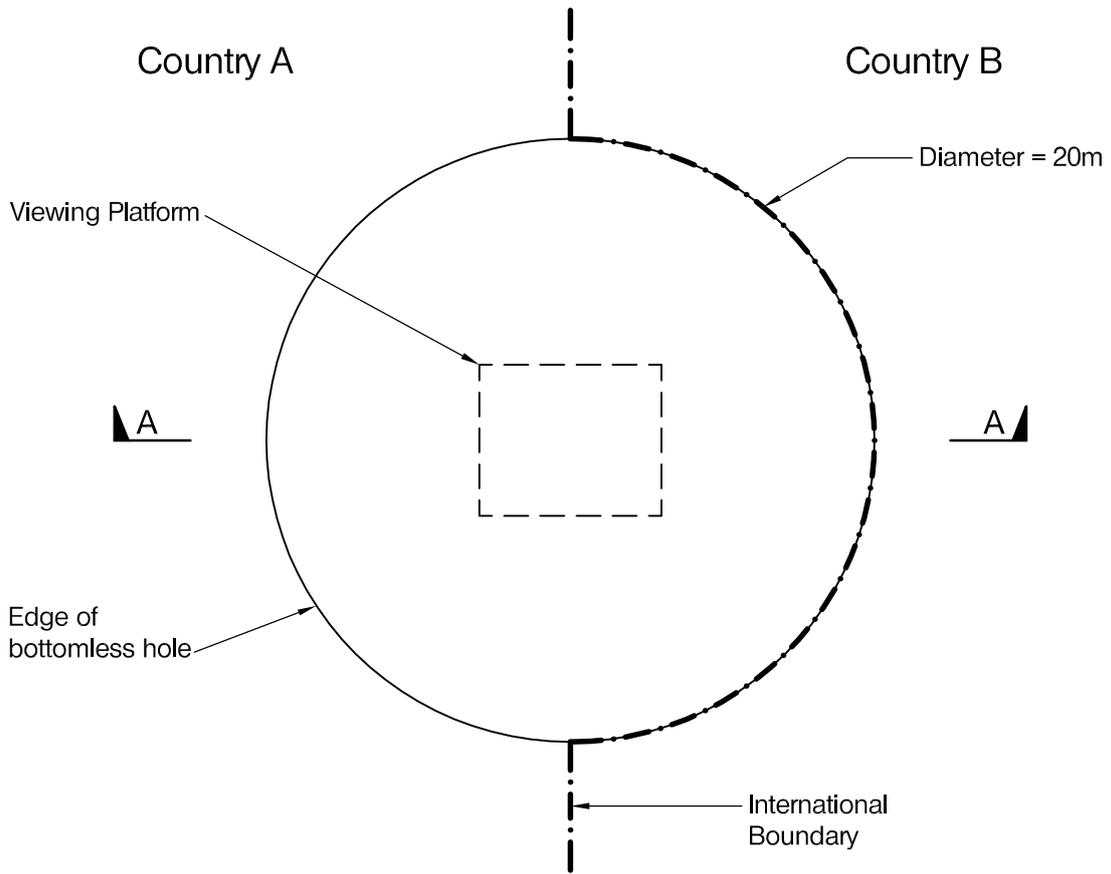
The unusual requirement of the examination is that you demonstrate the validity of the training and experience that you have acquired in recent years. The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of structural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

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

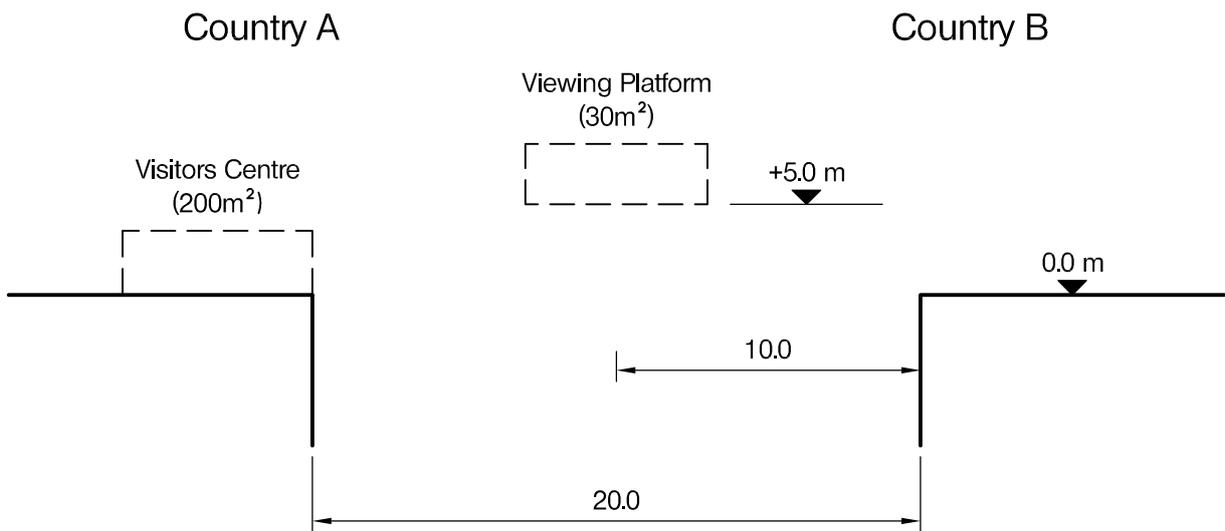
In selecting and developing your design you should also remember the guidance given in the Institution's report, Aims of Structural Design, and in particular:

- (1) "the structure must be safe",
- (2) "a good design has certain typical features – simplicity, unity and necessity",
- (3) "the structure must fulfil its intended function".

If you have difficulty in deciding the correct interpretation of a question, pay particular attention to point 6. notes to candidates, on the front cover. The examiners will take into account your interpretation – and the design you base on this – if this is clearly stated at the beginning of your answer.



PLAN



SECTION A - A

NOTE: All dimensions are in metres

FIGURE Q1

# Question 1. New visitors centre

## Client's Requirements

1. A 20.0m diameter bottomless hole sits on an international boundary between two countries.
2. Country A wishes to build a visitors centre and a connected viewing platform for tourists.
3. The visitors centre should provide 200m<sup>2</sup> of accommodation and the viewing platform should provide 30m<sup>2</sup> of space.
4. There are no limitations on headroom providing the structure remains usable
5. The centre of the viewing platform should be located directly over the centre of the hole.
6. The underside of the viewing platform should be 5.0m higher than the perimeter of the hole and allow unhindered views around three sides.
7. All structure, including foundations and temporary works, should be contained entirely within Country A.
8. The viewing platform is to contain two 2.0m<sup>2</sup> open sections through the floor for visitors to look down through.

## Imposed Loading

- |                            |                       |
|----------------------------|-----------------------|
| 9. All roofs               | 1.50kN/m <sup>2</sup> |
| 10. Visitors Centre Floor  | 4.0kN/m <sup>2</sup>  |
| 11. Viewing Platform Floor | 4.0kN/m <sup>2</sup>  |

## Site Conditions

12. The site is located in open countryside. Basic wind speed is 40m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20m/s.
13. Ground condition: 0 – depth. Dense, uniform rock, safe bearing pressure 1000kN/m<sup>2</sup>.
14. No ground water was encountered.

## SECTION 1

**(50 marks)**

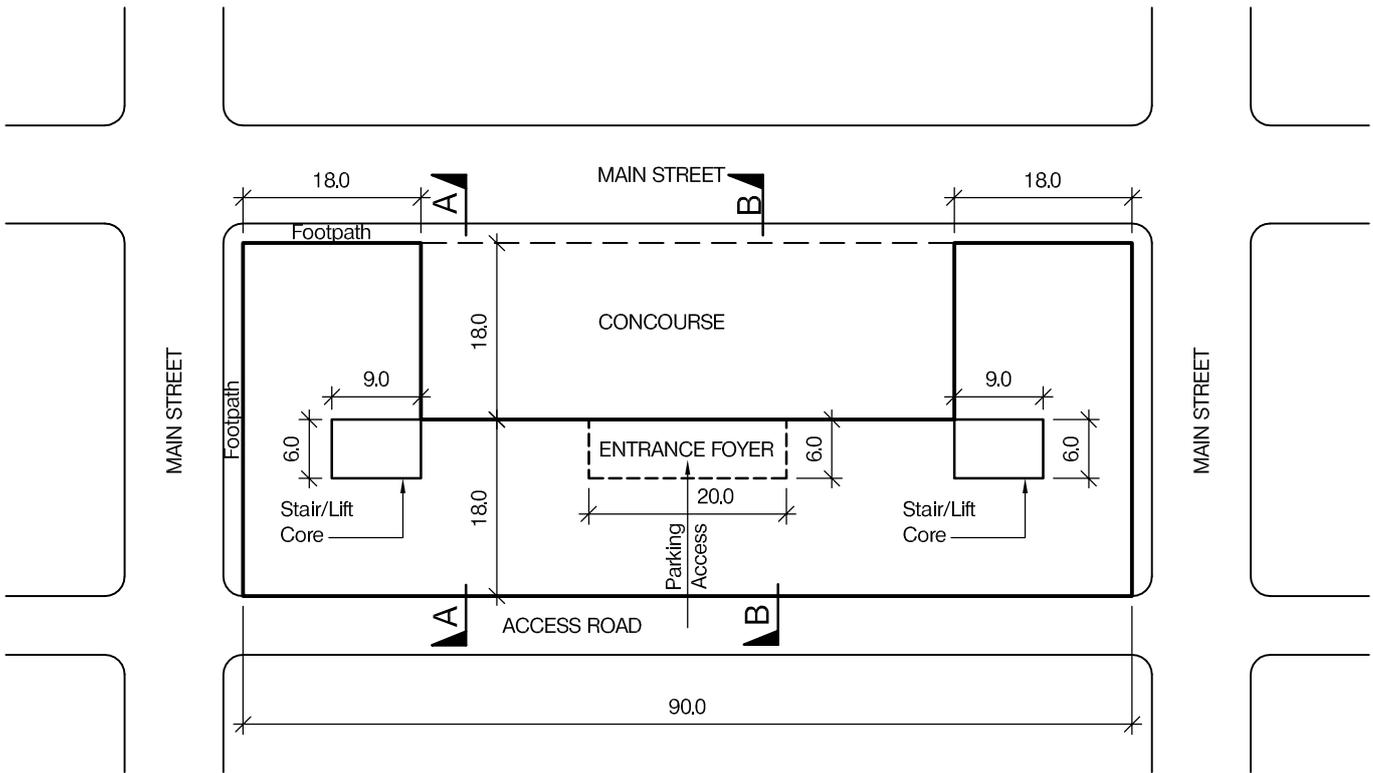
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After the design has been completed the client advises you that he has reached an agreement with Country B that allows construction of the centre to be placed anywhere around the perimeter of the bottomless hole. Write a letter to advise him of the implications of this agreement with regard to the design of the centre. (10 marks)

## SECTION 2

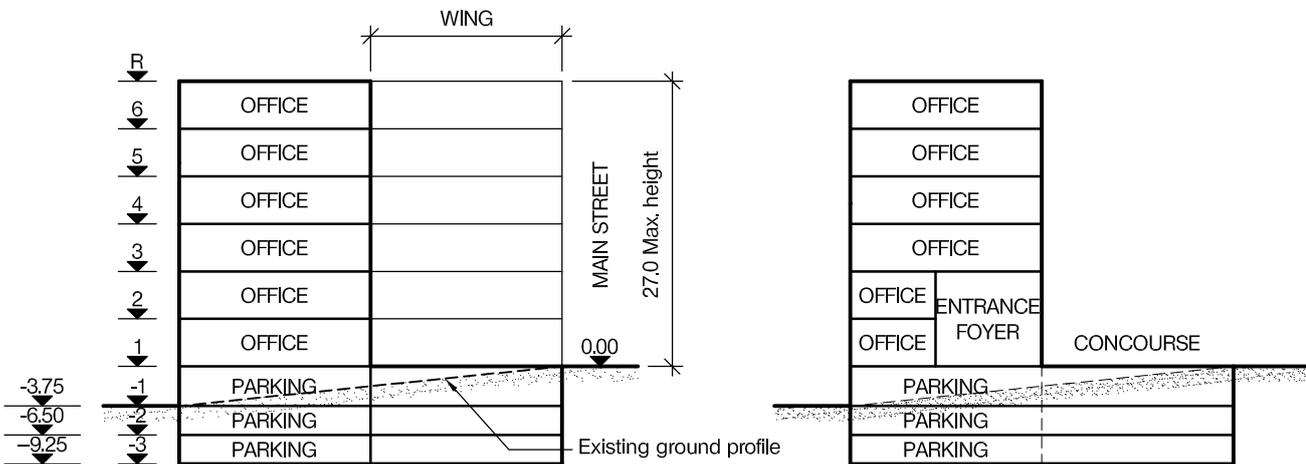
**(50 marks)**

For the solution recommended in Section 1(a)

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



LEVEL 1 PLAN



SECTION A-A

SECTION B-B

NOTE: All dimensions are in metres

FIGURE Q2

## Question 2. New city centre office block

### Client's requirements

1. A new city centre six-storey offices block with lower basement parking; see Figure Q2. The site is bounded by a public footpath on three sides and an access road at the rear. Main streets adjacent to the site are busy, and traffic flow is to be maintained during construction.
2. Two stair and lift cores extend the full height of the building. The front and concourse elevations will be fully glazed with no bracing permitted. 70% of the area of the side and rear elevations will be glazed and the remainder will be clad in stone panels.
3. Floor-to-ceiling heights in the office are to be 2.9m. A 0.55m-deep ceiling services zone is to be provided over each office floor. The maximum height of the eaves of the building above Level 1 is 27.0m. The clear storey heights in levels -1 to -3 are to be 2.25m. The structural zone for the ground floor (level 1) is 1.5m deep and for levels -1 and -2 floors it is 0.5m deep.
4. Car-parking bays are to be a minimum of 5.0m x 2.5m with aisles 6.9m wide for vehicle circulation.
5. One internal row of columns is permitted within the office floors, with columns spaced at least 7.5m apart centre-to-centre. There is no restriction on column locations in the car-park levels providing circulation is not impaired.

### Imposed Loading

6. Roof	1.5kN/m <sup>2</sup>
Office floors	5.0kN/m <sup>2</sup>
Concourse	5.0kN/m <sup>2</sup>
Car Park	2.5kN/m <sup>2</sup>

Loadings exclude allowances for floor finishes, ceilings and services.

### Site Conditions

7. The site is in a city centre location. Basic wind speed is 51m/s based on a 3-second gust; the equivalent mean hourly wind speed is 25.5m/s.
8. Ground Conditions
 

0 – 1m	Made ground
1.5 – 25m	Stiff clay C = 150kN/m <sup>2</sup>
Below 25m	Sandstone, safe bearing pressure 2,500kN/m <sup>2</sup>

Some ground water was encountered at 4.0m below ground level but seepage rates were low.

### Omit from consideration

9. Detailed design of staircases, lifts within cores, and car park access ramps.

### SECTION 1

**(50 marks)**

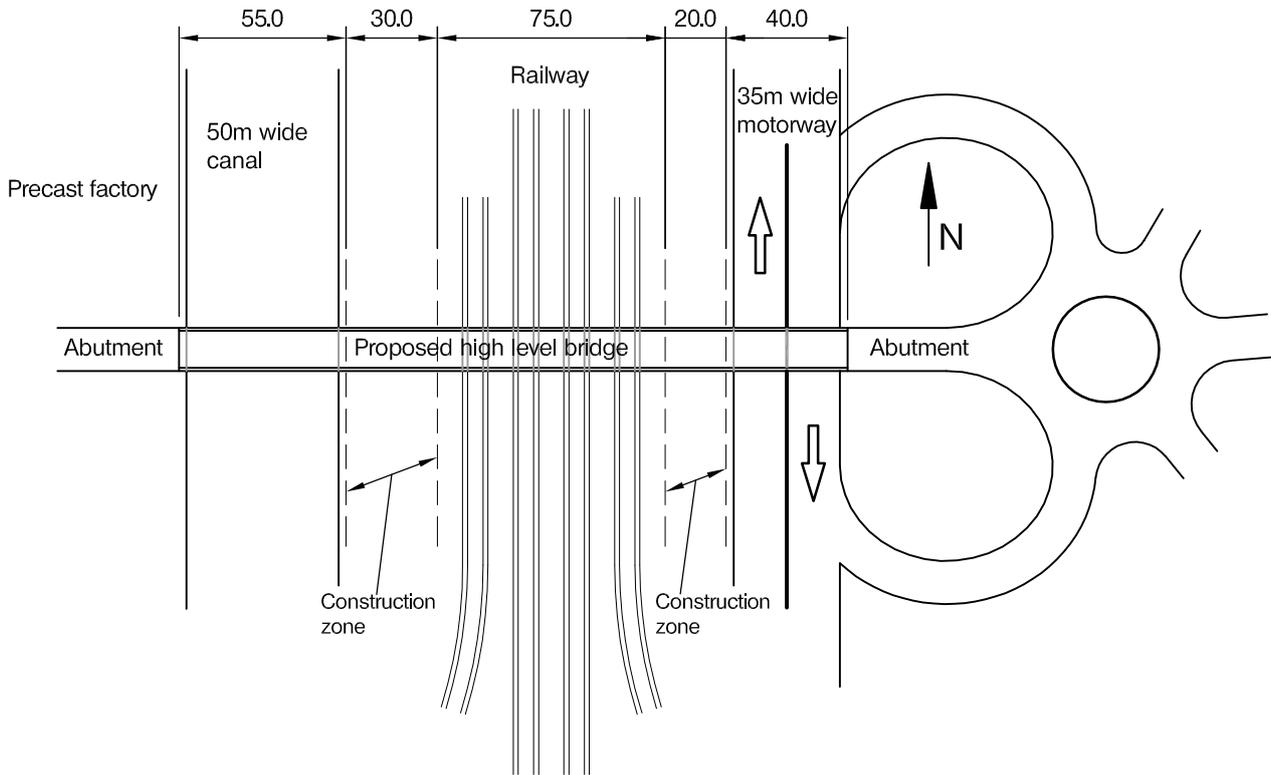
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the fundamental framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After completion of the design and before construction has started, the client advises that only one half of the building footprint is to be constructed as an initial phase. Write a letter to the client explaining the feasibility and impact of this proposal. (10 marks)

### SECTION 2

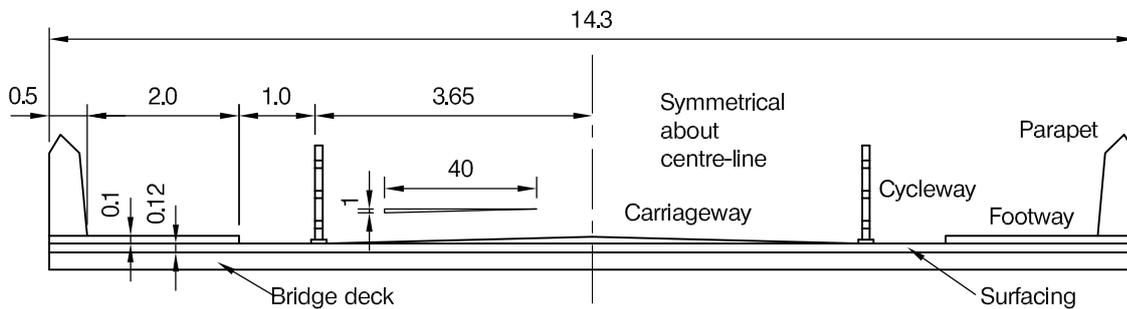
**(50 marks)**

For the solution recommended in Section 1(a):

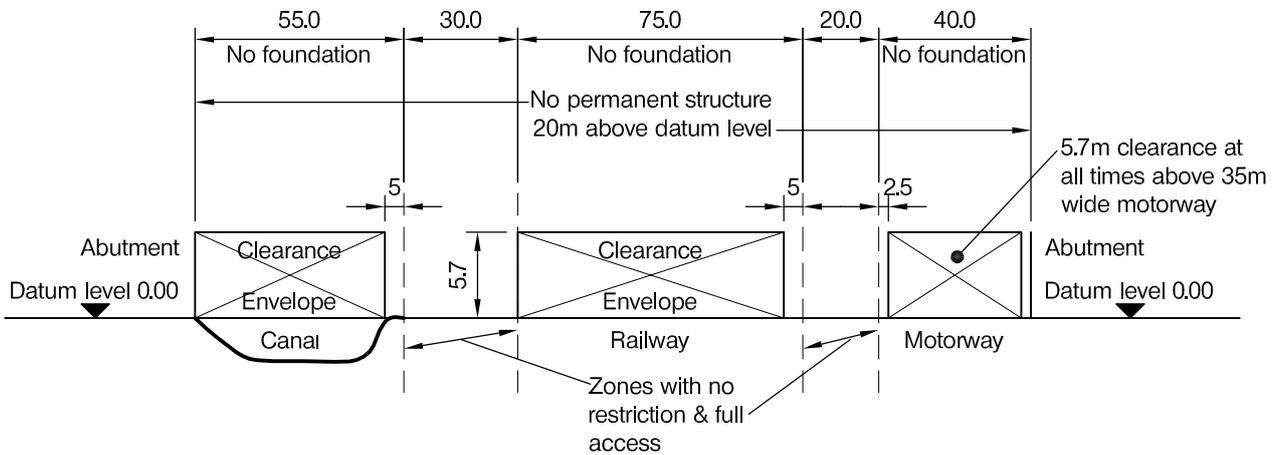
- c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)
- d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical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



SITE PLAN SHOWING PROPOSED BRIDGE ALIGNMENT TO CONNECT MOTORWAY



CROSS SECTION OF PROPOSED BRIDGE



LONGITUDINAL SECTION SHOWING CLEARANCE ENVELOPES

## Question 3. High level road bridge

### Client's requirements

1. A high level road bridge over a navigable canal, a busy railway and a motorway, to provide access between a precast concrete manufacturing factory and the motorway; see Figure Q3.
2. The site is near to an international airport. No part of the permanent structure may exceed 30.0m height above datum level. The road surface must not be higher than 9.0m above datum level. The approach roads at each abutment are at 8.5m above datum level.
3. Traffic may be halted on all three transport routes for one weekend each month between 11pm Saturday and 4am Monday. A 72-hour possession of all routes may be obtained once every 6 months.

### Imposed loading

4. Live load on bridge deck 10.0kN/m<sup>2</sup>

### Site conditions

5. The site is located near open sea. Basic wind speed is 56.0m/s based on a 3-second gust; the equivalent mean hourly wind speed is 28.0m/s.
6. Ground Conditions
 

0 – 10m	Stiff clay, $c = 200\text{kN/m}^2$
Below 10.0m	Sandstone, characteristic compressive strength 1,000kN/m <sup>2</sup>

### Omit from consideration

7. Longitudinal imposed loading. Design of the abutments.

### SECTION 1

**(50 marks)**

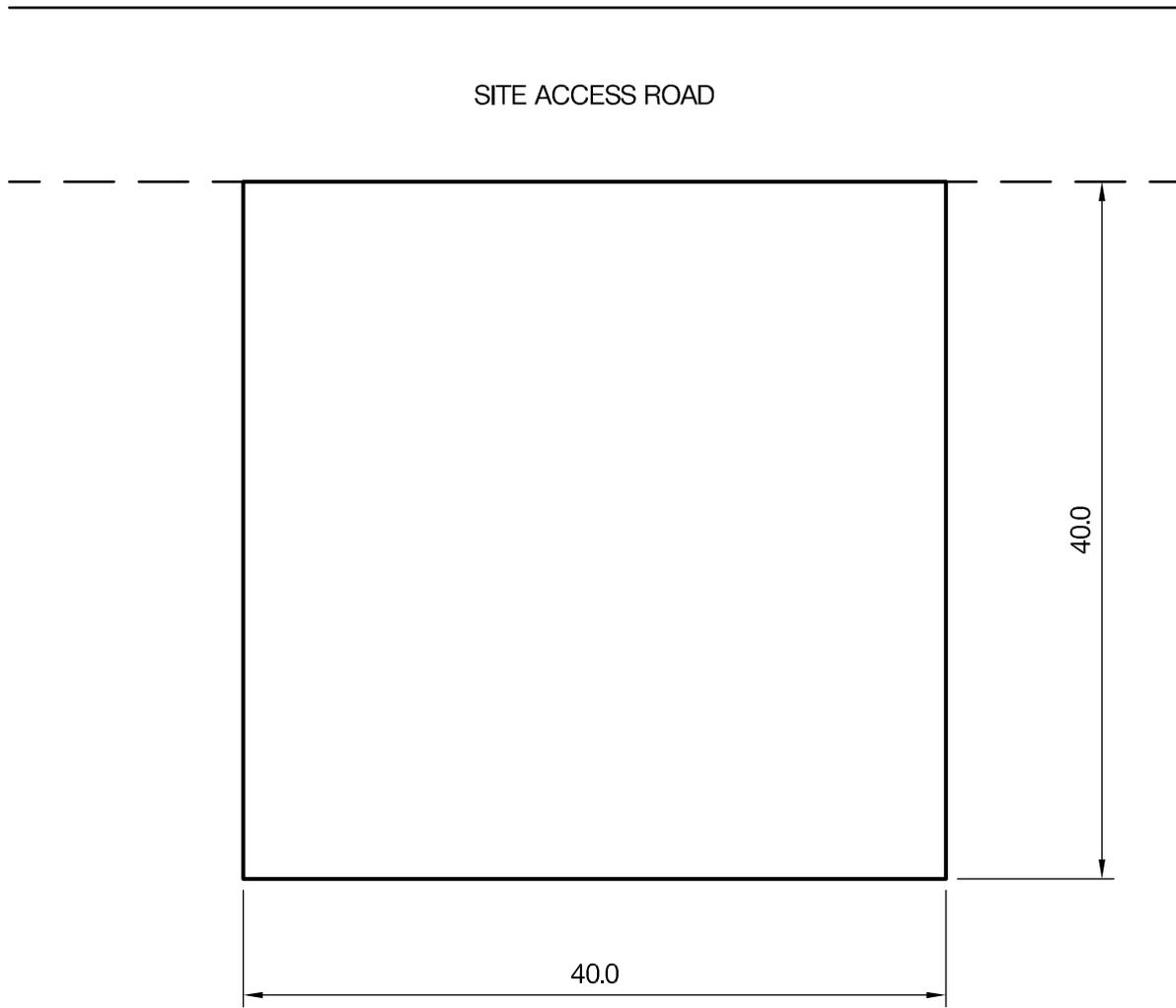
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After the completion of your design, the canal operator advises that owing to a change of use of the canal the deck of the bridge needs to accommodate an impact load of 3,000kN. Write a letter to the client to outline the changes required to the structure to accommodate this loading. (10 marks)

### SECTION 2

**(50 marks)**

For the solution recommended in Section 1(a):

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



SITE PLAN

NOTE: All dimensions are in metres

FIGURE Q4

## Question 4. Below ground pumping chamber

### Client's requirements

1. A buried pumping chamber is required for a large development. The site for the chamber is a level square plot 40.0m by 40.0m.
2. The chamber is to have a minimum volume of 1500m<sup>3</sup> and is required to be buried so that the upper surface of the chamber shall be 0.5m below ground level. The underside of the base of the chamber may not be deeper than 9.0m below ground level.
3. Once constructed, the only access to the chamber will be through a 2m x 2m hatch in the centre of the top of the chamber. This shall extend through the 0.5m soil cover above the chamber.
4. No internal columns are permitted inside the chamber.
5. No ground water ingress is acceptable into the chamber.
6. A minimum fire rating of 1 hour is required throughout.

### Imposed Loading

7. Roof of chamber 10kN/m<sup>2</sup> together with a point load of 100kN

### Site Conditions

8. The site is in open countryside. Basic wind speed is 46m/s based on a 3-second gust; the equivalent mean hourly wind speed is 23m/s.
9.
 

0 – 0.5m	Topsoil
0.5m – 7.0m	Sand, N = 10
7.0m – 20.0m	Gravel, N = 20
Below 20.0m	Rock, safe bearing pressure 500kN/m <sup>2</sup>

Ground water was encountered at 3.5m below ground level.

### Omit from consideration

10. Detailed design for hatch and cover.

### SECTION 1

**(50 marks)**

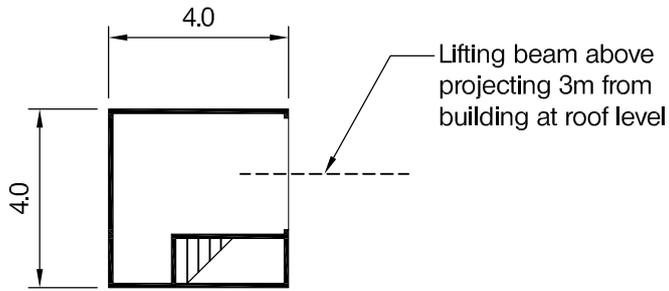
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After completion of the design and before construction has started, further site information is received which confirms that the ground water level can rise to 1.0m below ground level. Write a letter to the Client advising her of the implications on the design. (10 marks)

### SECTION 2

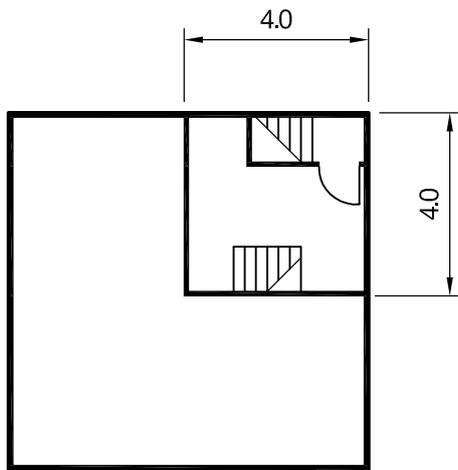
**(50 marks)**

For the solution recommended in Section 1(a):

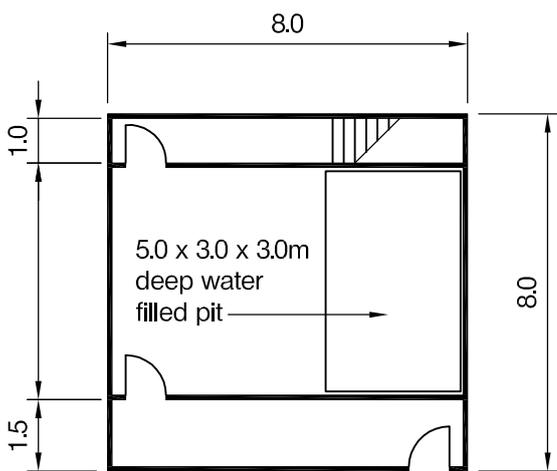
- c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)
- d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical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



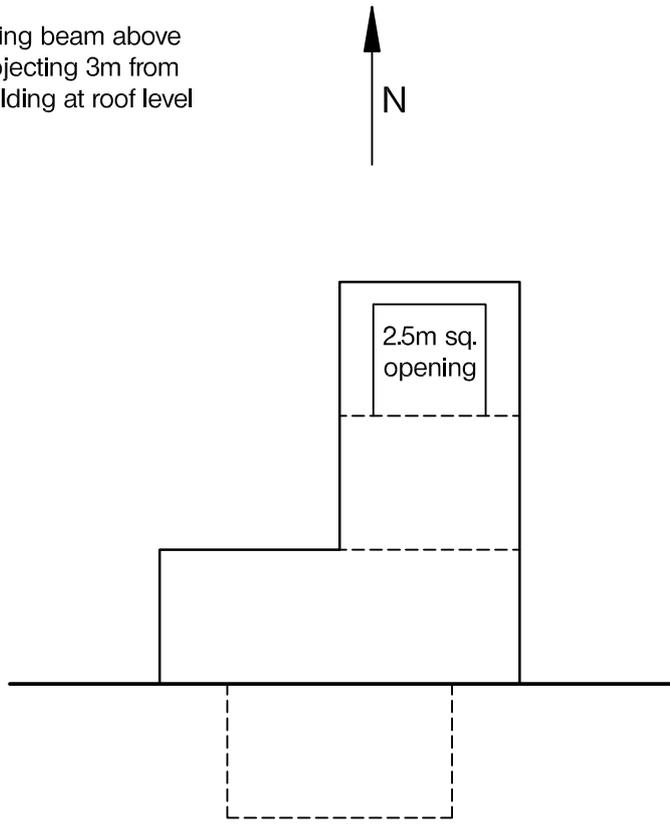
LEVEL 3 PLAN



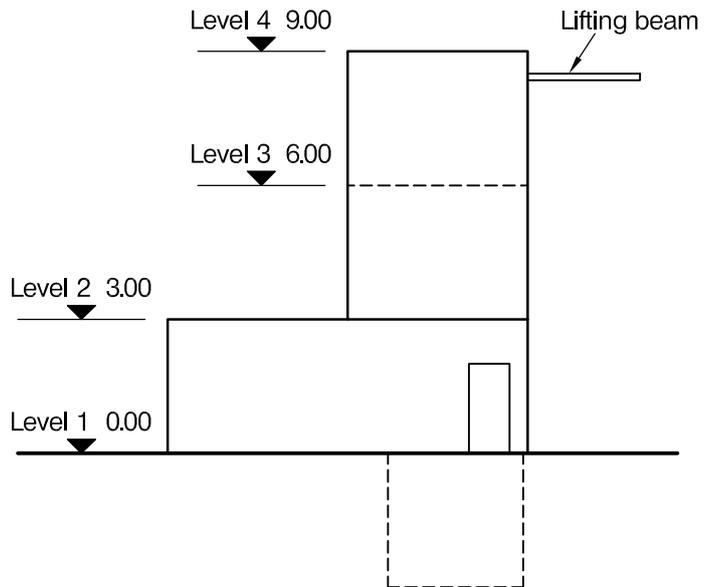
LEVEL 2 PLAN



LEVEL 1 PLAN



EAST ELEVATION



SOUTH ELEVATION

NOTE: All dimensions are in metres

FIGURE Q5

## Question 5. Fire fighter training building

### Client's Requirements

1. Construction of a building to train fire fighters; see Figure Q5.
2. The building comprises 3 levels that will be filled with smoke and achieve temperatures up to 200 deg C. At Level 3 is a rapid rise door that is used for emergency evacuation of smoke. Over Level 3 there is to be a lifting beam that projects 3m from the building face. The beam is to have a safe working load capacity of 5.0kN.
3. The minimum clear floor-to-ceiling height shall be 2.7m on each level.
4. A minimum of 2 hours fire resistance is required.
5. At Level 1 is a 5.0m long x 3.0m wide x 3.0m deep water filled pit which must be capable of being pumped out for maintenance
6. The site lies within a flood plain that regularly floods to a depth 300mm above the Level 1 slab

### Omit from Design

7. Stairs

### Imposed Loading

- |               |                      |
|---------------|----------------------|
| 8. All floors | 2.5kN/m <sup>2</sup> |
| Roof          | 0.8kN/m <sup>2</sup> |

### Site Conditions

9. The site is situated in open countryside. Basic wind speed is 46m/s based on a 3 second gust; the equivalent mean hourly wind speed is 23 m/s.
10. Ground conditions below ground level which is approximately level
 

Ground level to 1.8m	Soft Clay with a High organic content
1.8 -3.0m	Firm Clay, C = 70kN/m <sup>2</sup>
3.0m-6.0m	Stiff clay, C = 110kN/M <sup>2</sup>
Below 6.0m	Sandstone, safe bearing pressure 800kN/m <sup>2</sup>

Ground Water is not normally present but the site periodically floods

### SECTION 1

**(50 marks)**

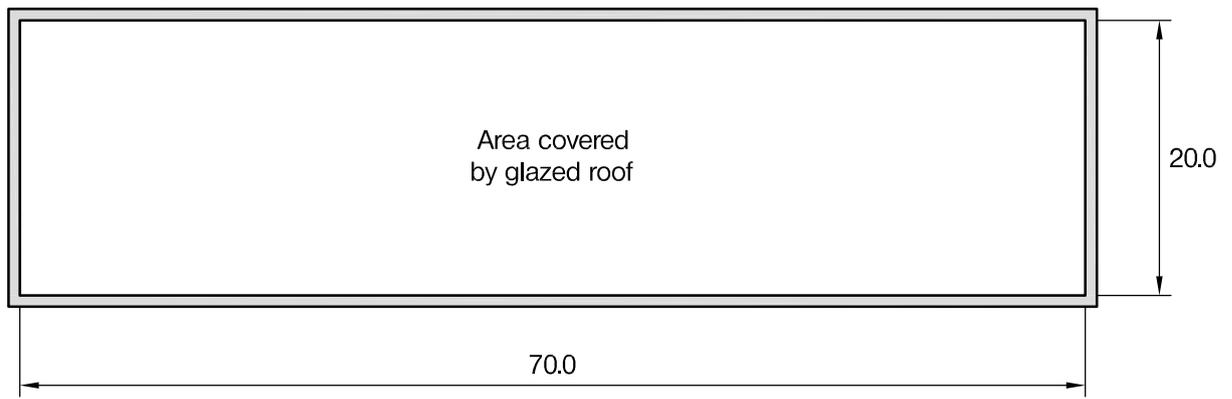
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After you have completed your design the client asks you to investigate the feasibility of installing a water tank on Level 2, 1.5 m deep with a plan dimension of 6m x 6m. Write a letter to your client explaining the implications of this potential change. (10 marks)

### SECTION 2

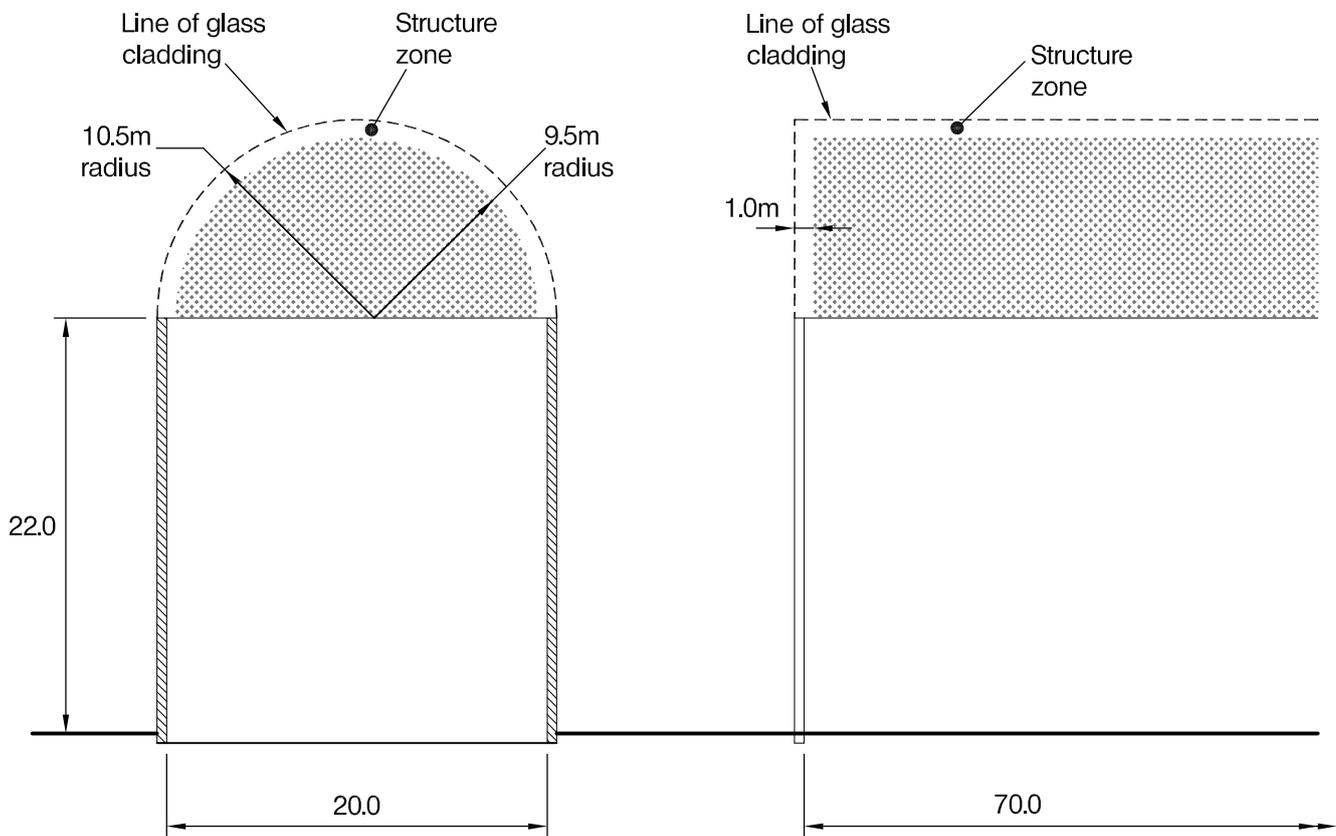
**(50 marks)**

For the solution recommended in Section 1(a)

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



PLAN OF ROOF AREA



SECTION ACROSS ENTRANCE

PART SECTION ALONG ENTRANCE

NOTE: All dimensions are in metres

FIGURE Q6

## Question 6. Glazed entrance to civic building

### Client's requirements

1. A new civic building is to have a free-standing entrance with a glazed roof: See Figure Q6
2. The glazing comprises cavity glass units 30.5 mm thick, weighing 0.30 kN/m<sup>2</sup>. All glass elements have a maximum size of 1.5m by 2.0 m. The glass units and panes may be supported by partial or complete framing or be point fixed. Mounting must be arranged so that any glass unit can be independently removed for maintenance.
3. The support system for the glass must present minimum interruption to light and should enhance the visual aspect of the roof. The support system must be entirely on the inside face of the glass, and is restricted to the structure zone indicated in Figure Q6.
4. The roof is to be supported around its perimeter on columns with foundations. The minimum spacing of adjacent columns is to be 10.0m. No internal columns are permitted but a 10.0m-wide zone is available outside each long side of the structure in which external bracing may be installed.

### Imposed loading

5. Imposed load on roof: 0.6 kN/m<sup>2</sup>, which applies up to a slope of 30° from the horizontal. This can be reduced pro-rata down to zero at a slope of 60° or more.
6. A maintenance point load of 0.5 kN applied normal to the glass anywhere on the glazed area.
7. Collision loading on any column: 5kN unfactored load applied horizontally at 1.5m above ground level in any direction

### Site conditions

8. The site is located on the edge of a town, close to the open country. Basic wind speed is 46 m/s based on a 3 second gust; the equivalent mean hourly wind speed is 23 m/s.
9. Ground Conditions:
 

Ground level – 5.0m	Very loose fill, N = 4
Below 5.0m	Sand, N = 20

### Omit from consideration

10. Detailed design of the glass units and panes.

### SECTION 1

**(50 marks)**

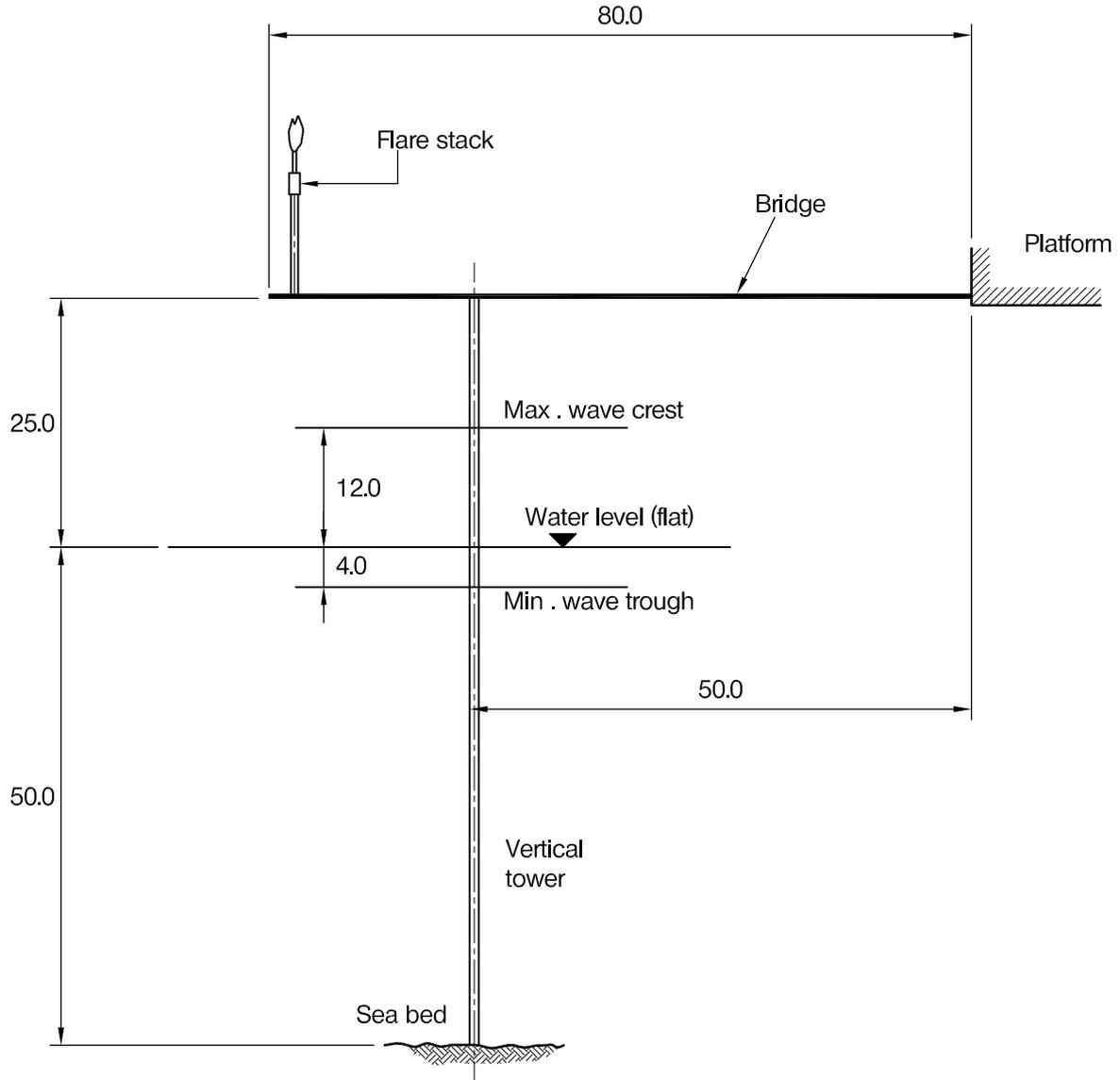
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After your design is complete, the client informs you that the collision load on columns has been increased to 50kN. Write a letter to your client advising of the implications of this change. (10 marks)

### SECTION 2

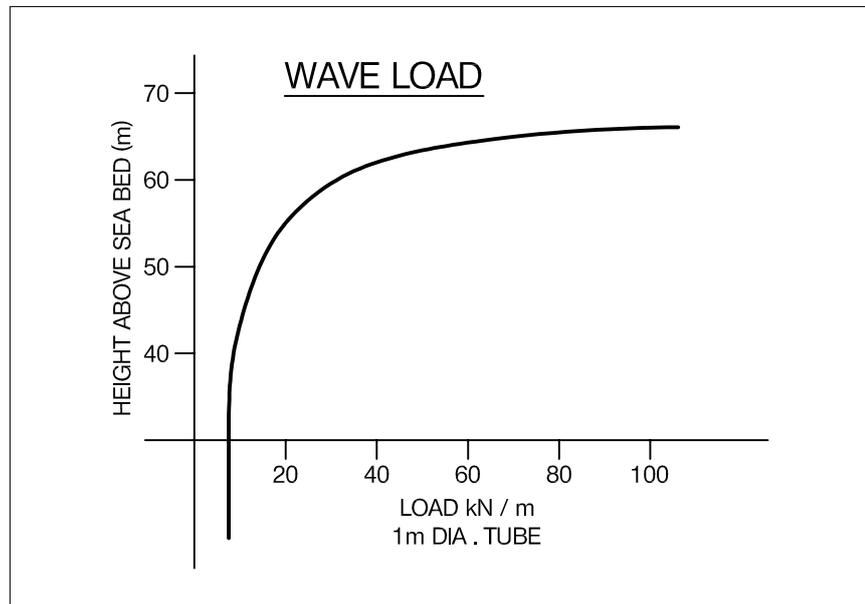
**(50 marks)**

For the solution recommended in Section 1(a):

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



ELEVATION



NOTE: All dimensions are in metres

FIGURE Q7

## Question 7. Flare structure

### Client's Requirements

1. A flare structure, consisting of a 80m bridge and a vertical support tower, is required to carry a main flare line from an existing platform to a new flare stack; see Figure Q7
2. The bridge is to support a flare stack weighing 50kN. (5 tonnes). The main gas pipe is 600 mm diameter x 25 mm wall thickness. A 100 mm diameter water pipe and a 50 mm diameter pilot pipe are also required. All pipes run the full length of the bridge. Walkway access is required to the flare stack.
3. The connection of the bridge to the existing platform is to allow for horizontal and vertical rotation of plus or minus 10 degrees.

### Site Conditions

4. Basic wind speed is 50 m/sec based on a 3-second gust; the equivalent mean hourly windspeed is 25m/s.
5. Extreme ice thickness is 50 mm, ice density 900 kg/m<sup>3</sup>
6. Wave loading profile is shown in Figure Q7.
7. Ground conditions. Dense fine sand.  $\phi = 35$  degrees.  $\delta = 30$  degrees.  $N_q = 45$

### Omit from consideration

8. Dynamic and fatigue checks.
9. Access requirements.

### SECTION 1

**(50 marks)**

- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed flare structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend giving reasons for your choice. (40 marks)
- b. Having received your recommended design, your client proposes that the tower structure be designed to resist ship impact forces of 0.5 MJ (operational) and 4.0 MJ (accidental). 1 MJ = 100 tonne.m.  
Write a brief illustrated design note to your client explaining the structural implications this would have on your design. (10 marks)

### SECTION 2

**(50 marks)**

For the solution recommended in Section 1(a):

- c. Prepare sufficient design calculations to establish the form and size of all principal structural elements taking into account both temporary and permanent conditions. (20 marks)
- d. Prepare general arrangement plans, elevations and sections to show the dimensions, layout and disposition of the structural elements, as required for estimating purposes.  
Prepare detailed, annotated sketches to illustrate the following connections for a designer to produce detailed CAD drawings
  - Bridge to platform connection
  - Bridge to tower connection
 (20 marks)
- e. Prepare a detailed method statement for the safe transport and installation of the flare structure at the field location. (10 marks)





The Institution of Structural Engineers  
International HQ  
47-58 Bastwick Street  
London, EC1V 3PS  
United Kingdom  
tel: +44 (0)20 7235 4535  
[mail@istructe.org](mailto:mail@istructe.org)  
[www.istructe.org](http://www.istructe.org)  
Registered Charity