

# Chartered Membership Examination

Friday, 7 July 2017

## 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. Candidates should note that Figures are produced to illustrate the question and are not necessarily drawn to scale. Figured dimensions should be followed.
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.

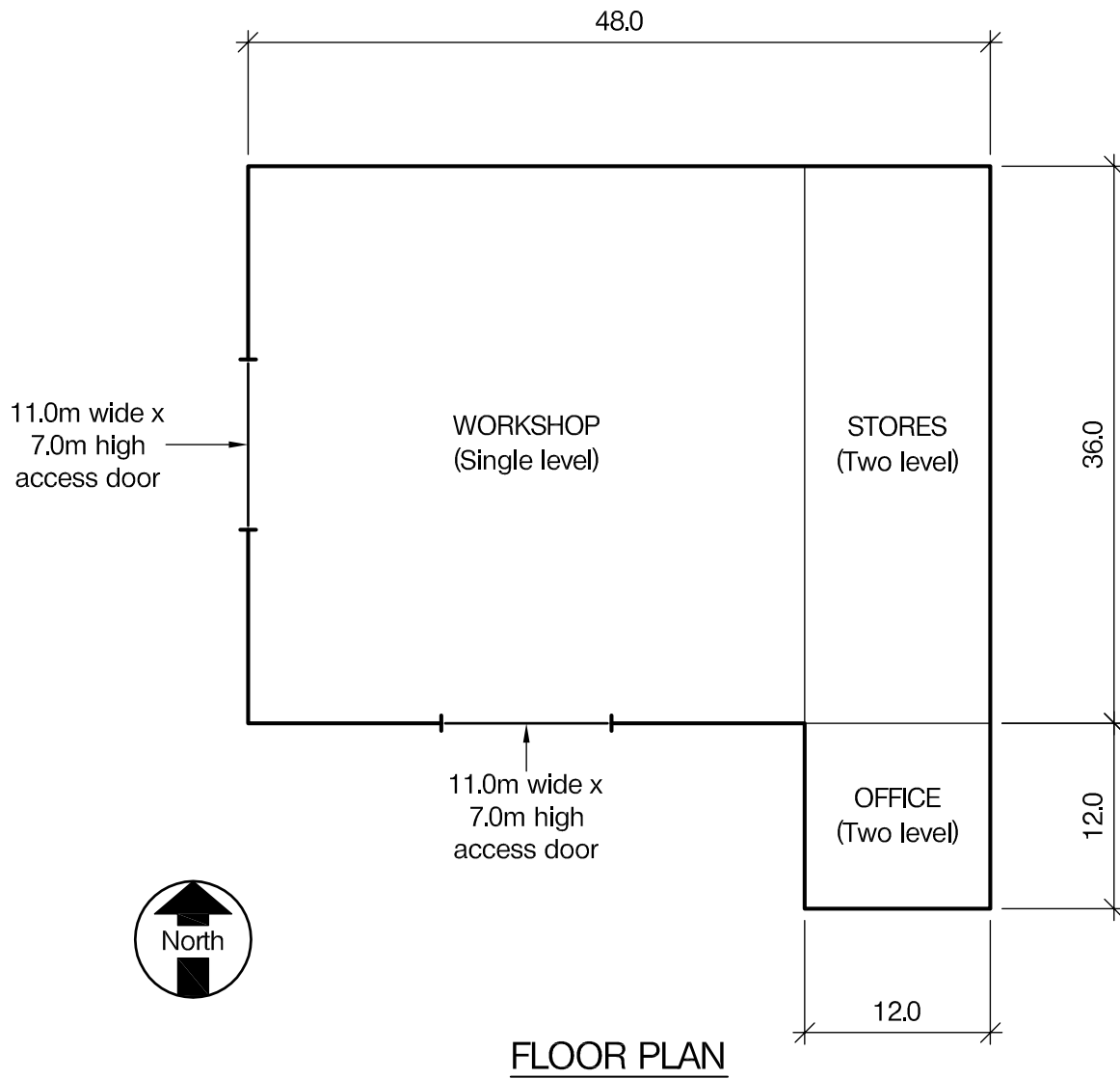
The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of structural design problems – whether or not the problem is presented in terms that are within your actual experience.

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 understood the general structural engineering principles involved.

In selecting and developing your design you should also remember the guidance given in the Institution's report, Structural design - achieving excellence, 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.



# Question 1. Steel fabrication unit

## Client's requirements

1. A steel fabricator is to construct a new workshop with offices and stores. A crane with a safe working load of 15 tonnes will provide full coverage of the workshop area, which is to be column-free. See Figure Q1.
2. Two doors each 11.0m wide x 7.0m high are to be provided in the west and south elevations.
3. The elevations for the whole development including the roof are to be in lightweight construction using metal cladding. Roof lights are to be provided over 20% of the roof area.
4. The maximum overall height of the workshop is to be limited to 15.0m. The maximum spacing of perimeter columns is to be 10.0m. The office and store areas are each to have two levels with a minimum floor to floor height of 4.0m.
5. The minimum hook approach is to be 1.5m. The overall depth of the crane including hoist is to be 1.5m with a clear height of 8.0m from floor level to the underside of the crane bridge.

## Imposed loading

6. Roof	0.75 kN/m <sup>2</sup>
Office floors	5.0 kN/m <sup>2</sup>
Factory floor	50.0 kN/m <sup>2</sup>
Stores	10.0 kN/m <sup>2</sup>
Crane weight	200 kN
Hoist unit	20 kN

## Site conditions

7. The site is located in the country. Basic wind speed is 48m/s based on a 3-second gust; the equivalent mean hourly wind speed is 24m/s.
8. Ground conditions are consistent across the site:
 

0 – 1.0m	top soil / fill
1.0m – 2.0m	loose gravel, N = 4
Below 2.0m	dense sand and gravel N = 25

 Ground water was encountered 3.0m below ground level.

## Omit from consideration

9. Detailed design of the crane rails, and stairs for the office/stores.

## SECTION 1

(50 marks)

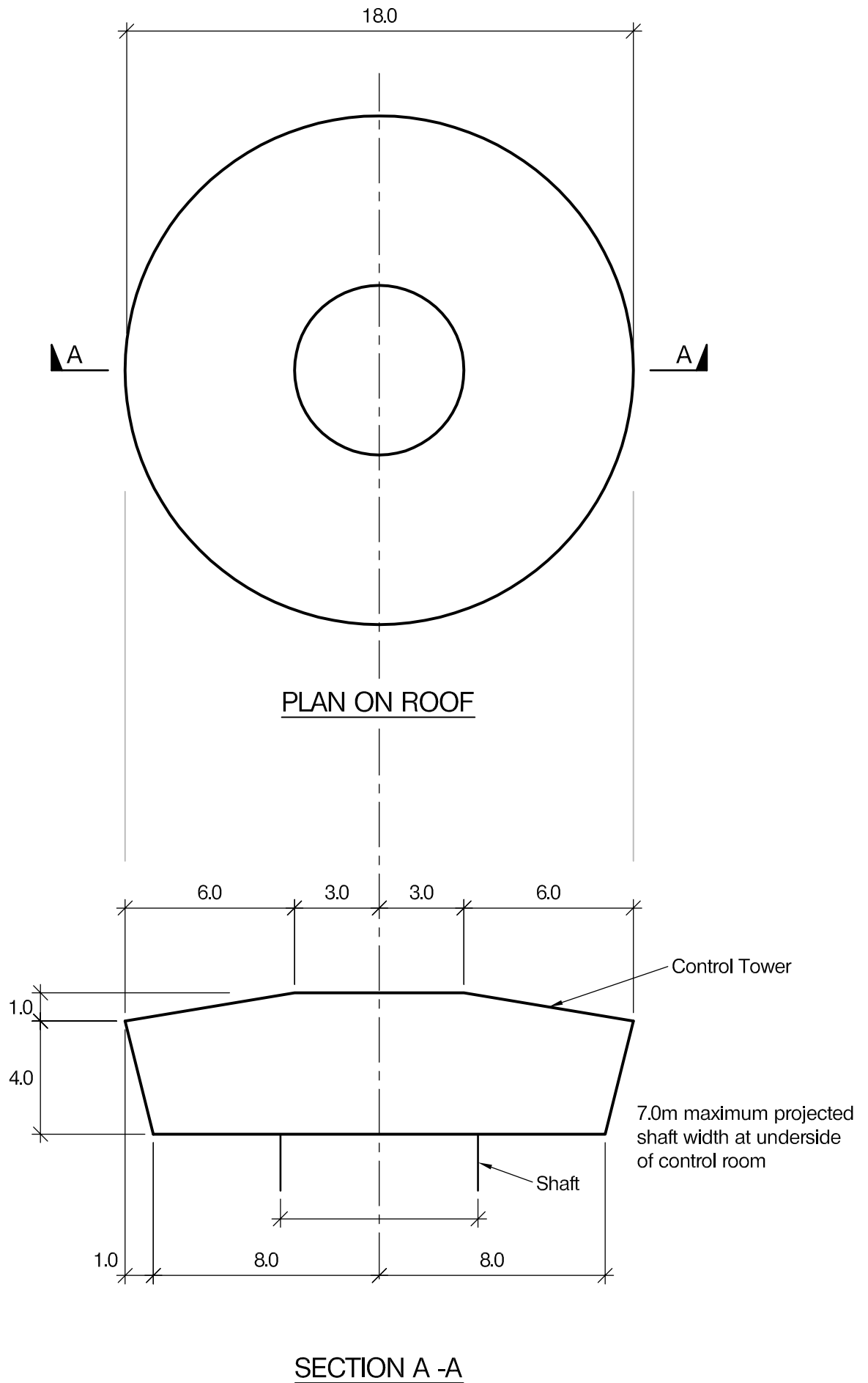
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After the workshop has been built, and due to an increase in workload, the Client needs to replace the existing crane with a higher capacity one capable of lifting up to 30 tonnes. Write a letter to the Client explaining how this can be achieved. (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 an erection sequence showing how temporary stability is maintained throughout construction of the building. (10 marks)



NOTE: All dimensions are in metres

FIGURE Q2

## Question 2. Airport Control Tower

### Client's requirements

1. A new control tower with an elevated control room: see Figure Q2.
2. The support and access to the control room is to be provided by a central shaft housing a lift of external dimensions 2.5m x 2.5m and a staircase with a minimum width of 1.0m. The maximum projected width of the shaft at the underside of the control room is to be 7.0m.
3. The control room is to have a minimum internal height of 3.0m and the floor area outside the central shaft is to be column-free.
4. The central 6.0m-diameter section of the control room roof is to be flat to accommodate plant and equipment.
5. The control room is to be located at a minimum height to the underside of 20.0m above the existing ground level to achieve an unobstructed view of the surrounding area.
6. The perimeter of the control room is to be fully glazed with minimal obstructions.
7. The client requires the control tower to be aesthetically pleasing.

### Imposed loading

- |                    |                       |
|--------------------|-----------------------|
| 8. Roof            | 0.75kN/m <sup>2</sup> |
| Roof plant area    | 2.5kN/m <sup>2</sup>  |
| Control room floor | 5.0kN/m <sup>2</sup>  |

### Site conditions

9. The site is level and in a rural location. Basic wind speed is 46m/s based on a 3-second gust; the equivalent mean hourly wind speed is 23m/s.
10. Ground conditions:
 

0 – 1.0m	top soil
1.0m – 2.5m	sand and gravel N = 8
2.5m - 8.0m	sand and gravel N = 15
Below 8.0m	sandstone, allowable bearing pressure 1,500kN/m <sup>2</sup>

 No ground water was encountered

### Omit from consideration

11. Detailed design of lift and stairs within core.

### SECTION 1

(50 marks)

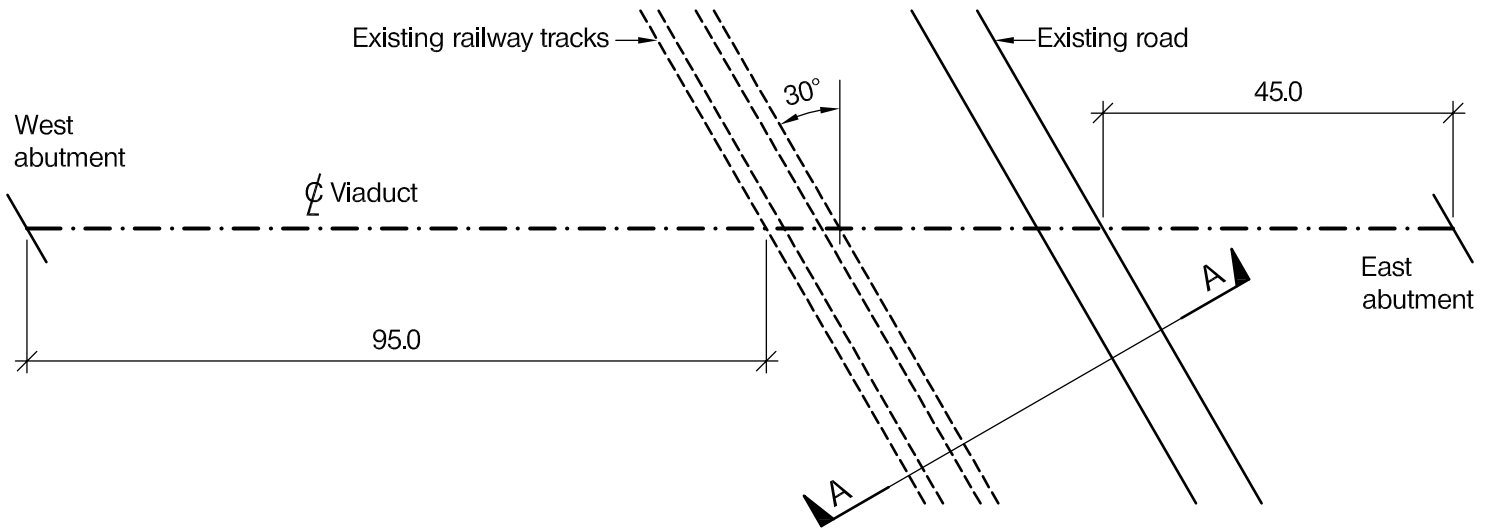
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After the design has been completed the Client advises that they wish to increase the maximum diameter of the control room to 20.0m and the minimum height to the underside to 25.0m. Write a letter to the Client explaining the effect this would have on the design and how this requirement may be accommodated. (10 marks)

### SECTION 2

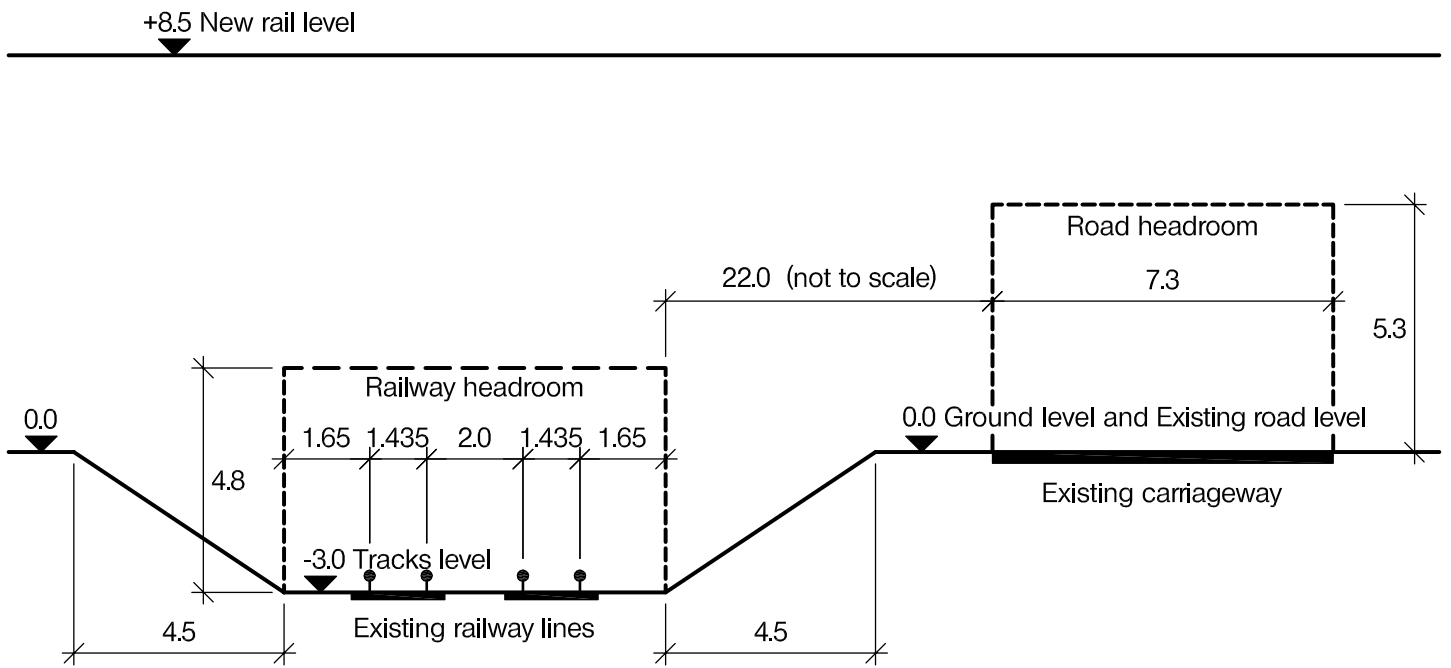
(50 marks)

For the solution recommended in Section 1(a):

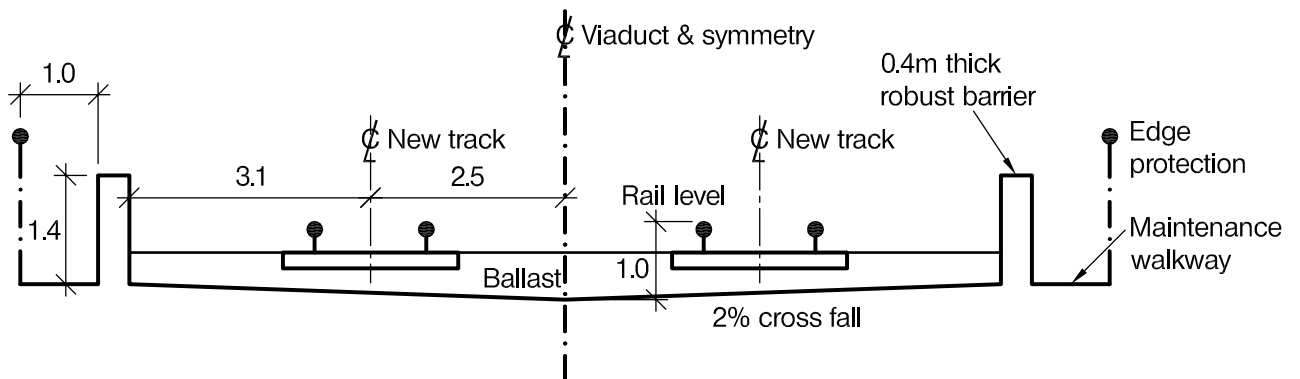
- c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)
- d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical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



PLAN VIEW



SECTION A -A  
(square to rail and road)



TYPICAL DECK CROSS SECTION

NOTE: All dimensions are in metres

FIGURE Q3



## Question 3. Railway Viaduct

### Client's requirements

1. A railway viaduct is proposed in a rural area. The new viaduct crosses a cutting, with two existing rail tracks and an existing road, at a high skew: see Figure Q3. Due to planning requirements, a height restriction has been imposed and the new structure must not rise more than 3.0m above the new rails.
2. The new deck is to carry two ballasted tracks with concrete kerbs and maintenance access walkways. See Figure Q3. The alignment is to remain horizontal over the length of the viaduct with abutments designed and built under a separate contract and skewed at 30 degrees. The top of the bankseat will be +5m and no longitudinal forces may be carried on the abutment.
3. A minimum horizontal clearance of 4.5m is to be maintained between the edge of the existing running rails and the face of any new bridge pier. The horizontal clearance to the edge of the existing carriageway must be at least 2.5m in order to satisfy sight distance requirements. The required minimum headroom is 4.8m above the existing tracks and 5.3m above the existing road.
4. The existing railway is to remain in service as much as possible during the construction of the new viaduct. The existing tracks may be closed between 22:00 hours on Saturday evening to 06:00 hours on the following Sunday morning for a maximum of 8 times in a year. The existing road can be temporarily diverted during the works but the most acceptable designs are those that will involve minimum traffic disruption.

### Imposed loading

5. Vertical loading for each track of 100 kN/m together with a single vertical point load of 350 kN per track (including dynamic effects). Horizontal braking load and traction load of 20 kN/m per track. Traction may occur on one track at the same time as braking on the other.
6. The ballasted tracks impose a load of 15.0 kN/m<sup>2</sup> on the bridge superstructure.
7. A nominal vertical live load of 1.5 kN/m<sup>2</sup> is to be considered on the maintenance walkways with a lateral load of 0.5 kN/m for the edge protections.

### Site conditions

8. 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.
9. Ground conditions:
 

0 – 0.3m	Top soil/made ground
0.3m – 3.0m	Sands and Gravels, N = 15
3.0m – 20.0m	Dense Gravels, N = 40
Below 20.0m	Rock, characteristic compressive strength 2,500 kN/m <sup>2</sup>

Ground water was encountered 5.0m below ground level.

### Omit from consideration

10. Design of tracks, detailed consideration of wind loading and detailed consideration of rail-structure interaction under horizontal loading.

### SECTION 1

**(50 marks)**

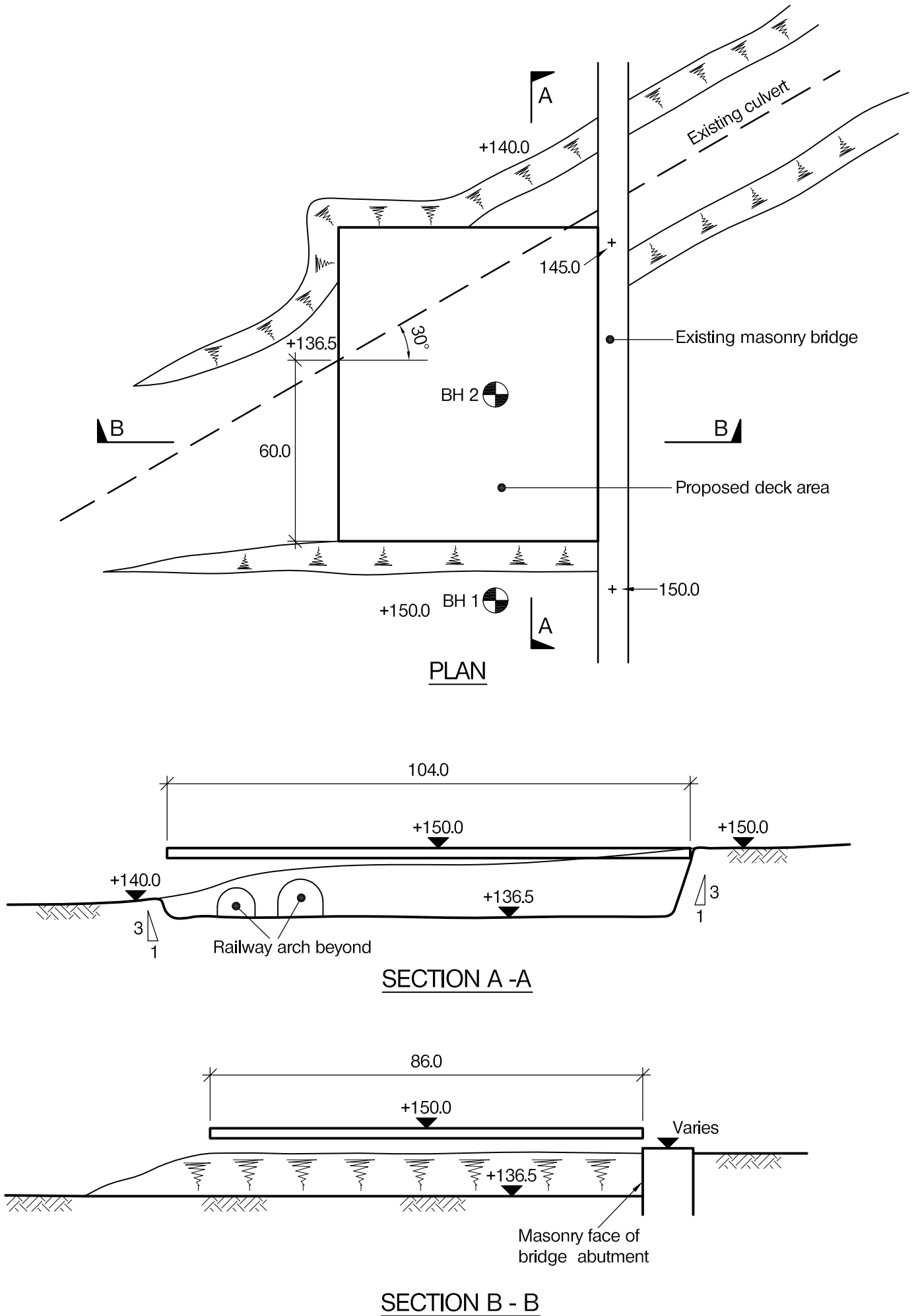
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After your recommended solution has been accepted in principle, the Client asks that the horizontal clearance to the west of the existing tracks be increased by an additional 5.0m. Write a letter to the Client explaining the design implications and advising in which ways the design would need to be modified to accommodate this change. (10 marks)

### SECTION 2

**(50 marks)**

For the solution recommended in Section 1(a):

- a. 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 viaduct and an outline construction programme. Identify any rail closures requirements and any principal temporary works necessary during the works. (10 marks)



NOTE: All dimensions are in metres

**FIGURE Q4**

## Question 4. Supermarket Deck

### Client's requirements

1. A suspended deck to support a future supermarket development over a former railway yard; see Figure Q4. The single-storey supermarket will cover the entire area of the deck and will be constructed on a 6.0m x 6.0m column grid.
2. The supermarket deck is to have a footprint of 104.0m x 86.0m and a top level of +150.0m above site datum.
3. The railway yard is at a level of +136.5m and was constructed over former mine workings. The slopes to the north and south sides of the railway yard are unstable and require new retaining walls to be provided. To the east of the site an existing bridge runs parallel to the deck.
4. A culvert runs across the railway yard and no foundations are permitted within 2.5m of its centreline.
5. The area below the deck is to be used for parking heavy goods vehicles. Columns are to be positioned to accommodate movement of the heavy goods vehicles and are to be designed to resist an impact loading

### Imposed loading

6. Imposed loading for the supermarket deck and the parking area below = 10 kN/m<sup>2</sup>.  
Allow unfactored dead loads on the deck of 200kN at each supermarket column position plus a perimeter line load of 50.0kN/m.  
Impact load to columns supporting the deck to be 500kN applied at a height of 2.0m above ground level.

### Site conditions

7. The site is located on the outskirts of a large city. The basic wind speed is 48 m/s based on a 3-second gust; the equivalent mean hourly wind speed is 24 m/s.
8. Ground Conditions (relative to site datum)
 

Borehole 1	
150.0m – 149.7m	fill
149.7m - 140.0m	loose, highly weathered sandstone
140.0m – 134.0m	alternate bands of sandstone and mudstone, safe BP 600-1,000kN/m <sup>2</sup>
134.0m - 132.0m	loosely-packed waste
Below 132.0m	sandstone, safe Bearing Pressure 2,000 kN/m <sup>2</sup>
Borehole 2	
136.50m – 134.0m	alternate bands of sandstone and mudstone, safe BP 600 – 1,000 kN/m <sup>2</sup>
134.0m - 132.0m	loosely-packed waste
Below 132.0m	sandstone, safe Bearing Pressure 2,000 kN/m <sup>2</sup>

### Omit from consideration

9. Supermarket superstructure.  
Interaction with existing bridge structure.

### SECTION 1

**(50 marks)**

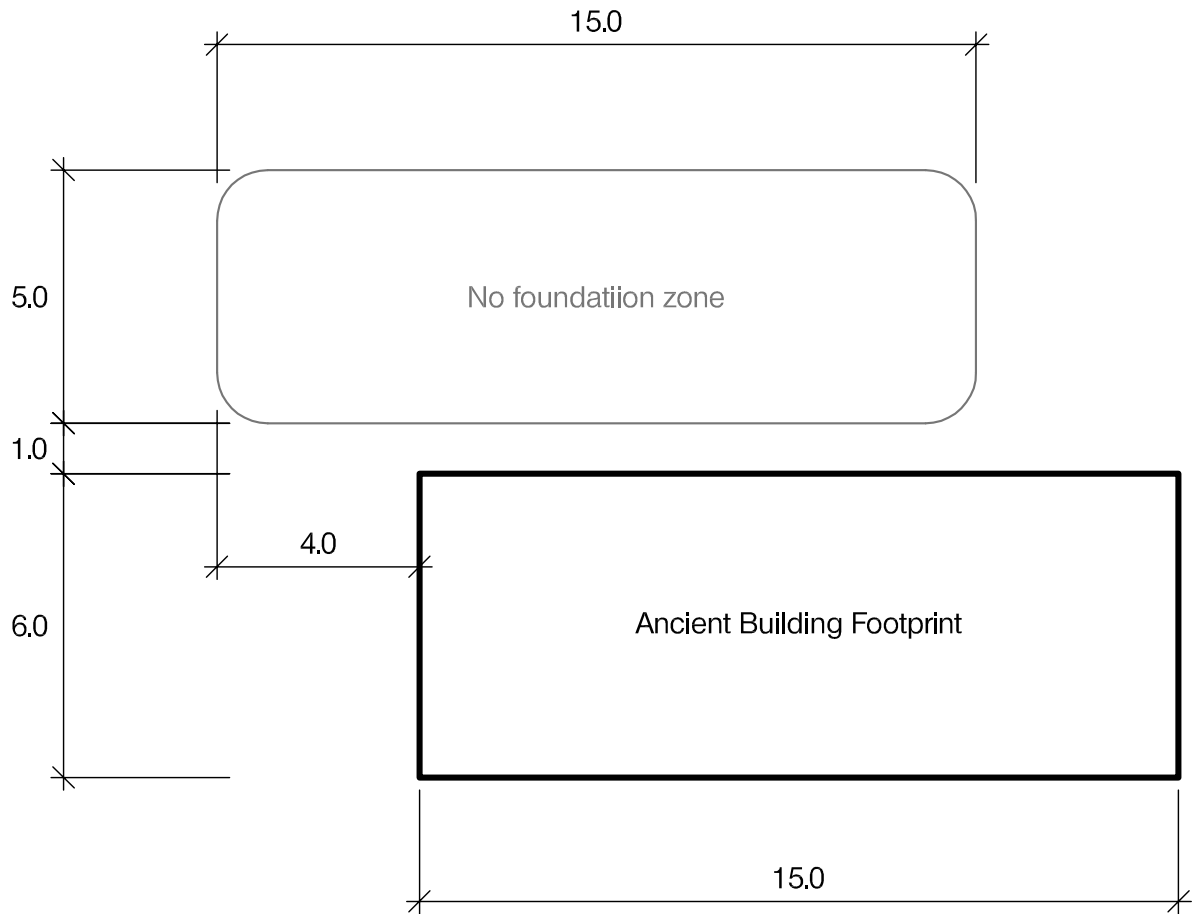
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After the design has been completed the Client asks for 4.0m-square openings to be provided at each corner of the deck within 1.0m from the deck edge to accommodate service routing. Write a letter advising the Client of the implications 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 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)



NOTE: All dimensions are in metres

FIGURE Q5

## Question 5. Protection for Ancient Building

### Client's requirements

1. An ancient building 3,000 years old is named within a World Heritage classification and needs to be protected from the weather to preserve it for future generations: see Figure Q5.
2. The ancient building is 15.0m long, 6.0m wide, and 5.0m tall and is constructed from compacted mud.
3. The ancient building is fragile and valuable, and must not be damaged or have loads applied to it either in the temporary or permanent condition.
4. A minimum clear perimeter of 2.0m should be provided around all sides of the ancient building.
5. Foundations must not be positioned within the zone shown in Figure Q5 due to the presence of subterranean caverns. The caverns are of historical interest and must not be disturbed.
6. The building must remain as visible as possible from the outside to maintain the World Heritage classification.
7. The internal environment needs to be climatically controlled and a 10m<sup>2</sup> plant room weighing 50kN should be provided on the roof.

### Imposed loading

8. Access and maintenance loads 1.5kN/m<sup>2</sup>  
Plant room 7.5kN/m<sup>2</sup>

### Site conditions

9. 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.  
Ground conditions are well-cemented, dense, uniform rock, N=80.  
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 the subterranean cavern extends further than previously thought, and that the foundation-free zone is therefore to be extended eastwards by 4.0m. Write a letter to advise the Client of the implications of this with regards to the design of the structure. (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)

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