

## Chartered Membership Examination

Monday 7 September 2020

### 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.

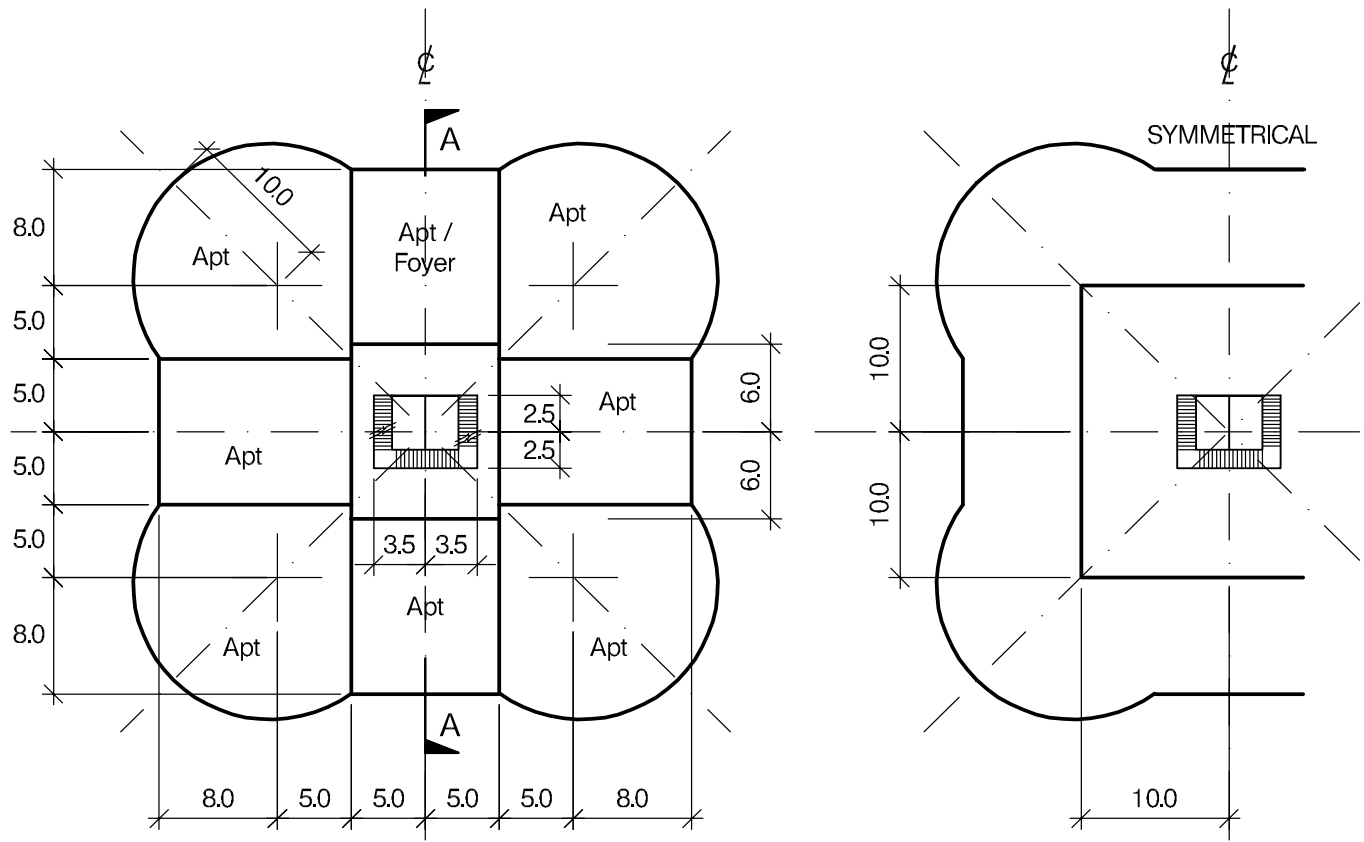
The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of structural design problems whether or not the problem is presented in terms that are within your actual experience.

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 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, 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".

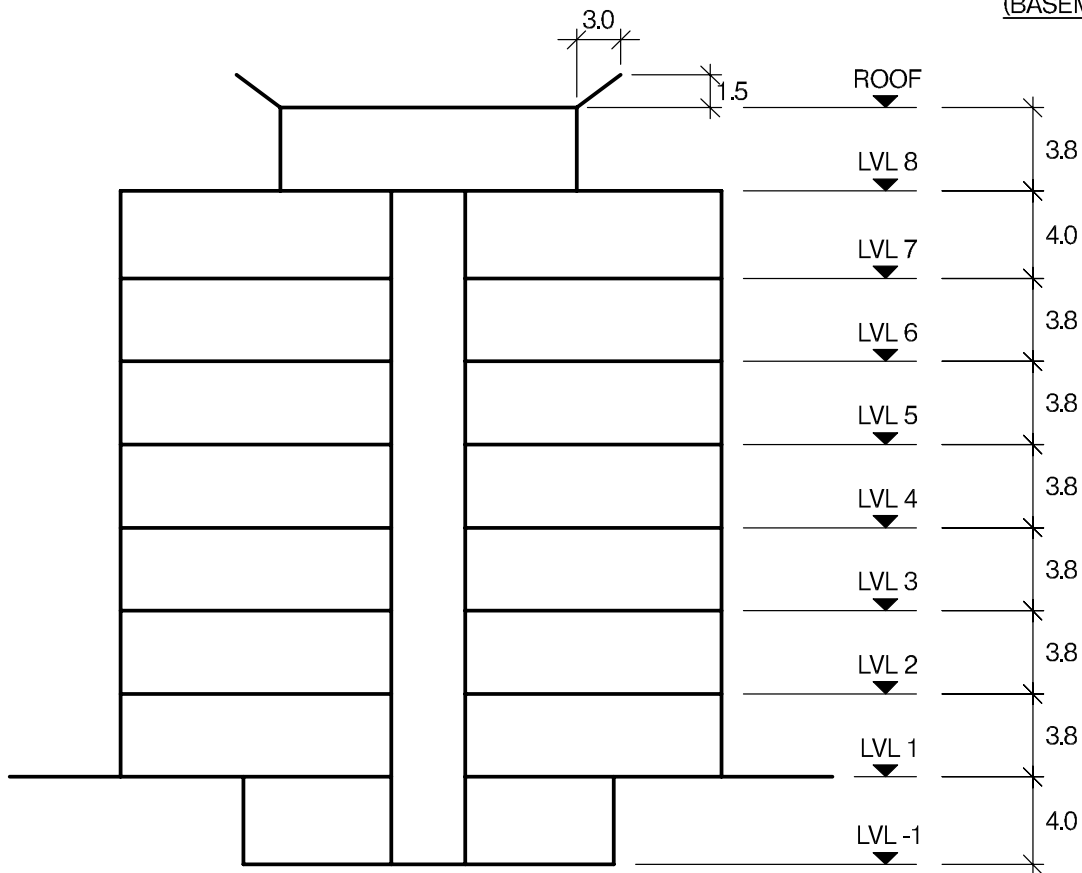
If you have difficulty in deciding the correct interpretation of a question, pay particular attention to point 6. notes to candidates, on the front cover. The examiners will take into account your interpretation – and the design you base on this – if this is clearly stated at the beginning of your answer.



TYPICAL FLOOR PLAN

PLAN AT LEVEL 8

(BASEMENT PLAN SIMILAR)



SECTION A - A

NOTE: All dimensions are in metres

FIGURE Q1

# Question 1. New Residential Development

## Client's requirements

1. A new nine-storey residential development consisting of 56 apartments. See Figure Q1.
2. The development is to have seven apartments and an entrance foyer at Level 1, and eight apartments per floor from Level 2 to Level 7. Level 8 has a single, open plan penthouse apartment
3. A basement is required with the same plan area as the penthouse and is to have a clear internal height of 3.0m. No internal columns are permitted.
4. Access to the upper floors is by a central core containing two lifts and a main staircase.
5. No columns are permitted within the central core area or within any of the apartments.
6. A minimum clear internal height of 2.6m is required to each apartment floor. Each apartment floor is to have a false ceiling service zone of 0.3 m below any structure.
7. All elevations to the development are to be fully glazed with the columns to elevations having a minimum spacing of 5.0m.
8. All roofs are to be flat except for the 3.0m perimeter overhang to the penthouse.
9. A fire resistance of 2 hours is required to the structure.

## Imposed loading

10. Roof	0.75kN/m <sup>2</sup>
11. Apartments	2.5kN/m <sup>2</sup>
12. Basement	4.0kN/m <sup>2</sup>

## Site conditions

13. The site is located in a city centre site. Basic wind speed is 40.0m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20.0m/s.
14. Ground conditions are constant across the site:
 

Ground level –1.5m	made ground
1.5m – 5.0m	silty sand, N value 10
5.0m - 10.0m	very dense sand and gravel, N value 45
Below 10.0m	sandstone allowable bearing pressure 2500kN/m <sup>2</sup>

Groundwater was encountered at a depth of 2.5m.

## Omit from consideration

15. Detail design of the lift and stairs.

## SECTION 1

**(50 marks)**

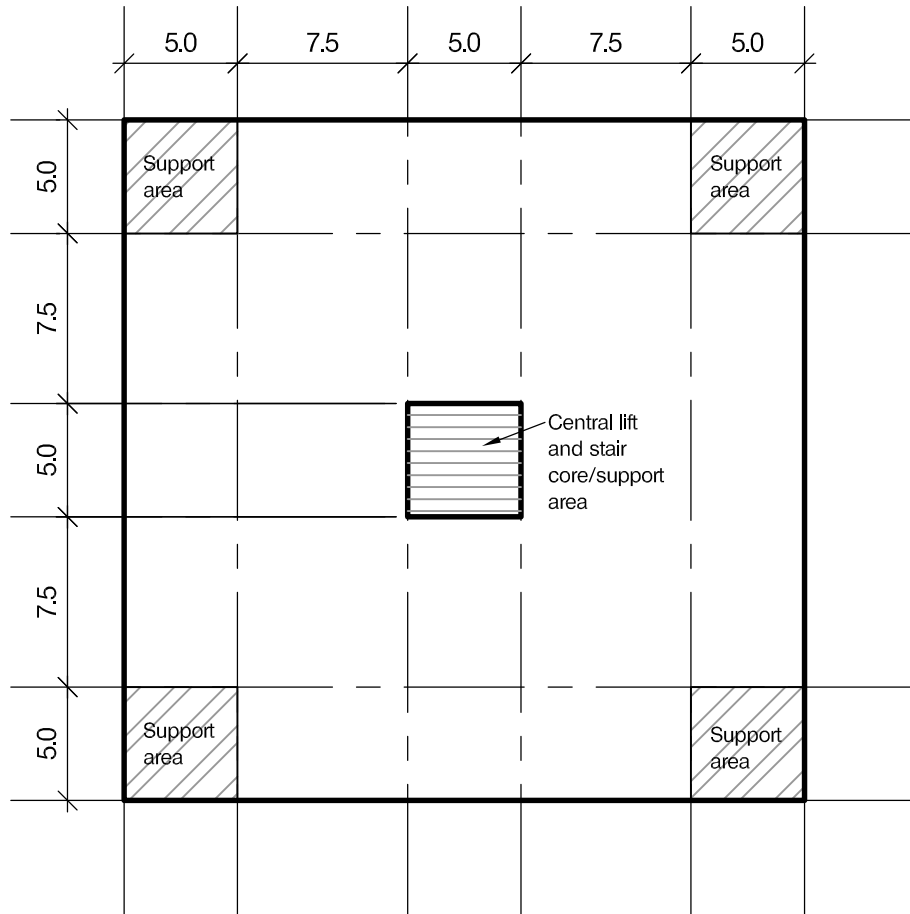
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Review and critically appraise the schemes and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After the scheme design is complete, the Client advises you that he wishes to add a further floor of eight apartments and a second penthouse apartment above the existing one. Write a letter to the Client explaining the implications on your design and the construction. (10 marks)

## SECTION 2

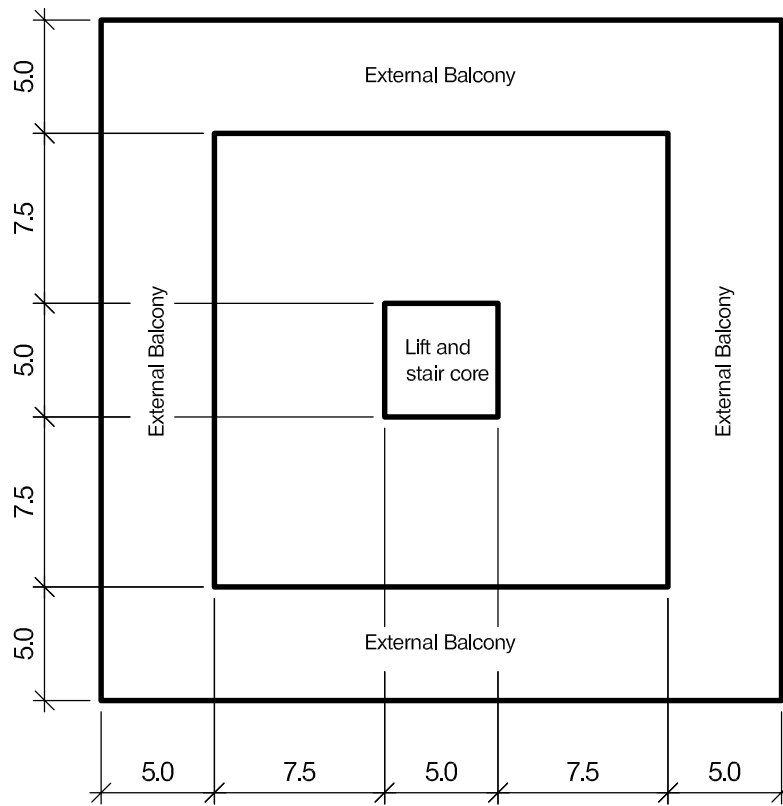
**(50 marks)**

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 works and an outline construction programme to include consideration of any temporary works that may be required. (10 marks)

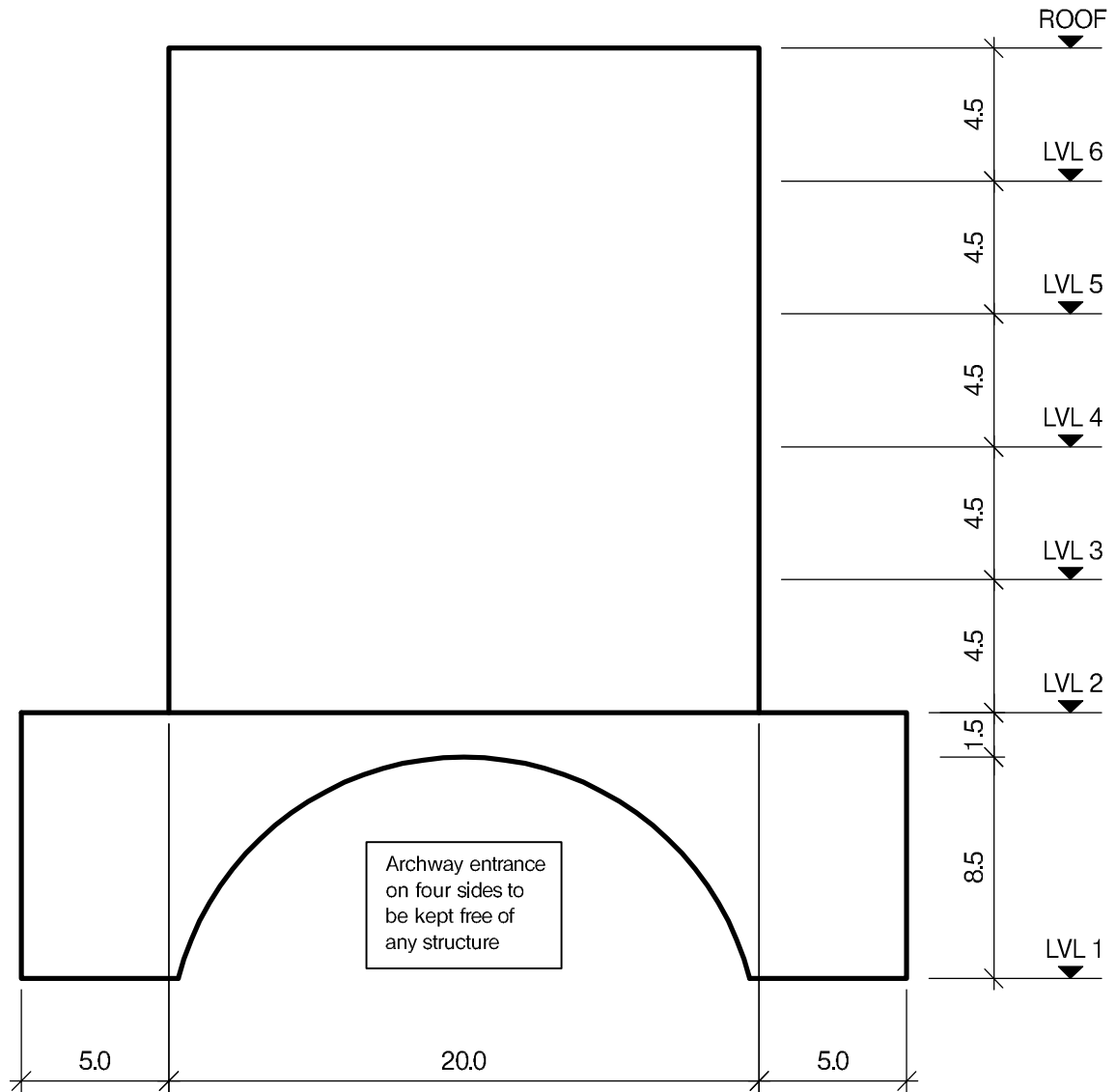


PLAN AT LEVEL 1



PLAN AT LEVEL 2

NOTE: All dimensions are in metres



TYPICAL ELEVATION

NOTE: All dimensions are in metres

FIGURE Q2 SHEET 2





## Question 2. Iconic City Centre Office Building

### Client's requirements

1. An iconic building is to be constructed in the heart of a city centre.
2. Vertical supports at Level 1 are only permitted within the areas indicated in Figure Q2. Access to the upper floors is to be provided through a central lift and stair core.
3. Level 2 is to have a 5.0m wide balcony as shown in Figure Q2. Levels 2 to 6 accommodate office space arranged around the central core.
4. Floor to floor height is 10.0m at Level 1 and 4.5m at the upper levels.
5. Plant is to be located at roof level.

### Imposed loading

- |                                       |                      |
|---------------------------------------|----------------------|
| 6. Roof including allowance for plant | 5.0kN/m <sup>2</sup> |
| 7. Offices and balcony                | 5.0kN/m <sup>2</sup> |

### Site conditions

8. The site is in a city centre. Basic wind speed is 40.0m/s based on a 3 second gust; the equivalent mean hourly speed is 20.0m/s.
9. Ground conditions are constant across the site:
 

Ground level – 1.0m	top soil/fill
1.0m – 6.0m	loose gravel, N value 5
Below 6.0m	dense sand and gravel, N value 30

Groundwater was encountered at -3.0m.

### Omit from consideration

10. Detail design of the lift and stairs.

## SECTION 1

**(50 marks)**

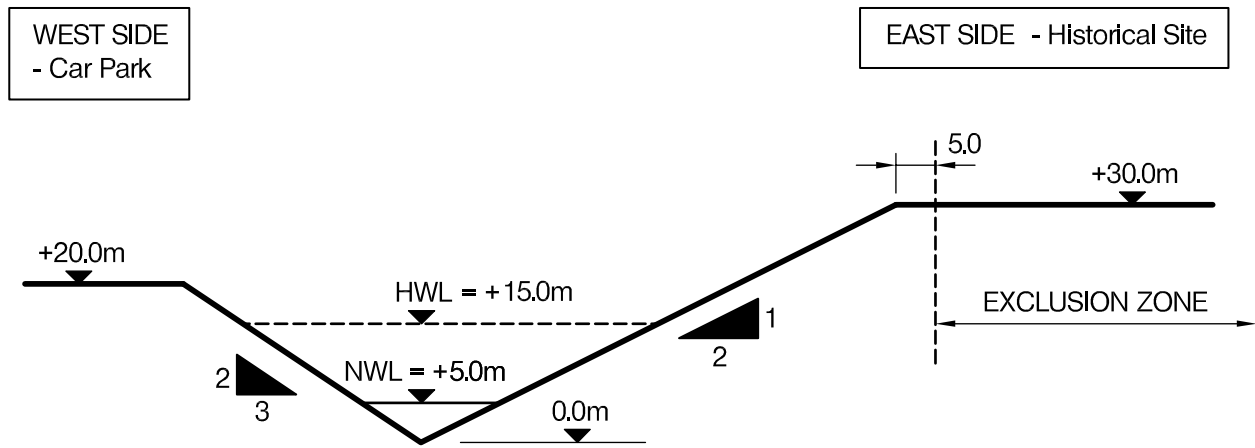
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Review and critically appraise the schemes and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. After a few years of use, the Client decides to add a further storey with clear internal space to allow the area to be used for recreational purposes. Write a letter 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 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 to include consideration of any temporary works that may be required. (10 marks)



LONGITUDINAL SECTION THROUGH THE SITE

NOTE: All dimensions are in metres

FIGURE Q3

## Question 3 – Pedestrian Access Bridge

### Client's requirements

1. A new footbridge is required across a deep valley to provide access from a public car park on the west side to a tourist visitor centre and historical ruins on the east side as shown in Figure Q3.
2. The new bridge deck shall accommodate a 3m wide pedestrian route with 1.5m high parapet handrails on each side. The maximum gradient along the route cannot exceed 1 in 20.
3. The valley contains a river with variable seasonal water level. The Normal Water Level (NWL) occurs between May and September at +5.0m. During the other months of the year the water level can increase to +15.0m. The water velocity of the river is significant and no permanent works can be allowed to disturb its flow.
4. The historical area on the east side contains some archaeological ruins. An exclusion zone exists from a point 5m from the top of the slope and no works are permitted in this area.
5. The new access bridge shall be aesthetically pleasing.

### Imposed loading

- |  |   |
|--|---|
| 6. Vertical load from pedestrians              | 5.0 kN/m <sup>2</sup>                           |
| 7. Horizontal load along the parapet handrails | 1.0 kN/m (in any direction)                     |
| 8. Maintenance vehicle load                    | 10 kN wheel load over 100mm square contact area |

### Site conditions

9. The site is in a coastal location. Basic wind speed is 40.0m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20.0m/s.
10. Ground conditions:  

Below 0.3m	Rock, allowable bearing pressure 2000 kN/m <sup>2</sup>
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### Omit from consideration

11. Detail design of any access ramps.

## SECTION 1

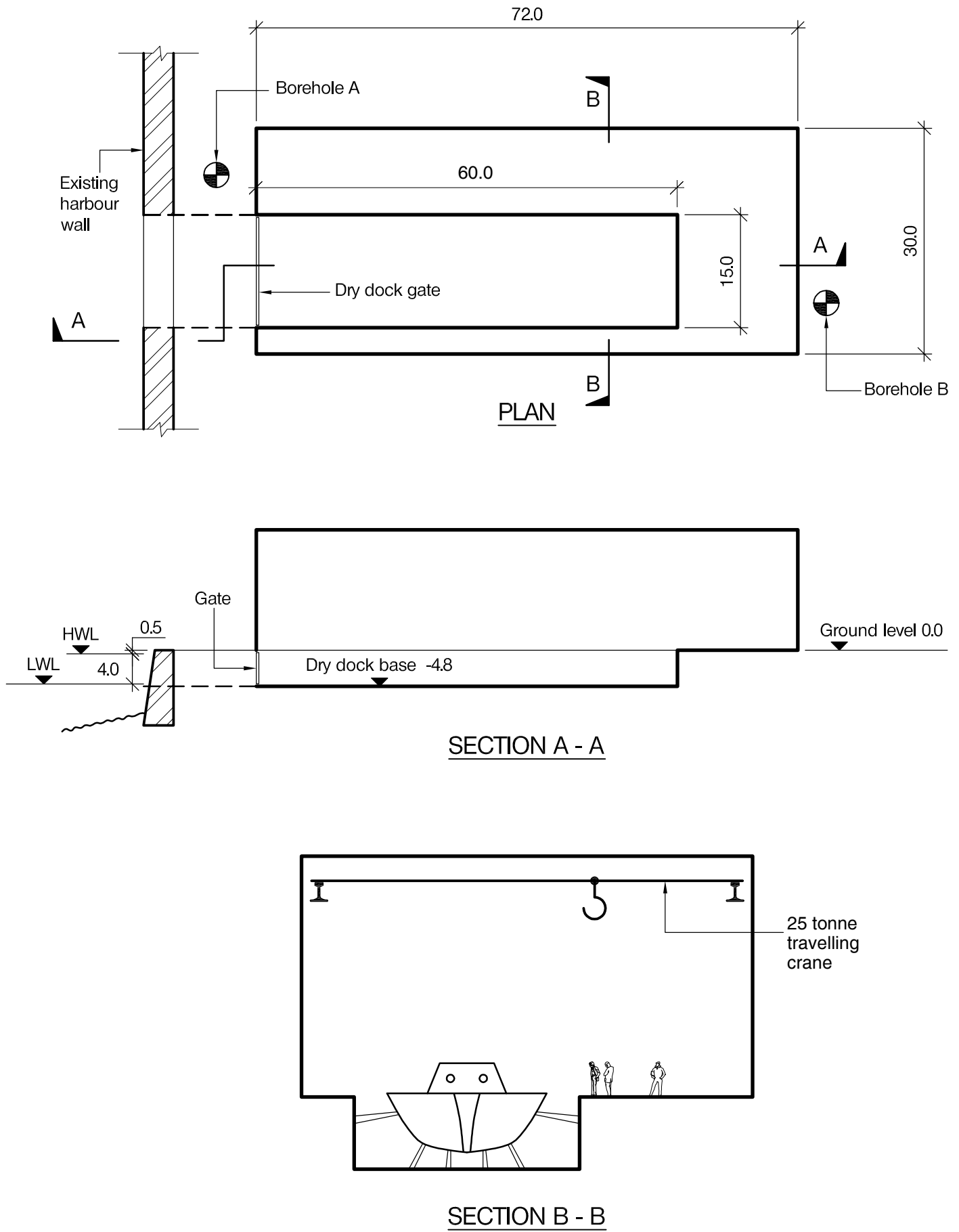
**(50 marks)**

- 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 an additional archaeological investigation has identified further historical ruins which require the exclusion zone to be shifted 5m further to the west to the top of the slope. Write a letter to the Client explaining the design and construction implications and advising how the design could be modified to accommodate this constraint. (10 marks)

## SECTION 2

**(50 marks)**

- 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 footbridge and an outline construction programme taking account of the seasonal variation in water levels. Identify any principal temporary works necessary during the works. (10 marks)



NOTE: All dimensions are in metres

FIGURE Q4

# Question 4 - Dry Dock and Exhibition Hall for Historic Ship

## Client's requirements

1. A new exhibition hall incorporating a dry dock to display an historic warship and associated exhibits is required. The hall is to be 72.0m long by 30.0m wide and the dock is to have clear internal dimensions of 60.0m long by 15.0m wide by 4.8m deep. External dimensions are not restricted. See Figure Q4.
2. The dry dock is to be on the landward side of an existing harbour wall and the ship will be floated in, the entrance then closed from the harbour, the ship propped and the water pumped out. The entrance gate may occasionally be opened in the future.
3. A 25 tonne travelling crane will be used to move heavy exhibits in the hall and an appropriate headroom to achieve this and a feeling of space is required.
4. The client requires as much natural light as possible and would like to use renewable energy to assist powering the hall.
5. The dry dock may be placed anywhere reasonable in the cross section of the hall.

## Imposed loading

- |                          |  |
|--------------------------|--|
| 6. Exhibition hall floor | 10.0kN/m <sup>2</sup>  |
| 7. Dry dock floor        | 20.0kN/m <sup>2</sup>  |
| 8. Roof                  | 1.2kN/m <sup>2</sup>   |
| 9. Loads from crane      | A pair of 180kN loads spaced 2.0m apart can act anywhere on each crane rail. |

## Site conditions

10. The site is located next to the open sea. Basic windspeed is 40.0m/s based on a 3 second gust. The equivalent mean hourly windspeed is 20.0m/s.
11. Ground conditions:
 

Borehole A: Ground level – 6.0m	Made ground
6.0 - 7.0m	Stiff clay, C=150kN/m <sup>2</sup>
Borehole B: Ground level - 1.0m	Made ground
1.0 - 7.0m	Stiff clay, C=150kN/m <sup>2</sup>
Below 7.0m:	Sandstone, allowable bearing pressure 1000kN/m <sup>2</sup>

Groundwater was encountered at 0.6m below ground level.

## Omit from consideration

12. Detailed design of the dry dock gate.

## 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 the scheme design, the Client asks that the hall be capable of withstanding a tsunami wave 2.0m above design high water level. Write a letter to the Client explaining the implications on your design.

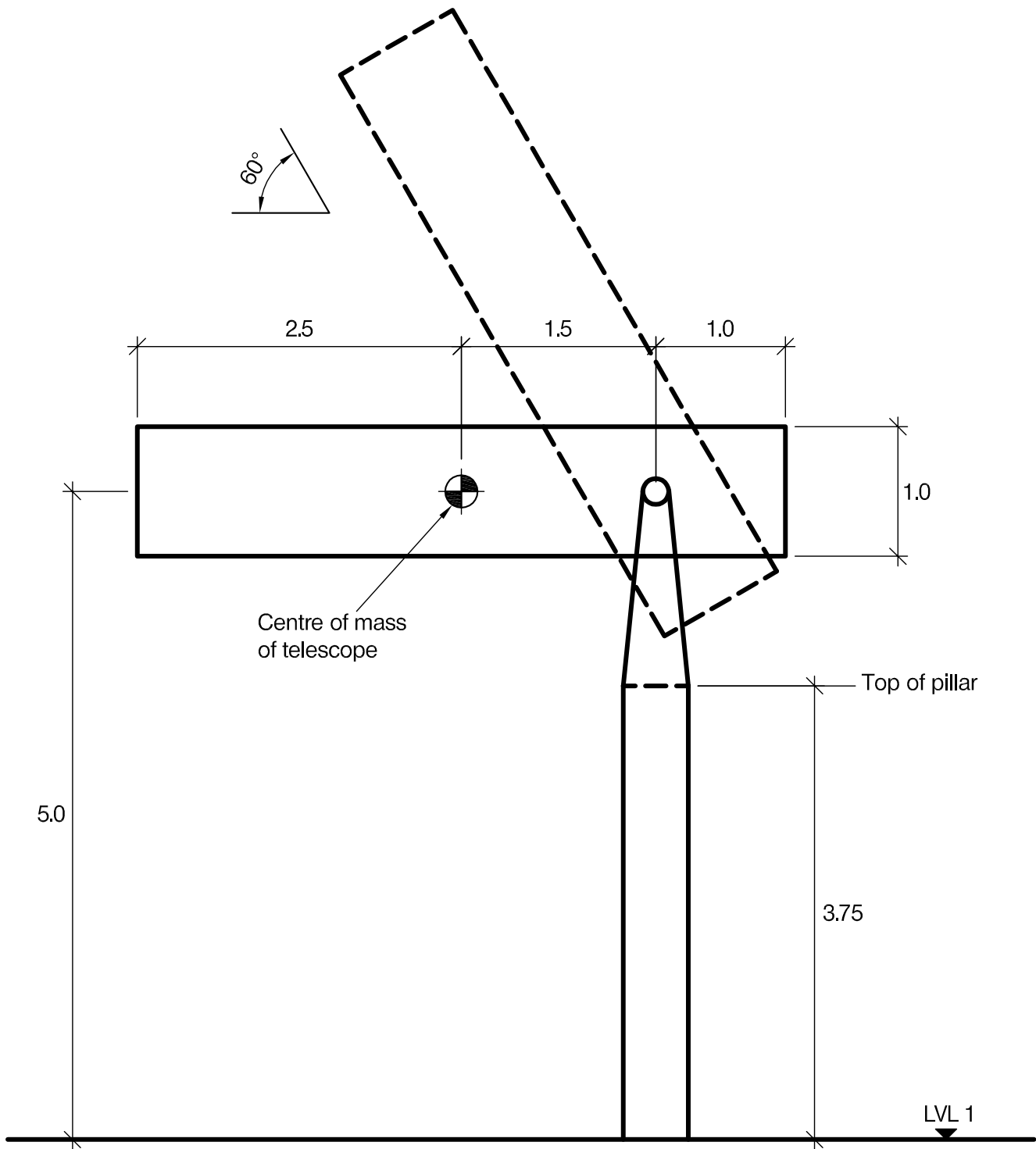
(10 marks)

## 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 crane beam and 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 works and an outline construction programme to include consideration of any temporary works that may be required. (10 marks)



NOTE: All dimensions are in metres

FIGURE Q5

# Question 5 - Astronomical Observatory

## Client's requirements

1. Design of a building structure of any appropriate form to enclose a large astronomical telescope, and design of the pillar on which the telescope is mounted.
2. The telescope has a diameter of 1.0m and a length of 5.0m and weighs 1500kg. It is mounted on a bearing that allows it to rotate vertically from horizontal to 60 degrees above horizontal as shown in Fig Q5. The telescope can also rotate horizontally through 360 degrees.
3. An aperture 2.0m wide with sliding doors is to be provided in the building. The aperture must provide a completely unobstructed view from any position of the telescope and must therefore also be capable of being rotated through 360 degrees.
4. A 1.0m minimum clear zone is required around the telescope.
5. The site is situated at an elevation of 3000m above sea level at the top of the steeply sloping side of an extinct volcano with a gradient of 1 vertical to 3 horizontal.
6. No heating is required to the building which can only be used on clear nights when there is very little wind.
7. No columns are permitted in the building.

## Imposed loading

8. Telescope weight            1500kg with centre of mass as indicated in Fig Q5
9. Floor load at level 1        10 kN/m<sup>2</sup>

## Site conditions

10. The site is situated on an extinct volcano in open countryside. Basic wind speed is 40.0m/s based on a 3-second gust; the equivalent mean hourly wind speed is 20.0m/s.
11. Ground conditions are uniform below ground level:
 

Ground level to 2.5m	Volcanic ash N value 5
Below 2.5m	Basalt with safe bearing capacity 3000kN/m <sup>2</sup>
No ground water is present	

## Omit from consideration

12. Design of the telescope mounting bearings, any sliding/rotating mechanisms and aperture 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, 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 5 years use the Client wishes to consider relocating the telescope and its enclosure to a new site approximately 0.5km away. Write a letter to your Client explaining the feasibility of this.
 

(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 footbridge and an outline construction programme.
 

(10 marks)

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