

## Chartered Membership Examination

Monday 27 September 2021

### 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.

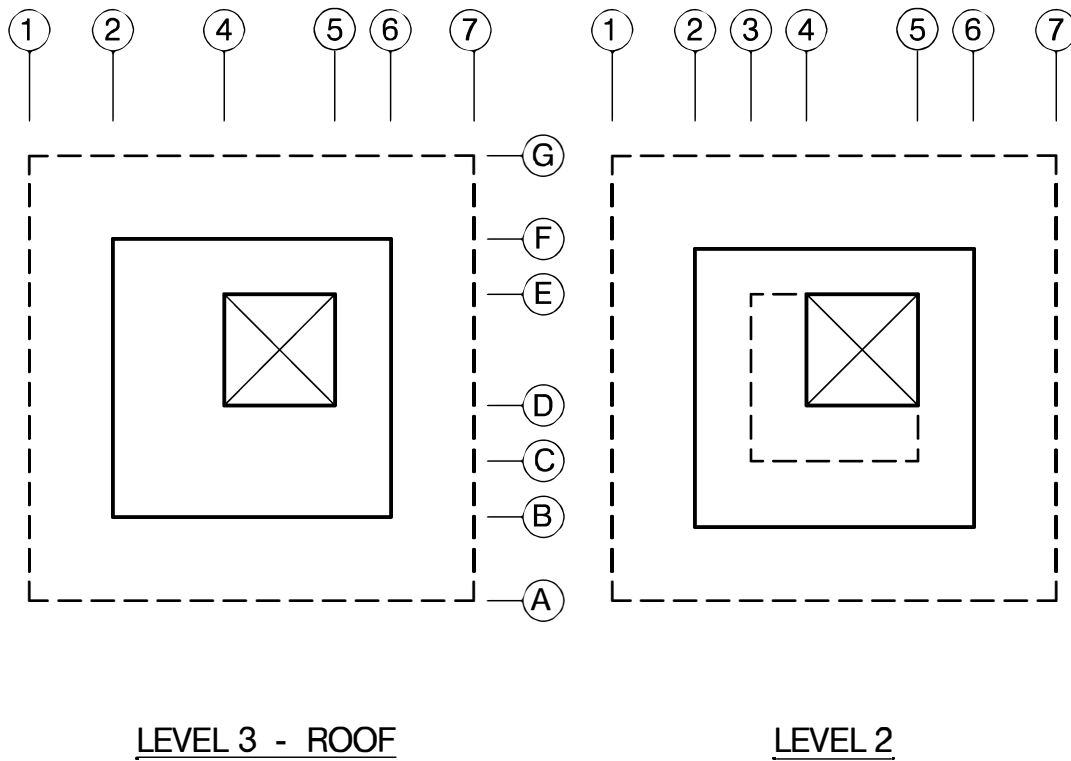
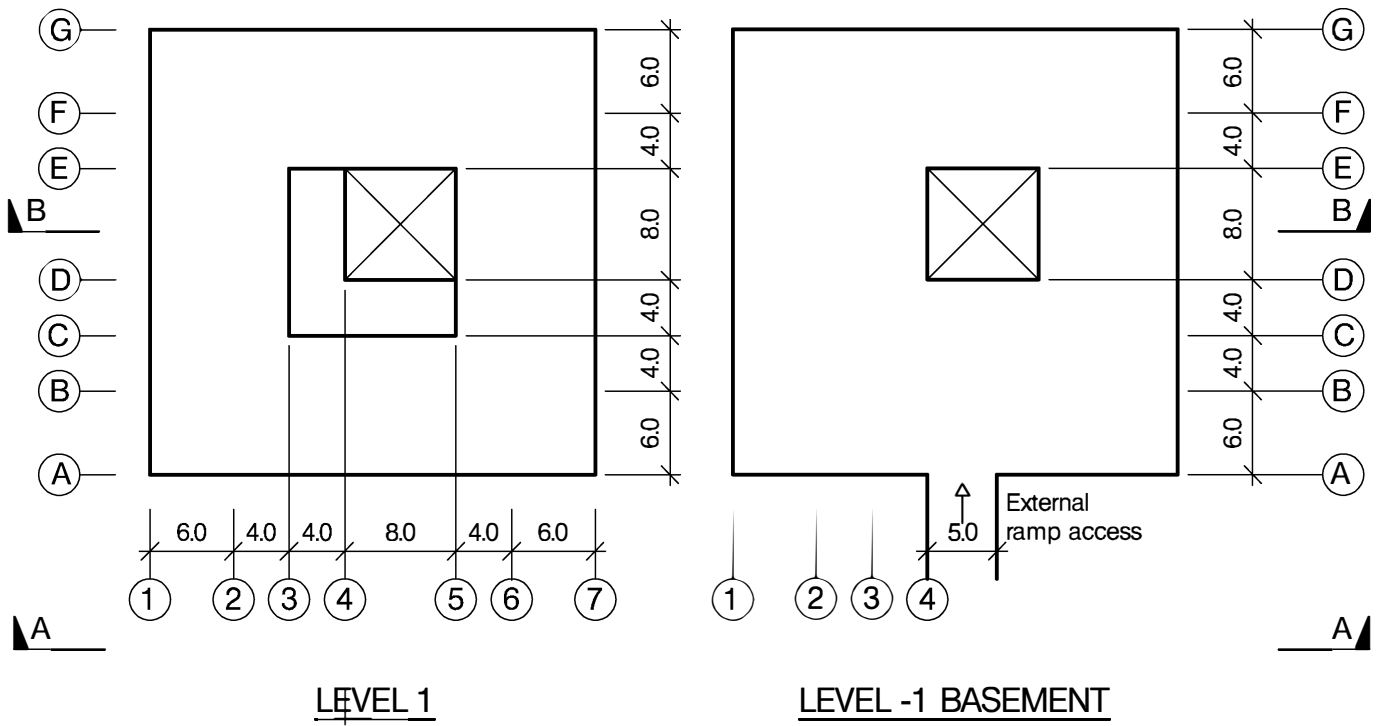
The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of structural design problems whether or not the problem is presented in terms that are within your actual experience.

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 understand the general structural engineering principles involved.

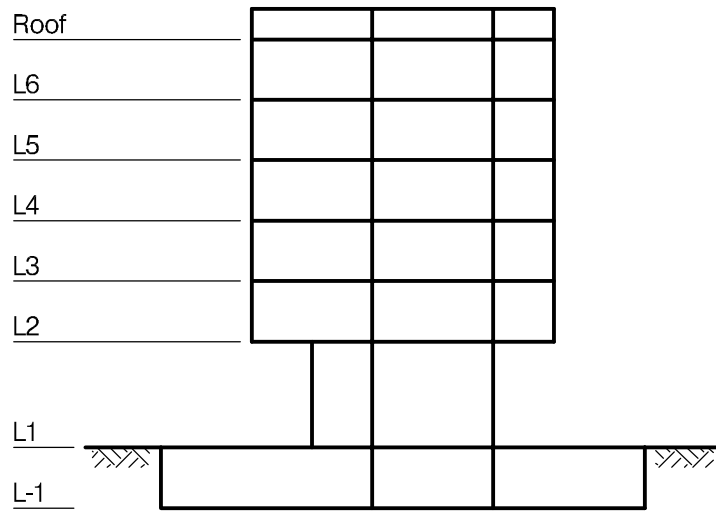
In selecting and developing your design you should also remember the guidance given in the Institution's report, Structural design - achieving excellence, and in particular:

- (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".

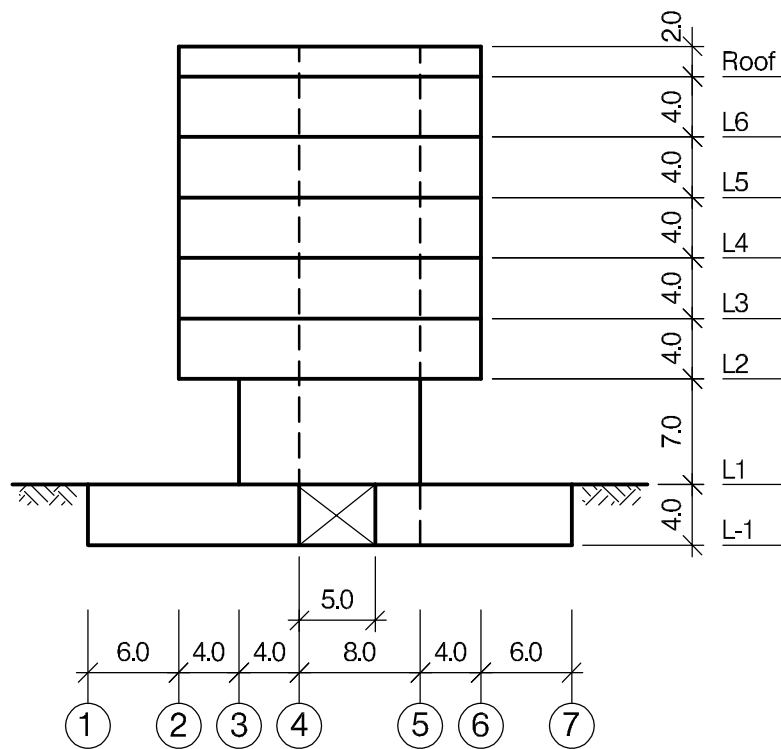
If you have difficulty in deciding the correct interpretation of a question, pay particular attention to point 6. notes to candidates, on the front cover. The examiners will take into account your interpretation – and the design you base on this – if this is clearly stated at the beginning of your answer.



NOTE: All dimensions are in metres



SECTION B - B



ELEVATION A - A

NOTE: All dimensions are in metres

# Q1. Residential Building with basement car park

## Client's requirements

1. A new multi-storey residential building with car parking – see Fig Q1 (a and b). The car park is accessed via an external and separate 5m wide ramp structure.
2. The roof has a 2m high perimeter parapet screen and encloses a plant room of 32 square metres.
3. The car park is on level L-1 basement, and any internal columns are to have a minimum horizontal clearance of 5m centre to centre spacing from the perimeter of the stair and lifts core.
4. All floors including the basement are to have a floor-to-floor height of 4.0m with structural depth kept to a minimum, except level L1 to L2 where 7m is required with a minimum clearance of 5m to underside of structure and no exterior columns are allowed.
5. Columns within the floor plans are to be kept to a minimum of 4m centre to centre spacing.
6. A single stair and lifts core extends the full height of the building.
7. Cladding is full height glazing at all levels, apart from levels L1 to L2 which is brick clad.
8. A minimum fire rating of 2 hours is required throughout.

## Imposed loading

9. Roof 7.5 kN/m<sup>2</sup> (Plant)  
 Car park – 2.5kN/m<sup>2</sup>  
 Residential – 3.5kN/m<sup>2</sup>

Loadings include allowances for floor finishes, ceilings and services.

## Site conditions

10. City centre location. Basic wind speed is 40m/s based on a 3 second gust; the equivalent means hourly wind speed is 20m/s.

## Ground conditions

11. Ground level – 0.5m Topsoil/made ground  
 0.5m – 3m Sands and Gravels, N = 15  
 3m – 20m Dense Gravels, N = 50  
 Below 20m Rock, allowable safe bearing pressure 500kN/m<sup>2</sup>

Ground water is present 4m below Ground level.

## Omit from consideration

12. Detailed design for staircases and lifts within cores and external car park ramp structure.

## SECTION 1

**(50 marks)**

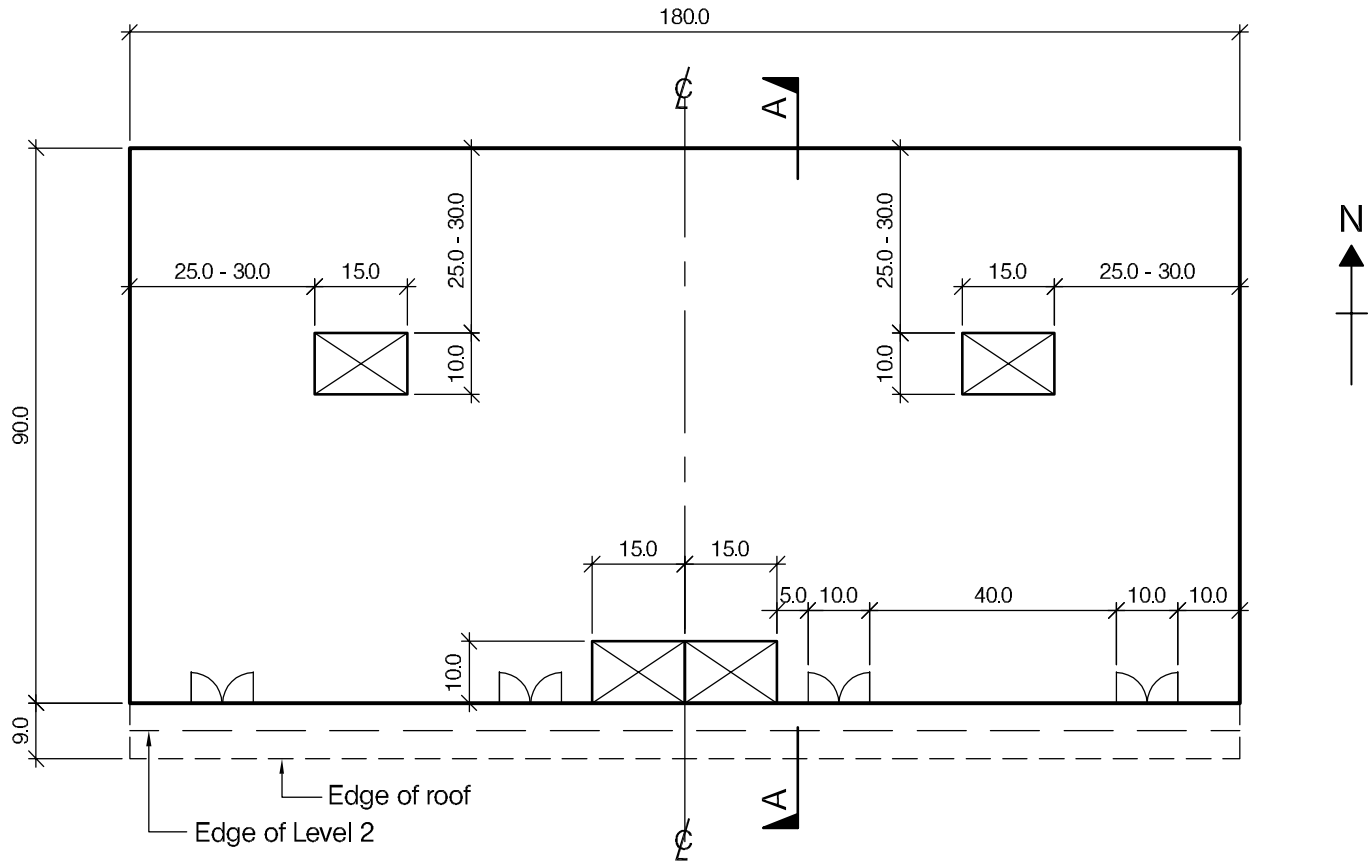
- a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer, serviceability, and stability aspects of each scheme. Review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice.  
(40 marks)
- b. After completion of the design and before construction has started, the client states that they are considering increasing the 20m by 20m building width at levels L2 to the roof to 28m by 28m. Write a letter to the Client advising them of the implications on the design.  
(10 marks)

## SECTION 2

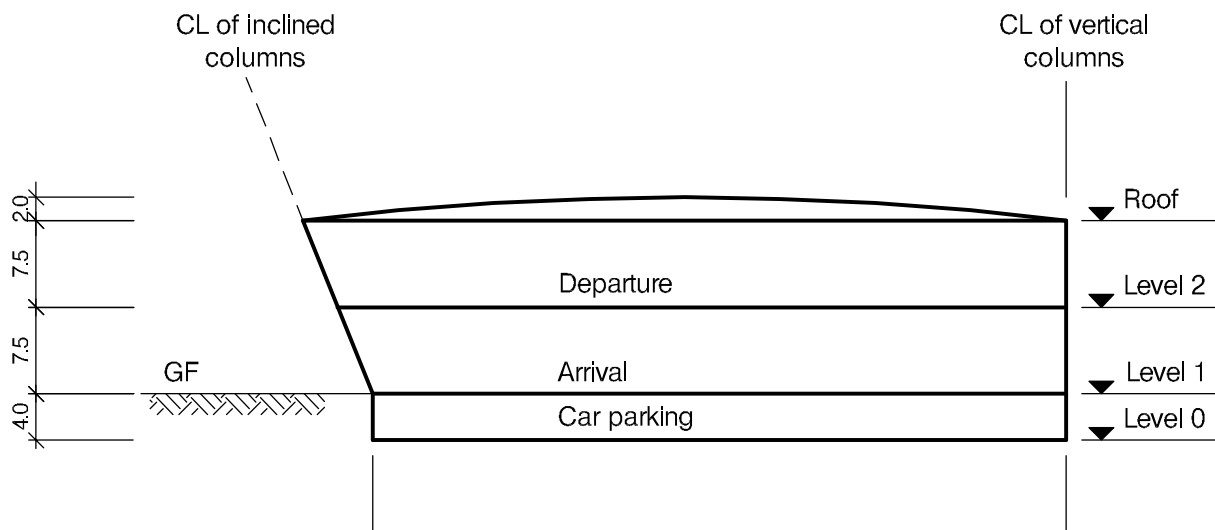
**(50 marks)**

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 building and an outline construction programme.  
(10 marks)



PLAN AT LEVEL 1



SECTION A - A

NOTE: All dimensions are in metres

FIGURE Q2

## Q2. Airport Main Terminal

### Client's requirements

1. The client requires a new airport main terminal in the outskirts of a city. The terminal is to be constructed in three levels, a basement for car parking, ground level for arrivals and first floor level for departures. Access to Level 2 departure is via a separate road constructed above the drop off area. The front façade is inclined projecting 9m at the roof level, see Fig Q2.
2. The ground floor (level 1) accommodates luggage claim areas, security offices, and restaurants. The first floor (level 2) accommodates baggage check in, immigration control, and transit lounge. The areas highlighted as core areas contain stairs, lifts/elevators, services and risers. The basement (level 0) is used for car parking space.
3. The column spacing in levels 1 and 2 shall not be less than 25m (except in the cores where columns are permitted at the corners). Columns may be reduced to 15m in level 0. This applies to both transverse and longitudinal directions.
4. The minimum clear floor heights shall be 2.30m in level 0, and 4m in levels 1 and 2. A mechanical services zone of 0.5m deep shall be allowed at all levels except the car park. However, if the choice of structure permits to pass the services through the structure this can be fully integrated in the structure zone. The overall heights are shown in Fig Q2.
5. The building facades shall be fully glazed. No internal bracing/shear wall is permitted in levels 1 and 2, except around core areas and a 3m wide zone in the four external corners of the building.
6. The roof is of a convex shape rising to a maximum of 2.0m from the eaves level and shall be clad with insulated cladding panels. The roof structure shall be kept exposed internally (no ceiling) and hence needs to be architecturally pleasing.
7. Floors in levels 1 and 2 shall be of a suitable construction to provide a smooth, even, durable, and slip-resistant surface.
8. A minimum fire resistance period of 2 hours is required for structural elements.

### Imposed loading

- |                |   |
|----------------|---|
| 9. Roof        | 1.50KN/m <sup>2</sup>   |
| Levels 1 and 2 | 5.0KN/m <sup>2</sup> + 1.50KN/m <sup>2</sup> for baggage handling systems |
| Level 0        | 2.5KN/m <sup>2</sup>  |

### Site conditions

10. The site is flat. The basic wind speed is 50m/s on a 3-second gust; the equivalent mean hourly wind speed is 25m/s.

### Ground conditions

- |                 |                   |
|-----------------|-------------------|
| 11. 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 5m below the ground level.

### Omit from consideration

12. Detailed design of staircase/lift (elevator), façade cladding, and access roads.

## SECTION 1

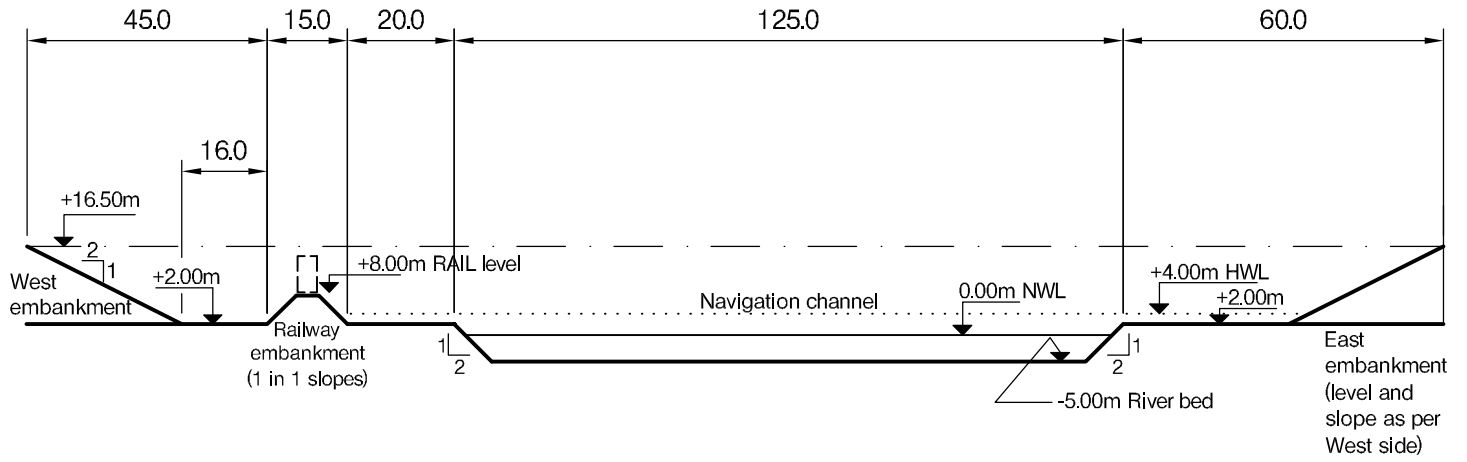
**(50 marks)**

- 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 if the inclined fascia on the south face of the building can be inclined further such that the overhang is 12m. Write a letter to the client, advising on the structural implications of this change with a description of ways to achieve it. (10 marks)

## SECTION 2

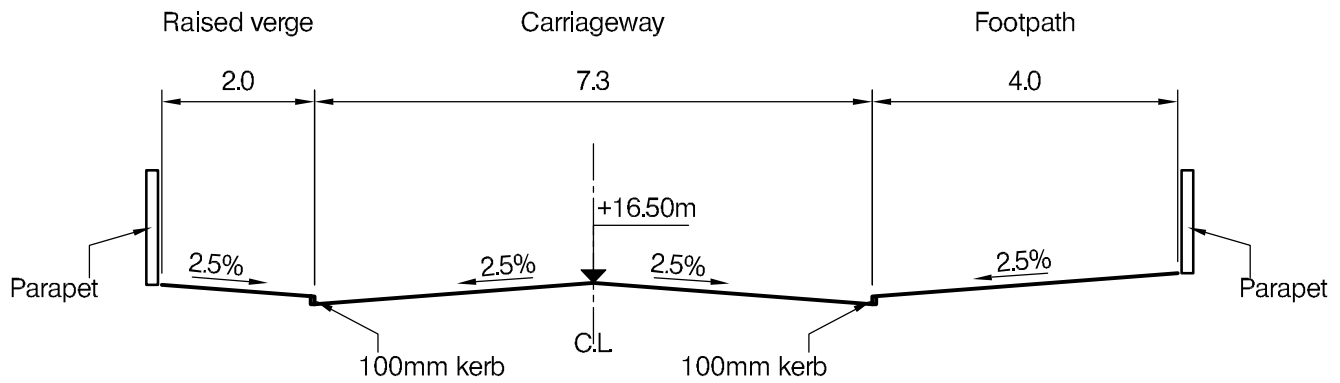
**(50 marks)**

- c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20marks)
- 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)



**LONGITUDINAL SECTION**

(At centre line of carriageway)



**CROSS SECTION**

NOTE: All dimensions are in metres

**FIGURE Q3**



## Q3. Crossing over River and Railway Line

### Client's requirements

1. A new road is to cross a 125m river within a flood plain and a single railway line as shown in Figure Q3. The river is navigable and the bridge shall always maintain a structure-free clearance of at least 50m wide and 10m tall from normal water level within the river.
2. The 265m long new bridge deck shall accommodate a 7.3m wide carriageway with pedestrian access provided within 2m wide raised verge on one side and 4m wide footpath on the opposite side. The edge of the deck shall accommodate vehicle containment parapets.
3. The single-track railway line is located over an embankment. No works are allowed within 2m from the base of the embankment and a minimum headroom of 6m is to be respected above the railway. The railway line shall be kept in service as much as possible during construction of the new bridge. The existing track may be closed every weekend from 24:00 hours Friday night to 22:00 hours on the following Sunday.
4. Due to spawning fish, any works within the water at normal water level is restricted within the period of January to June.
5. The site is within an environment sensitive area. The new structure is required to minimise the environmental impact from use of material, construction methods, maintenance and use.

### Imposed loading

- |                                       |                      |
|---------------------------------------|----------------------|
| 6. Traffic load on carriageway        | 10 kN/m <sup>2</sup> |
| Pedestrian load on verge and footpath | 5 kN/m <sup>2</sup>  |

An accidental horizontal ship impact load of 2000kN, acting perpendicular to the road at the maximum flood level for any support within the normal width of the river.

### Site conditions

7. The site is in a rural area. Basic wind speed is 44 m/s based on a 3 second gust; the equivalent mean hourly wind speed is 22 m/s.

### Ground conditions

8. Below 0.3m sand and gravel, N=30

### Omit from consideration

9. Design of the embankments (made of granular materials, N=15).

## SECTION 1

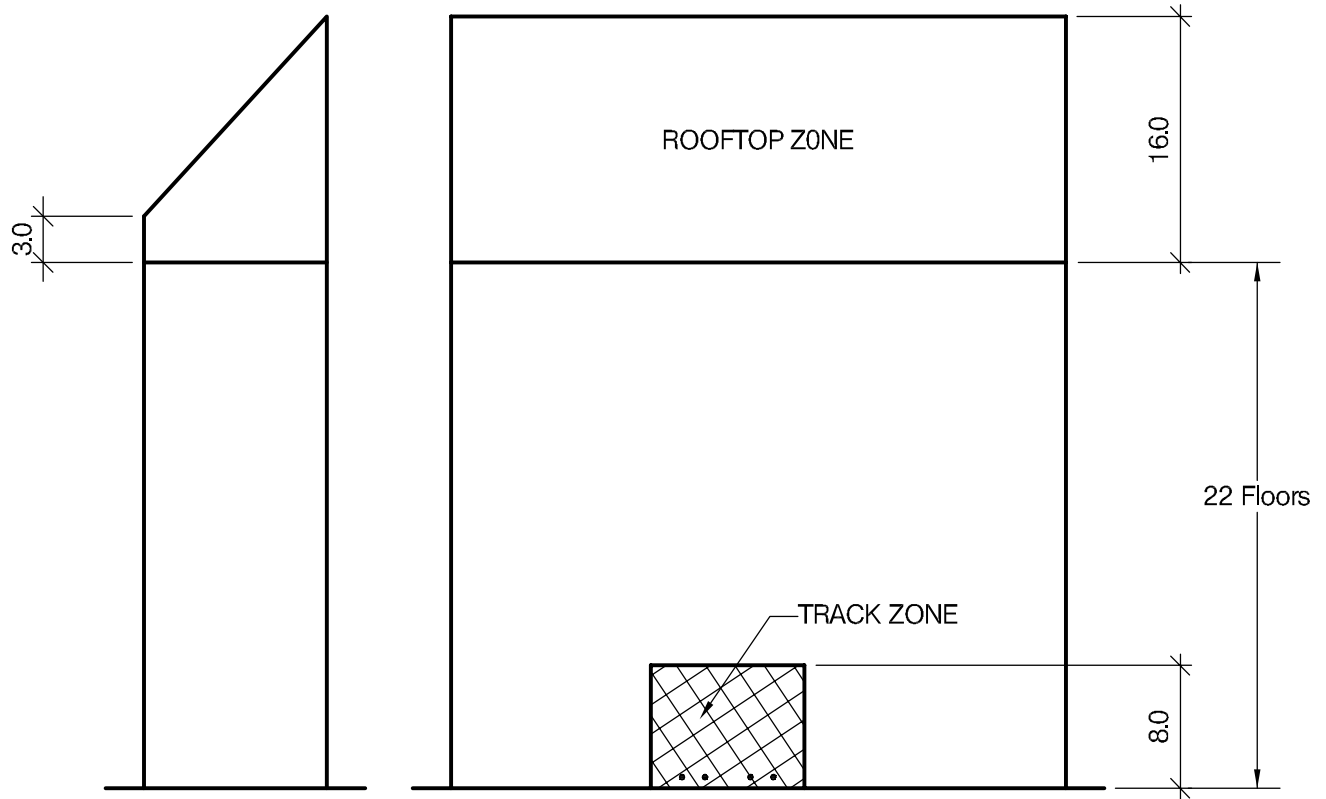
**(50 marks)**

- 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 authority requested an extended horizontal railway clearance of 15m to the East from the existing rail embankment. Write a letter to the Client explaining the design and construction implications and advising in which way the design would need to be modified to accommodate this constraint.  
(10 marks)

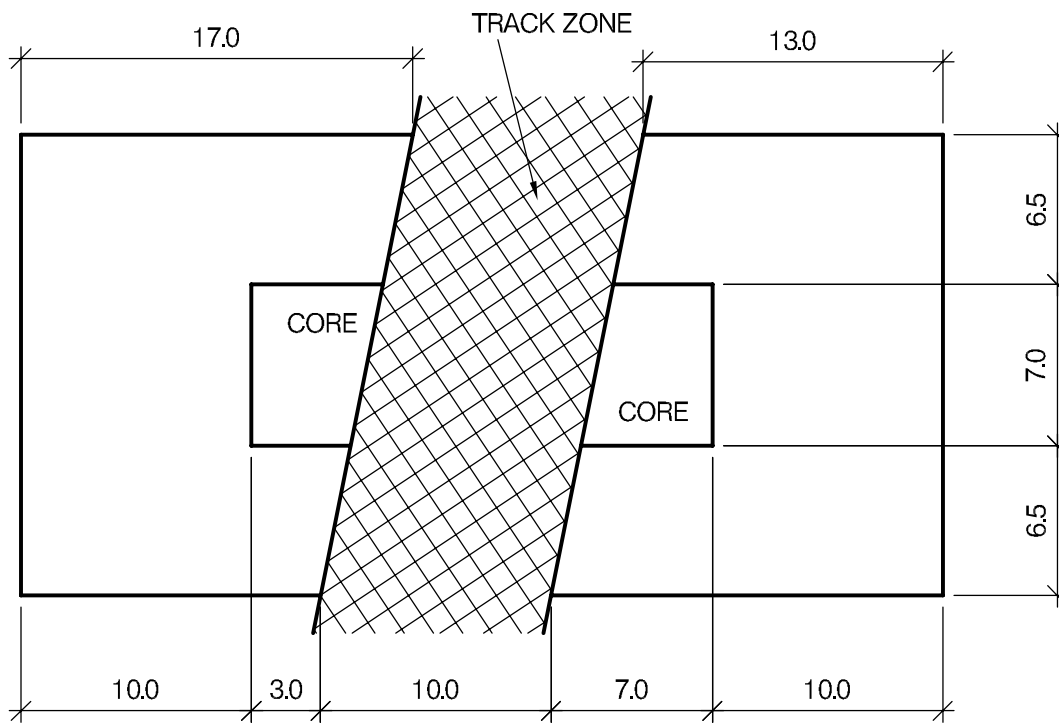
## SECTION 2

**(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 bridge and an outline construction programme in line with the railway possessions and seasonal requirements. Identify any principal temporary works necessary during the works.  
(10 marks)



ELEVATIONS



PLAN AT TRACK ZONE

NOTE: All dimensions are in metres

FIGURE Q4

## Q4. Tall building over tramway

### Client's requirements

1. A new headquarters office building is required for an insurance company. The site available is 23.0m by 43.0m in plan and is constrained by nearby roads and existing buildings. Two tram tracks run through the middle of the site and the building will have to span over these. See Figure Q4.
2. The building itself is to be 20.0m by 40.0m in plan and twenty-two floors are required in order to provide sufficient office space. A clear floor to ceiling height of 2.6m, a 0.2m raised floor and a 0.6m ceiling services zone are required. Two cores are required with external dimensions as shown. Except in the rooftop zone, no other internal vertical structure is allowed throughout the height of the building. See Figure Q4.
3. Building services plant, a sky garden and café area is to be provided at roof level in a clear space up to 16.0m high. The roof itself is to be glazed and clad in part with solar panels.
4. All foundations must be kept within the site area. Foundations may be provided under the tram tracks. No above ground structure, either temporary or permanent, is permitted for a height of 8.0m within the track zone. The client would not object to expressed structure on the external elevations within the site area.
5. The site is in a coastal city and concerns on climate change have led to a requirement to design against hurricane wind loads. The trams stop running between midnight and 6.00 am and work in the track zone is permitted during this period. The client has negotiated a continuous two-week period over Christmas when work can also be carried out in the track zone.

### Imposed loading

- |                                 |                       |
|---------------------------------|-----------------------|
| 6. Roof, including solar panels | 1.0 kN/m <sup>2</sup> |
| Roof garden floor               | 10.0kN/m <sup>2</sup> |
| Ground and office and floors    | 5.0kN/m <sup>2</sup>  |

A single accidental point load of 500.0kN shall be considered to act horizontally on a primary structural element adjacent to the track, at 1.2m above ground level

### Site conditions

7. The site is in a coastal city near the sea.
8. Basic wind speed is 64.0m/s based on a 3 second gust; the equivalent mean hourly wind speed is 32.0m/s.

### Ground conditions

- |                        |  |
|------------------------|--|
| 9. Ground level - 1.2m | Fill   |
| 1.2m – 2.5m            | Dense sand and gravel, N=30  |
| 2.5m – 35.0m           | Moderately weak weathered sandstone, safe bearing value 650kN/m <sup>2</sup> |
| Below 35.0m            | Strong unweathered sandstone, safe bearing value 6000kN/m <sup>2</sup>       |

Groundwater was found at 15.0m below ground

### Omit from consideration

10. Detailed design of 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. During construction of the foundations the client asks what the implications of adding a further two floors and changing the top 5 floors to residential would be. Write a letter to the client outlining possible solutions for this. 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 works and an outline construction programme. Identify any temporary works that may be required. (10 marks)

## Q5. Forestry Lookout Station

### Client's requirements

1. The forestry authorities require a temporary and reusable lookout tower for use in the summer months in a temperate climate. The tower needs to be transportable along forest roads in components and assembled on location with a minimum amount of equipment. The tower will be positioned within clearings in the forest and allow an open 360 degree view from the top.
2. The tower shall have an open platform with its flooring at an elevation of 20m above the ground. The platform shall have a minimum clear area of 9m<sup>2</sup> with safety rails 1.4m above the base of the flooring.
3. The towers shall be designed to resist both operational loads and extreme loads.
4. Ladder access to the platform is to be provided from the ground.
5. The structures shall have a design life of 30 years.

### Imposed loading

6. Operational loading:
 

Platform loading	3 kN/m <sup>2</sup>
Point load	20kN in a 0.5m x 0.5m area applied anywhere on the platform
7. Extreme loading:
 

Platform loading	self weight only
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### Site conditions

8. The tower shall be used at multiple sites within the forest. It may be assumed that the forest clearings are 30m in diameter and accessible by rough forest tracks. Operational wind speed is 24m/s based on a 3-second gust; the equivalent mean hourly wind speed is 12m/s. Extreme wind speed is 36m/s based on a 3-second gust; the equivalent mean hourly wind speed is 18m/s.

### Ground conditions

9. Assumed ground conditions at all sites shall be:
 

Ground level – 0.3m	Top soil
0.3m – 1.0m	Loose sand N = 20
1.0m – 6.0m	Medium sand N = 40
Below 6.0m	Rock, characteristic bearing strength = 4500 kN/m <sup>2</sup>

 Highest ground water was estimated 3.0m below ground level.

### Omit from consideration

10. Detailed design of ladders. However, the design appraisal should address their structural implications.

## 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, including the method of construction. Review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b. The first tower installation is partially underway when the erection engineers observe that the ground conditions are considerable worse than observed. Ground water is found at the surface and the loose sand has found to extend down to 3m in depth. Write a letter to the client explaining how the foundations could be modified onsite to overcome this unfortunate finding. (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)

**Please note that a figure is not provided for this question.**

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