

# Chartered Membership Examination

Thursday 4 July 2019

## 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. Clear drawings and sketches are required. They do not have to be to a defined scale, but should be in proportion.
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.

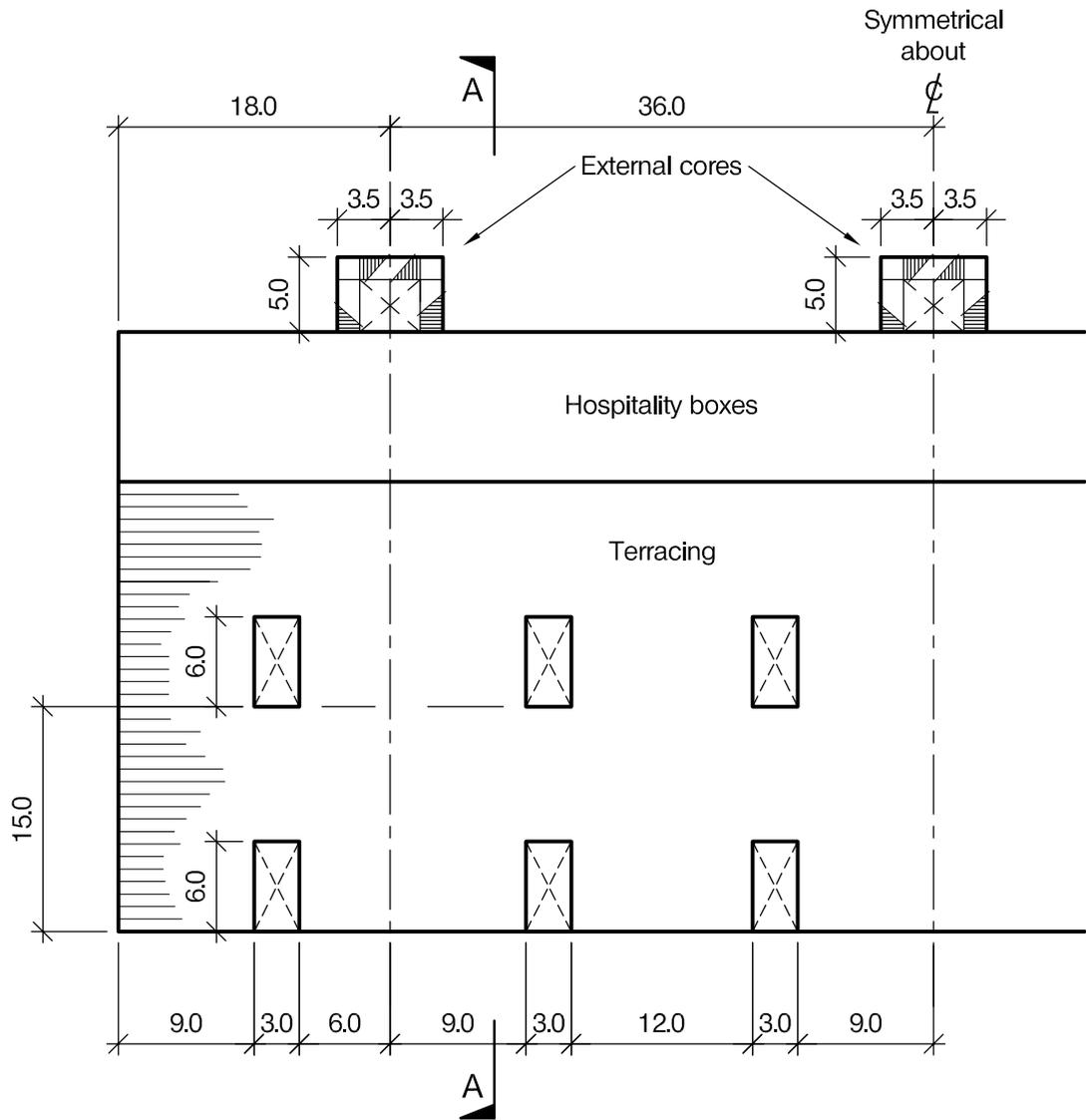
The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of structural design problems whether or not the problem is presented in terms that are within your actual experience.

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.

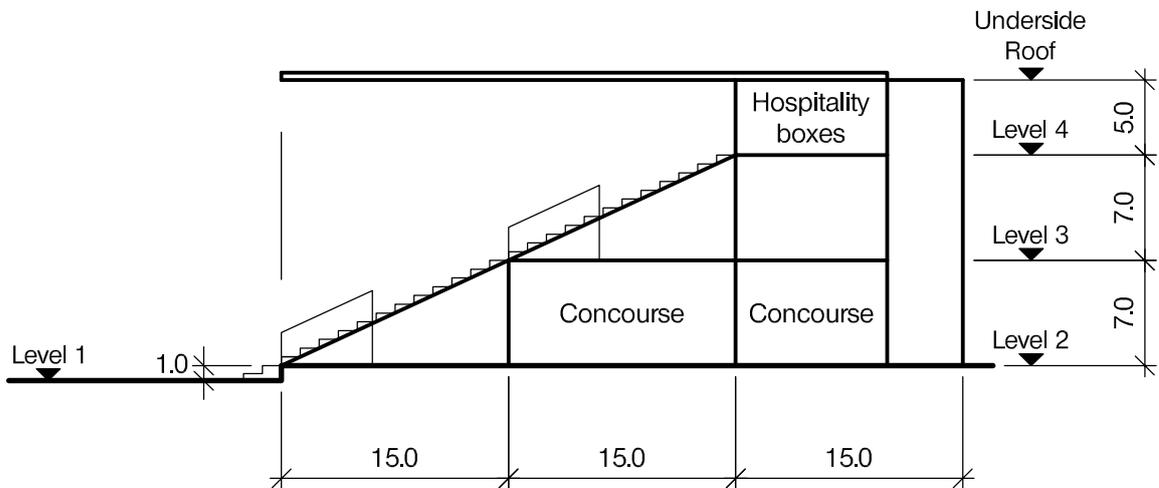
In selecting and developing your design you should also remember the guidance given in the Institution's report, Structural design - achieving excellence, and in particular:

- (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.



PLAN AT LEVEL 4



SECTION A - A

NOTE: All dimensions are in metres

FIGURE Q1

# Question 1. New stadium stand

## Client's requirements

1. A new three-storey stand with continuous terracing and hospitality facilities. See Figure Q1.
2. The stand is to have two floors of continuous terracing with access concourses to the rear.
3. Access to the terracing from the concourse is by access tunnels measuring 6.0 metres x 3.0 metres.
4. At Level 4 there is to be provision for hospitality boxes with a glazed elevation overlooking the terracing and an access corridor to the rear.
5. No columns or any other obstructions are permitted in the main concourse areas, or at Level 4.
6. Access to the respective floors is by external core areas accommodating a staircase and lift.
7. The roof over the terracing is clad with metal sheeting and is to be free-spanning with no columns permitted.
8. There is access for construction activities to all four elevations of the stand, but permanent structure is only permitted outside of the footprint shown in Figure Q1 to the rear of the stand.
9. The external elevations of the stadium are to be clad in composite metal sheeting and column spacing must be no less than 5.0m.
10. The steps to the terracing have a horizontal dimension of 1.0m

## Imposed loading

- |                          |                       |
|--------------------------|-----------------------|
| 11. Roof                 | 0.6 kN/m <sup>2</sup> |
| Terracing and Concourses | 5.0 kN/m <sup>2</sup> |

## Site conditions

12. The site is located on the outskirts of a large city. Basic wind speed is 40m/s based on a 3-second gust; the equivalent mean hourly wind speed is 20m/s.
13. Ground conditions are constant across the site:
 

Ground level – 1.5m	Top soil / fill
1.5m – 4.0m	Silty sand N=10
4.0m – 10.0m	Dense silty sand N=30
Below 10.0m	Rock with compressive strength 3000 kN/m <sup>2</sup>

Ground water was not encountered.

## Omit from consideration

14. Detailed design of the lift and stairs.

## 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, serviceability and stability aspects of each scheme. Review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice.
 

(40 Marks)
- b. After the design has been completed the Client advises you that they wish to add an additional level of terracing above the hospitality boxes at Level 4, the terracing having a vertical height of 4.0m and the underside of the roof being raised by 7.0m. Write a letter to the Client explaining 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 drawings, which may include 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)



# Question 2. Exhibition hall for steam preservation centre

## Client's requirements

1. A steam locomotive preservation centre has been given a generous donation to build a new exhibition hall. The hall is to be 64.0m long and 30.0m wide. Two railway tracks are to run into the hall, which is also to provide viewing areas, space for smaller exhibits, a cafe area and offices. The site slopes from west to east. See Figure Q2.
2. The railway tracks are to be 10.0m apart, each with a 4.0m-wide by 5.0m-high sliding door at the north end of the building to provide access for locomotives and railway carriages.
3. Clear headroom over the tracks and the central 18.0m-wide zone is to be 7.5m, reducing to 4.5m at the building's sides. This central zone must have no columns. See Figure Q2
4. The north and south walls are to be fully-glazed to provide natural light. Aside from this, the building envelope may be of any suitable material. Glazing panels up to 3.0m by 3.0m are available. The Client would be happy to see the building structure expressed and structure may be external to the building envelope. See Figure Q2.

## Imposed loading

- |  |                       |
|--|-----------------------|
| 5. Roof, including an allowance for hung exhibits                | 2.0 kN/m <sup>2</sup> |
| Ground floor, including an allowance for finishes and partitions | 7.5 kN/m <sup>2</sup> |
| Tracks, line load on each rail                                   | 50 kN/m               |

## Site conditions

6. The site is in open countryside and slopes downward from west to east at the building and is then flat. See Figure Q2.
7. Basic wind speed is 40m/s based on a 3-second gust; the equivalent mean hourly wind speed is 20m/s.

8. Ground conditions:

Borehole 1:	
Ground level – 1.0m	Made ground and topsoil
1.0m – 5.0m	Medium dense sand, N=12
Below 5.0m	Dense sand N=45

Borehole 2:	
Ground level – 0.5m	Made ground and topsoil
0.5m – 3.0m	Medium dense sand, N=12
Below 3.0m	Dense sand N=45

Ground water was encountered at 11.0m below ground level in both boreholes.

## Omit from consideration

9. Detailed design of sliding doors; however, the end wall structure must be designed.

## 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, serviceability, and stability aspects of each scheme. Review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice.

(40 Marks)

- b. During site preparation work an old site drain is found running east to west under the line of the north wall at 2.0m depth. See Figure Q2. The Client requires this drainage facility to be maintained and no foundation structure is permitted within a 3.0m zone containing the drain. Write a letter to the Client outlining possible solutions for this problem. Illustrate with sketches as necessary.

(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.

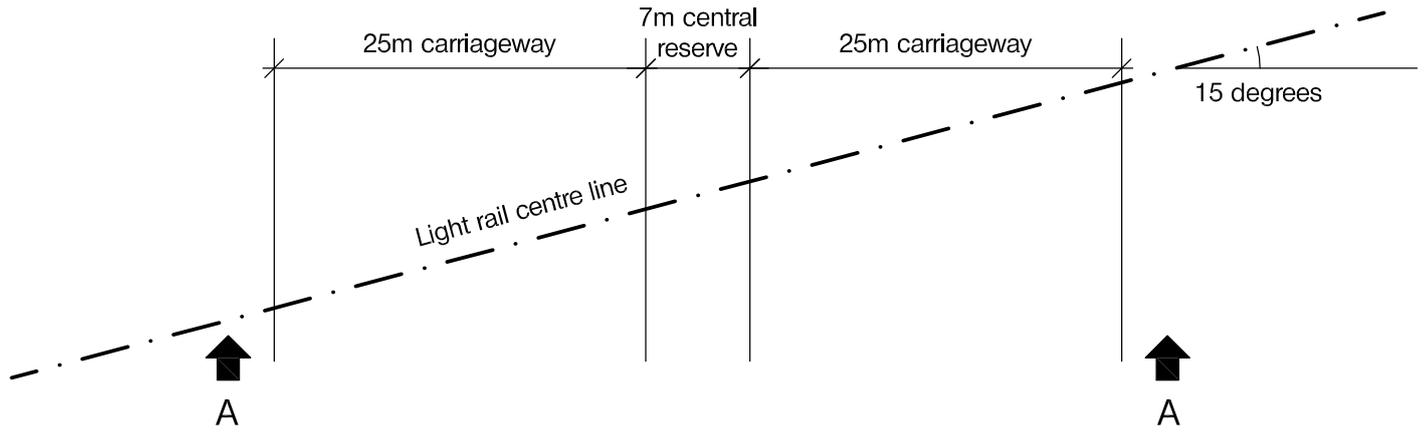
(20 marks)

- d. Prepare general arrangement drawings, which may include plans, sections and elevations, to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes.

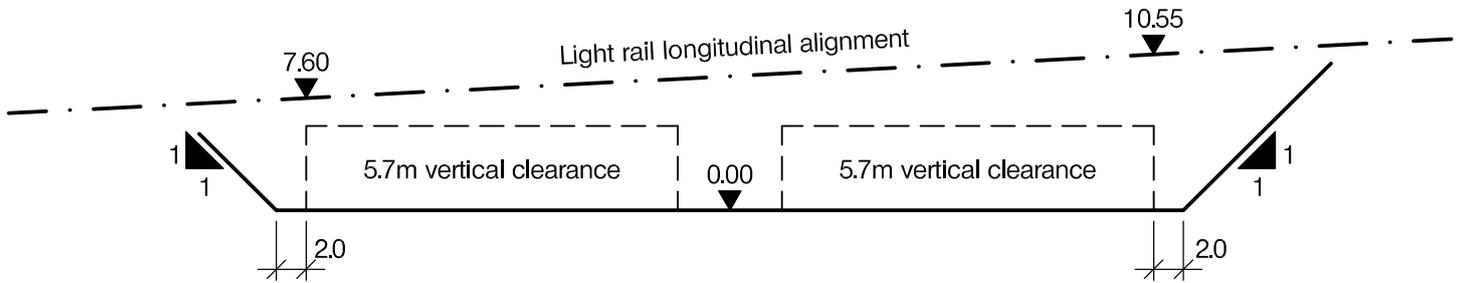
(20 marks)

- e. Prepare a detailed method statement for the safe construction of the building and an outline construction programme, including consideration of any temporary works that may be required.

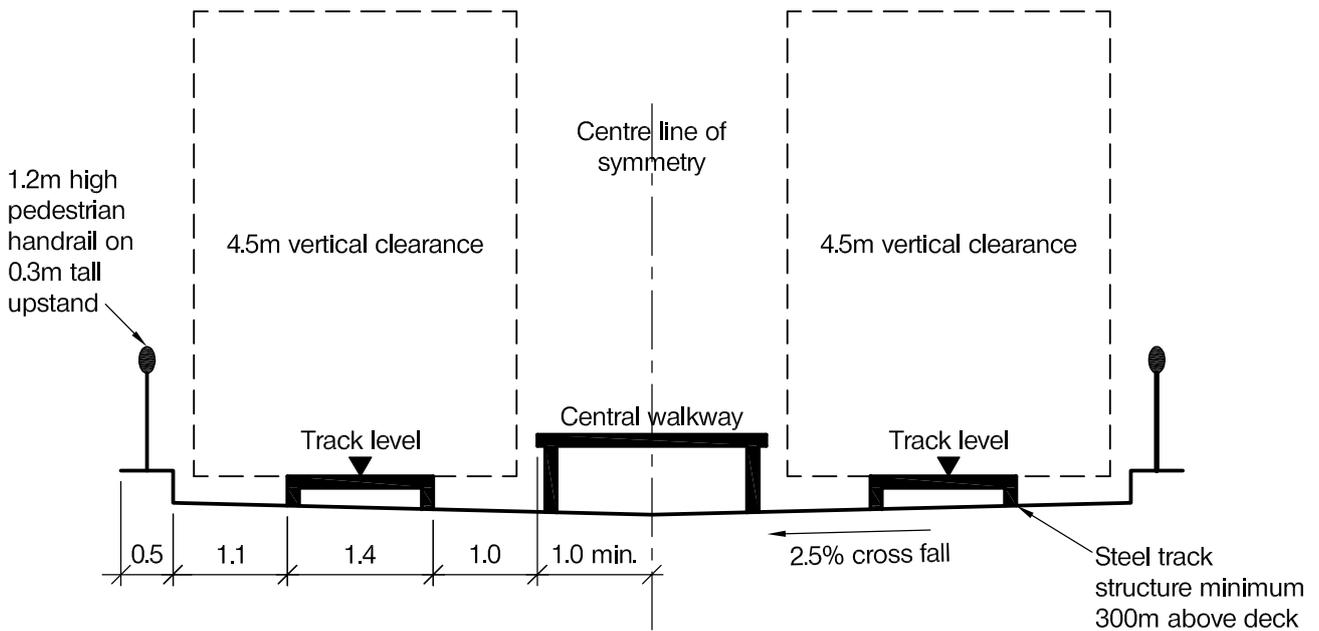
(10 marks)



PLAN VIEW



ELEVATION A - A



DECK CROSS SECTION

NOTE: All dimensions are in metres

FIGURE Q3

## Question 3. Bridge for light rail transit system

### Client's requirements

1. A new light rail passenger transit system is to cross an existing highway as shown in Figure Q3.
2. The bridge elevation shall follow the railway alignment in plan and in elevation, with a minimum vertical clearance of 5.7m above the existing carriageways.
3. The bridge abutments must be set at a minimum lateral clear distance of 5.0m from the edge of the existing carriageways. No permanent supports are allowed within the central reserve.
4. The bridge deck shall accommodate two tracks with a central walkway. Structure is permitted within the walkway zone if a minimum 750mm wide passage is provided alongside each track for access during inspection and maintenance of the railway system. Pedestrian handrails are to be provided along the edge of the deck.
5. Disturbance to road traffic during construction should be minimised. Temporary traffic diversion is allowed but limited to one carriageway at any time and for no more than 4 months per carriageway.

### Imposed loading

- |                       |   |
|-----------------------|---|
| 6. Light rail traffic | 30 kN/m vertical load over a train length of 60m and 175 kN axle load per train (per track)<br>Horizontal loads = 20% of train vertical load (in any direction)<br>Maximum speed of 40 km/h |
| Railway tracks        | 10 kN/m per track (self-weight of track and supporting steel structure)   |
| Central walkway       | 5 kN/m <sup>2</sup> pedestrian loads<br>2 kN/m <sup>2</sup> for self-weight of access walkway and utilities   |

### Site conditions

7. The site is in an urban location. Basic wind speed is 40m/s based on a 3-second gust; the equivalent mean hourly wind speed is 20 m/s.
8. Ground conditions:
 

Ground level – 1.0m	Top soil
Below 1.0m	Rock, allowable bearing pressure of 1500 kN/m <sup>2</sup>

Ground water was not encountered.

### Omit from consideration

9. Detailed design of the track structure and the maintenance walkway.

## 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, serviceability, and stability aspects of each scheme. Review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 Marks)
- b. After your recommended solution has been accepted in principle, the Client advises that the railway alignment needs to accommodate a plan curvature of 150m radius along the bridge centre line. Write a letter to the Client explaining the design implications and advising in which way the design would need to be modified to accommodate the revised alignment. (10 marks)

## SECTION 2

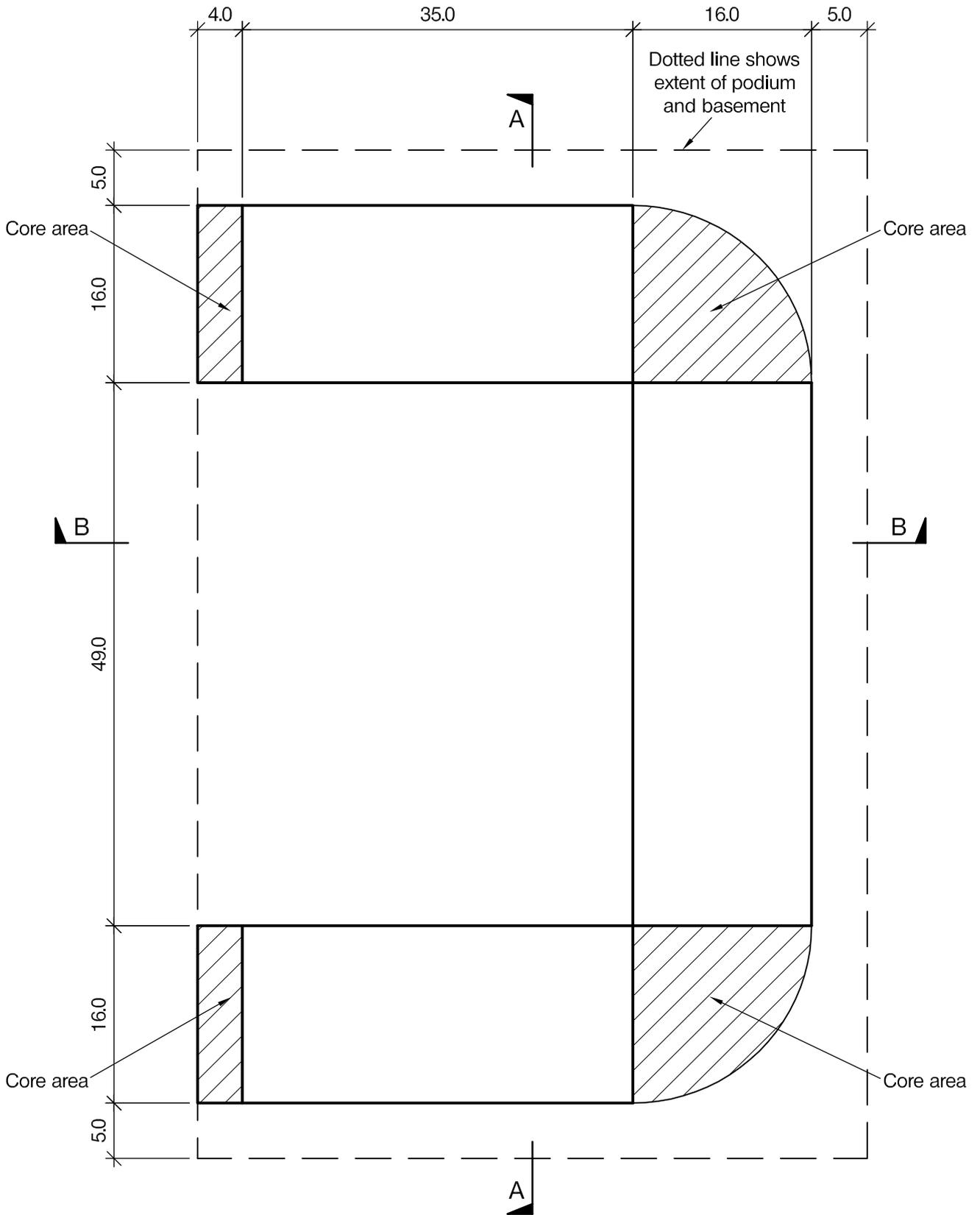
**(50 marks)**

For the solution recommended in Section 1(a):

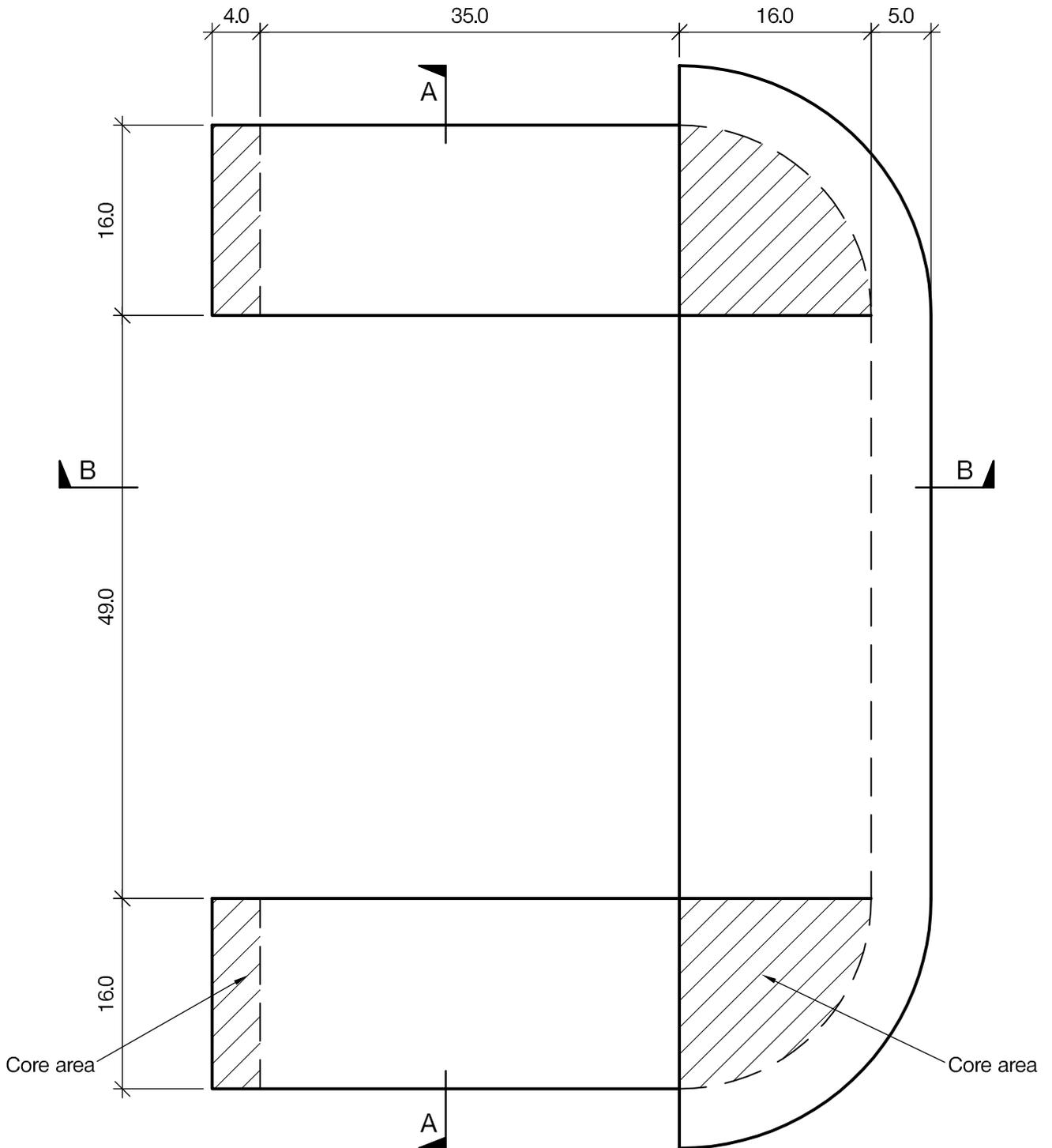
- c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)
- d. Prepare general arrangement drawings, which may include plans, sections and elevations, to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)
- e. Prepare a detailed method statement for the safe construction of the bridge and an outline construction programme. Identify any temporary traffic diversion and carriageway closure requirements and any principal temporary works necessary during the works. (10 marks)

**BLANK PAGE**

**BLANK PAGE**



TYPICAL PLAN AT LEVELS 2 TO 10



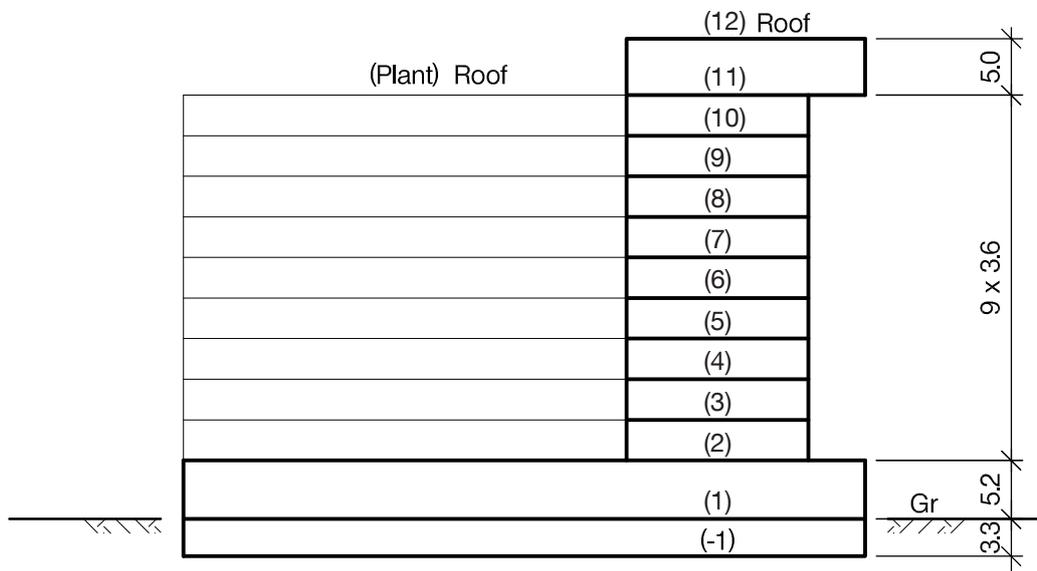
PLAN AT LEVEL 11

NOTE: All dimensions are in metres

FIGURE Q4 - 2



SECTION A - A



SECTION B - B

## Question 4. Multi-storey hotel

### Client's requirements

1. The Client requires a multi-storey hotel in the outskirts of a city. The building has three wings at right angles forming a U-shape configuration above a rectangular podium and a basement. The middle wing faces the main road with a full-length penthouse restaurant cantilevering outward. See Figure Q4.
2. The building is set back on three sides above the podium and accommodates bedrooms 3.5m x 7.0m with a central 2.0m corridor. The basement is used for car parking space.
3. The column spacing in the podium and car park shall not be less than 9m. Bedrooms shall be column-free.
4. The clear floor heights shall be 2.5m in Levels 2 to 9, 2.3m in the car park (Level -1) and 3.0m in the podium and penthouse (Levels 1 and 11 ). A services zone of 0.4m is required at all levels except the car park. The overall heights are shown in Figure Q4.
5. The building must be kept clear of any bracing or shear walls in external elevations except in the penthouse where feature bracing is permitted. No internal bracing or shear wall is permitted in the penthouse.
6. The roof is flat and the mechanical plant is accommodated on the side wing roofs.
7. Four service cores are provided containing stairs, lifts/elevators, services and risers as shown.
8. A minimum fire resistance period of 2 hours is required for structural elements.

### Imposed loading

- |                                |  |
|--------------------------------|--|
| 9. Rooms                       | 2.0 kN/m <sup>2</sup> + 1.0 kN/m <sup>2</sup> for partitions |
| Penthouse and Podium           | 5.0 kN/m <sup>2</sup>  |
| Corridors / Stairs, Roof plant | 4.0 kN/m <sup>2</sup>  |

### Site conditions

10. The site is flat. The basic wind speed is 46m/s based on a 3-second gust; the equivalent mean hourly wind speed is 23m/s.
11. Ground conditions:
 

0.0m – 1.0m	Made Ground
1.0m – 2.5m	Loose sand (N=12)
Below 2.5m	Dense sand (N=40)

Ground water was encountered at 20m below ground level.

### Omit from consideration

12. Detailed design of staircase/lift and façade cladding.

## 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, serviceability, and stability aspects of each scheme. Review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice.
 

(40 Marks)
- b. After completion of scheme design for the structure, the Client inquires whether a swimming pool can be added externally on the podium. Write a letter to the Client, advising on the structural implications of this change and how it may be achieved.
 

(10 marks)

## SECTION 2

**(50 marks)**

For the solution recommended in Section 1(a):

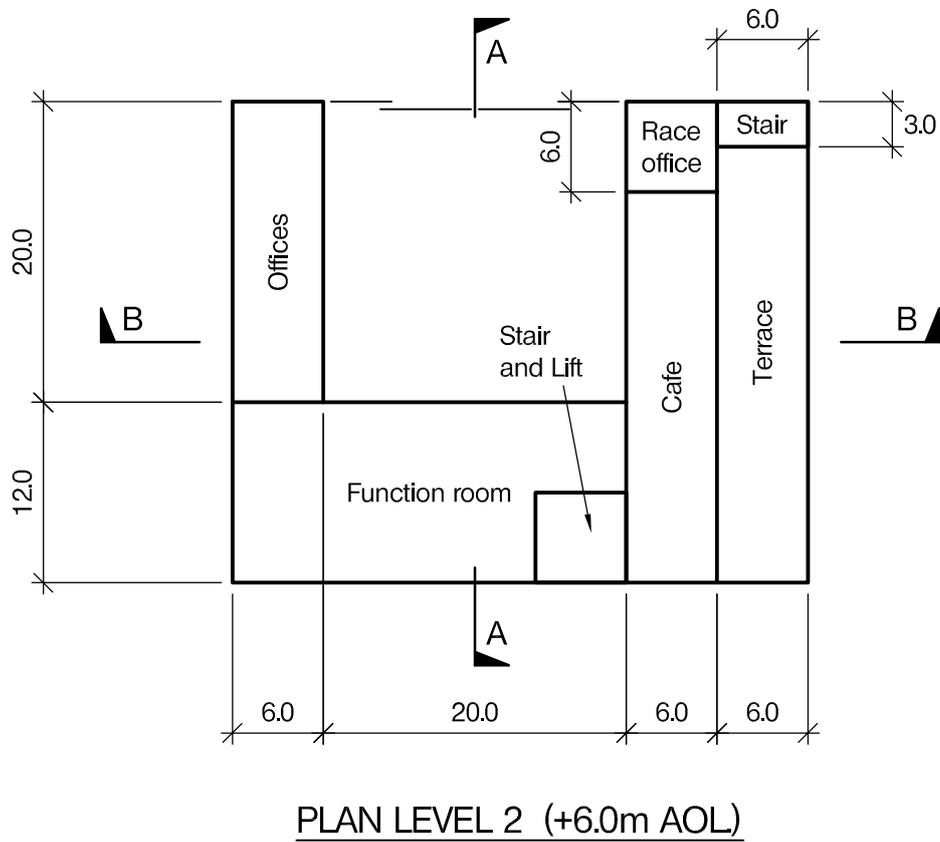
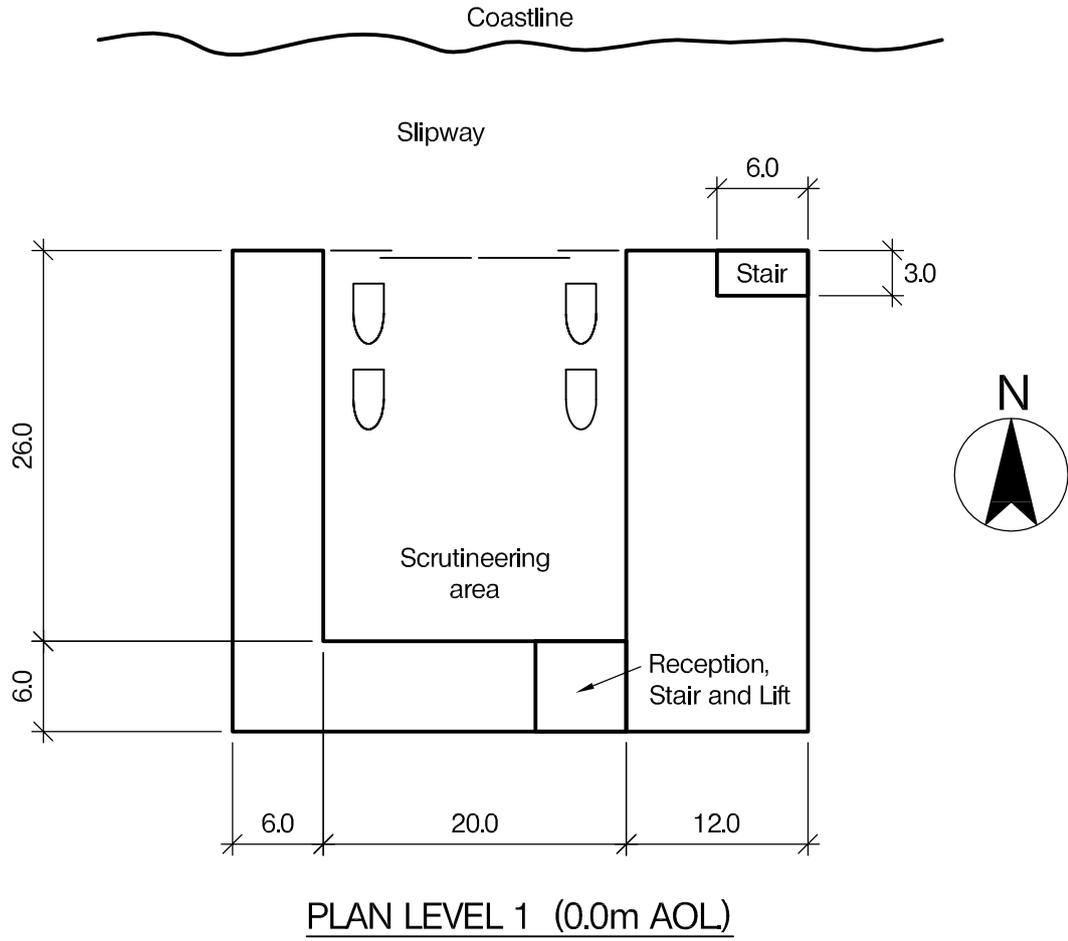
- c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations.
 

(20 marks)
- d. Prepare general arrangement drawings, which may include 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.
 

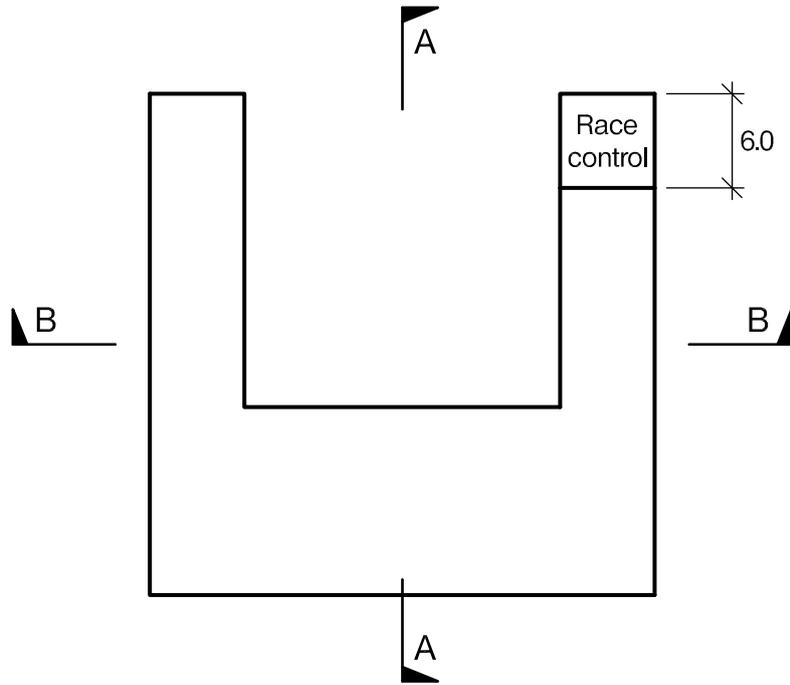
(10 marks)

**BLANK PAGE**

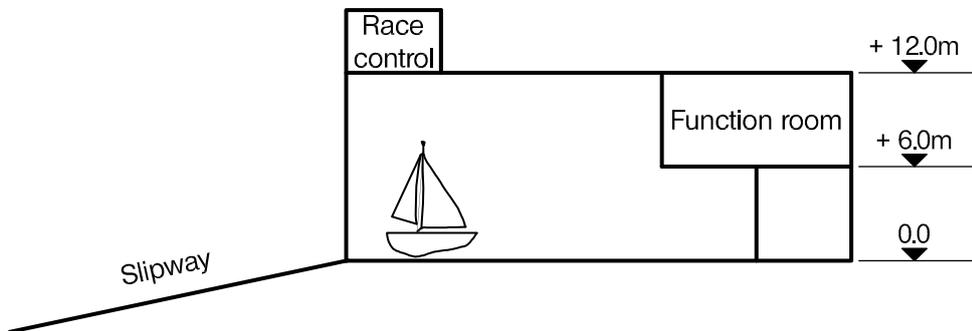


NOTE: All dimensions are in metres

**FIGURE Q5 - 1**



PLAN LEVEL 3 (+12.0m AOL)



SECTION A - A



SECTION B - B

NOTE: All dimensions are in metres

FIGURE Q5 - 2

## Question 5. Sailing academy

### Client's requirements

1. Design of a sailing academy on the coast with yacht inspection and changing facilities at Level 1; offices, function room, café with open terrace at Level 2 and race control at Level 3.
2. The site is within a nature reserve and the Client requires the structure to have a flat roof above the offices, function room and café.
3. The layout at Levels 1, 2 and 3 are shown in Figure Q4
4. No columns are permitted in the inspection hall.
5. The Client requires that the roof to the inspection hall should allow light into the hall.
6. Full-height sliding doors are required to the north elevation of the inspection hall.
7. A comfort cooling plant 5.0m x 5.0m x 1.2m high is to be located at roof level which the architect has screened from view by extending the facade.

### Imposed loading

- |            |                       |                       |
|------------|-----------------------|-----------------------|
| 8. Floors: | Level 1               | 10 kN/m <sup>2</sup>  |
|            | Upper floors          | 2.5 kN/m <sup>2</sup> |
|            | Comfort cooling plant | 5.0 kN/m <sup>2</sup> |
|            | Roof                  | 0.8 kN/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 – 1.5m	Top soil and fill
1.5m – 6.0m	Windblown sand, N=5
6.0m – 9.5m	Silty clay $C_u = 40 \text{ kN/m}^2$
Below 9.5m	Weathered sandstone, compressive strength = 1000kN/m <sup>2</sup>

Ground water – assume normal tidal range varies from -6.0m to -2.0m.

### Omit from consideration

11. Detailed design for stairs and sliding doors.

## 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, serviceability, and stability aspects of each scheme. Review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice.

(40 Marks)

- b. After the primary structure has been completed, revised data is published advising that global warming could raise the maximum high tide to 1.0m above Level 1 during severe storms likely to occur once every 2 years. Write a letter to your Client explaining the implications of this and the actions you recommend.

(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 drawings, which may include 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)

---

International HQ,  
47-58 Bastwick Street,  
London EC1V 3PS, UK

**T** +44 (0)20 7235 4535  
**E** [membership@istructe.org](mailto:membership@istructe.org)

**[www.istructe.org](http://www.istructe.org)**

---