

# Chartered Membership Examination

Tuesday 21 January 2025

## 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.

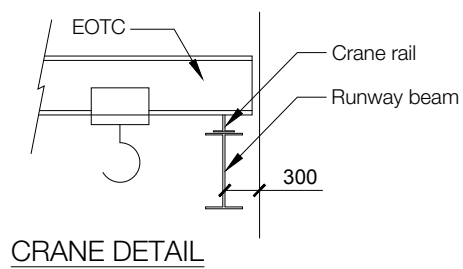
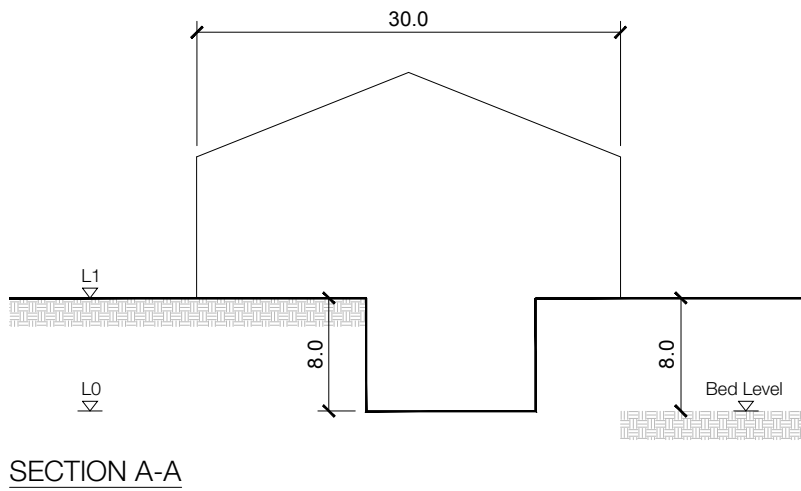
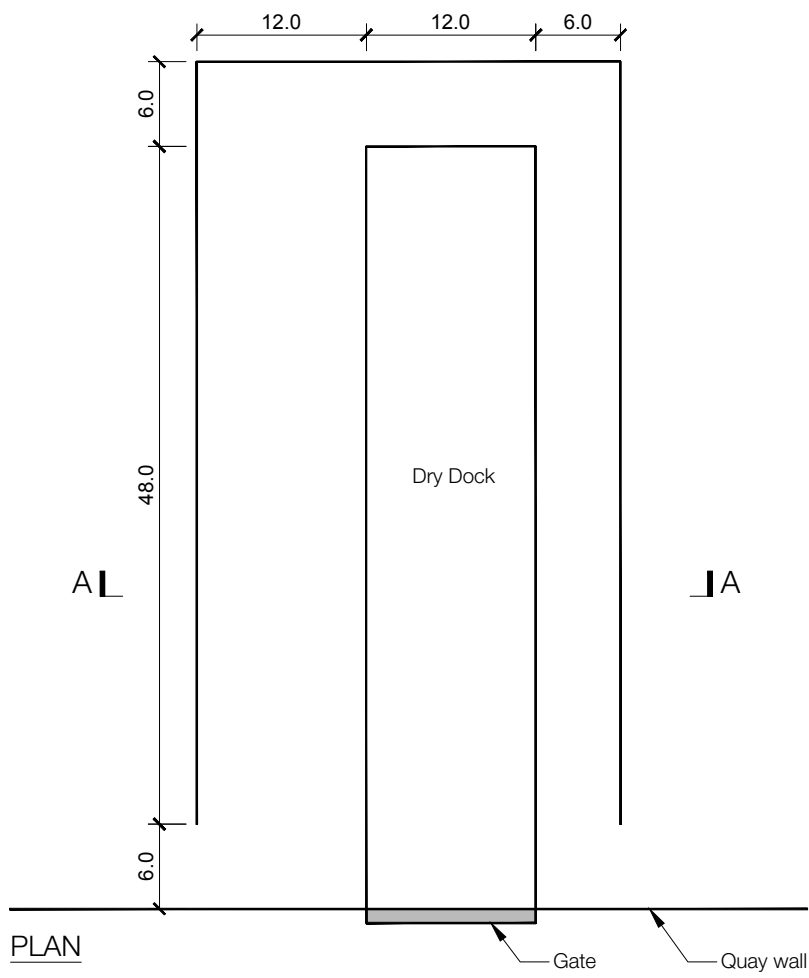
The Institution must be satisfied that you are able to bring all the various skills you are expected to possess to the effective solution of structural design problems, whether or not the problem is presented in terms that are within your actual experience.

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.



NOTE: All dimensions on details are in millimetres. All other dimensions are in metres.

FIGURE Q1

# Q1. Lakeside marine workshop

## Client's requirements

1. A lakeside marine workshop on a level site, see Figure Q1.
2. This consists of a building over a dry dock, which is open at the South end. Inside the building at the West side of the dry dock there is a workshop area.
3. The building over the dry dock is to have two single-girder Electric Overhead Travelling Cranes (EOTC) which can travel North to South along the length of the building. Each crane has a lifting capacity of 50kN and a self-weight of 15kN. Both cranes can be used independently or in tandem and are stored at the North end of the building when not in use.
4. Each end of the crane girders is supported on two wheels spaced 3.0m apart and a minimum of 300mm from supporting column face. The minimum distance between the wheels of two cranes in the direction of travel is 1.0m. The crane rail on top of the crane runway beam is 90mm high and weighs 0.18kN/m.
5. The clear height beneath the crane girder beam shall be 15m, and a clear height of 2.0m shall be provided between top of crane girder beam and underside of roof structure to allow operating space for the cranes.
6. Lightweight external cladding with 25% glazing and 10% roof lights. Two roller shutter doors are required, 11m in width and 8m in height on the West elevation.

## Imposed loading

7. Roof including services 1.5 kN/m<sup>2</sup>  
Workshop and dry dock surround 50.0 kN/m<sup>2</sup>  
Equivalent Line Load at centre line of dry dock for keel blocks 75 kN/m
8. Overhead crane imposed load effects.  
Vertical impact allowance 25%  
Longitudinal surge 10%  
Transverse surge 5%
9. A floating dock gate is to be provided which can be considered to apply water pressure to the side walls of the dry dock only.

## Site conditions

10. The site is on a level surface with an existing concrete quay wall. Basic wind speed is 40m/s based on a 3-second gust; the equivalent mean hourly speed is 20m/s.

## Ground conditions

- |                         |                                       |
|-------------------------|---------------------------------------|
| 11. Ground level – 0.3m | Topsoil.                              |
| 0.3m – 3.0m             | Very loose sand SPT = 2               |
| 3.0m – 8.0m             | Very dense sand and gravel SPT > 50   |
| Below 8.0m              | Stiff clay $C_u = 150 \text{ kN/m}^2$ |

The highest water level in the lake is 1m below ground level, the water level in the ground is to be considered the same as the lake. Bed level of the lake is 8m below ground level.

## Omit from consideration

12. Design of dock gate.
13. Draw down channel in the base of the dry dock or pump house.
14. Access into dry dock.

## SECTION 1

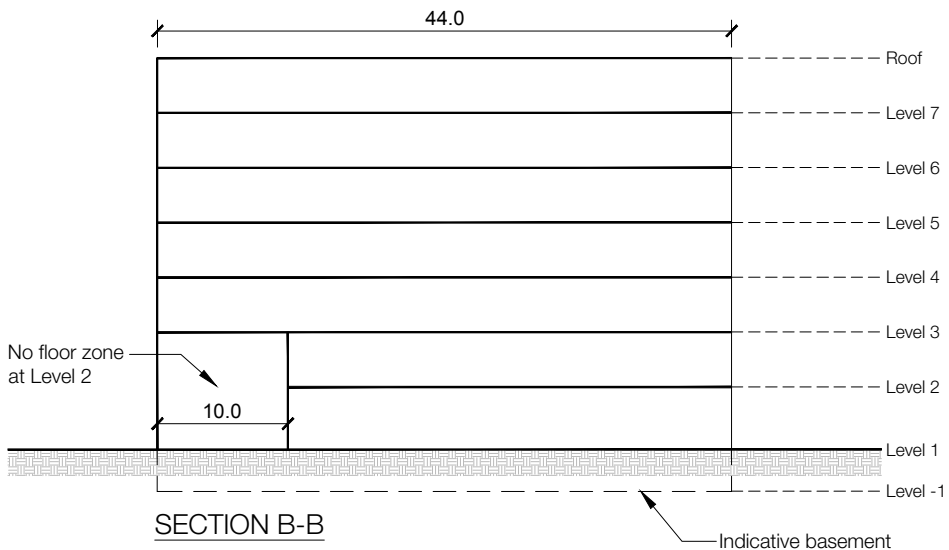
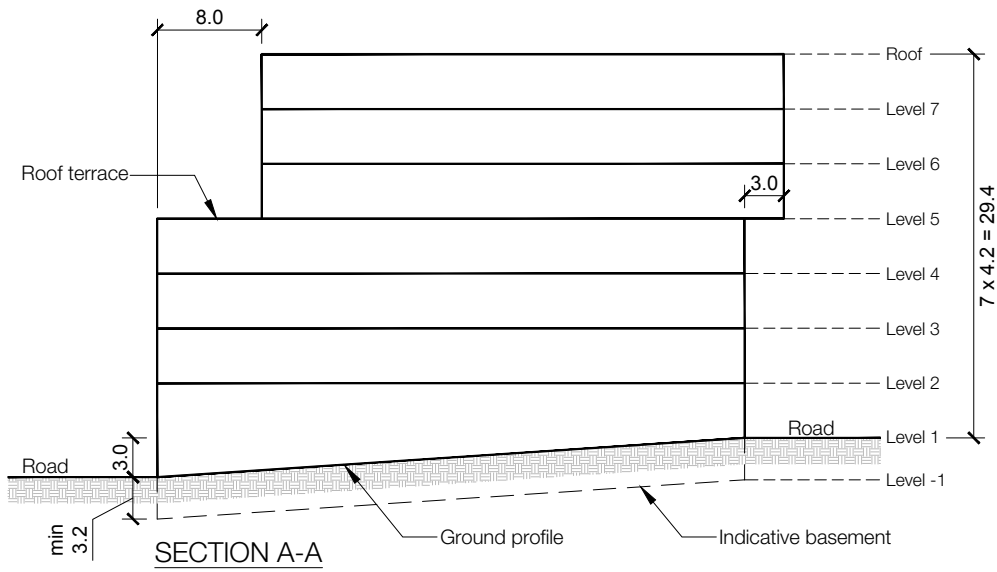
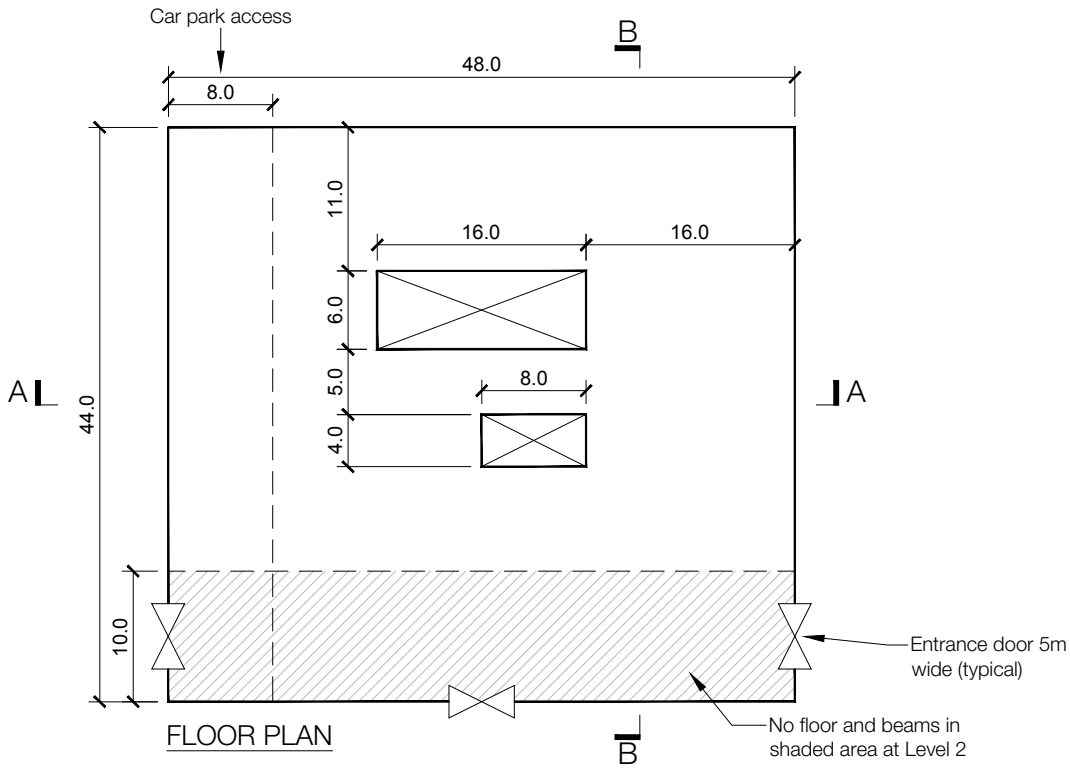
**(50 marks)**

- a) Prepare a design appraisal with appropriate sketches indicating two distinct, viable and sustainable solutions for the proposed structure including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability as a key criterion, review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b) After the scheme design has been completed, the client asks whether changes could be made to the brief in order to reduce the material usage while maintaining the overall building size, and a dry dock. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the design. (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. Include approximate A1-A3 carbon calculations for each of your principle elements. (22 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. (8 marks)



NOTE: All dimensions are in metres.

FIGURE Q2

## Q2. Government building

### Client's requirements

1. The client requires a new public service building in a city centre. The building comprises of offices and conference rooms for various government departments and is to be seven storeys plus a basement for car and bicycle parking, see Figure Q2.
2. The area shown shaded on the plan must be kept clear of any beams and floors between Levels 1 and 3. An external roof terrace will be provided on Level 5. The basement as shown is only indicative in view of the sloping site.
3. The minimum column centres spacing shall be 8m in both directions (this does not include distance between the walls and between external columns). Columns are permitted around the perimeter of lift/elevator/stair cores but not within the core areas.
4. Materials for the external envelope of the building shall be selected to minimise energy consumption while considering the function of the building.
5. The minimum clear floor-to-ceiling height shall be 2.70m for all levels above the ground, and 2.20m in the basement. A mechanical services zone of 350mm depth shall be allowed at all levels, except the basement. The overall height of the building is shown in Figure Q2. This height shall not be exceeded.
6. No bracings or shear walls are permitted internally or externally, except around the cores.
7. Cores accommodate lift/elevator shafts and stairs. No other cores are permitted except those shown in the figure.
8. The roof is flat and shall accommodate mechanical plant over an area of 200m<sup>2</sup>.
9. The building is to have a 2-hour fire rating.

### Imposed loading

10. Roof	1.00 kN/m <sup>2</sup>
Floors	5.0 kN/m <sup>2</sup>
Roof terrace	5.0 kN/m <sup>2</sup>
Plantroom	7.5 kN/m <sup>2</sup>

### Site conditions

11. The building is in an open area with the ground sloping in the east-west direction by 3m over the footprint of the building. The basic wind speed is 42m/s on a 3-second gust; the equivalent mean hourly wind speed is 21m/s.

### Ground conditions

12. Ground Conditions:	
0.0m – 0.5m	Made Ground
0.5m – 5.0m	Sandy Clay (C=80 kN/m <sup>2</sup> )
Below 5.0m	Stiff Sand (N=40)

Ground water was encountered at 8m below ground level.

### Omit from consideration

13. Detailed design of stairs/lifts/elevators, and façade cladding/glazing.

## SECTION 1

**(50 marks)**

- a) Prepare a design appraisal with appropriate sketches indicating two distinct, viable and sustainable solutions for the proposed structure including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability as a key criterion, review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b) After the scheme design has been completed, the client asks whether changes could be made to the brief in order to reduce the material usage while maintaining the floor plan and number of storeys as indicated. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the design. (10 marks)

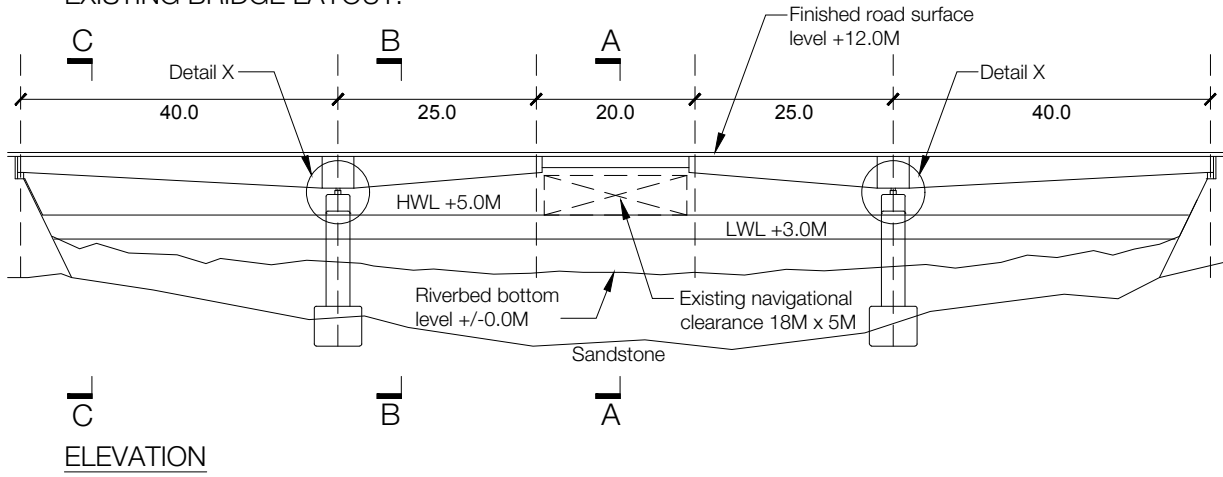
## SECTION 2

**(50 marks)**

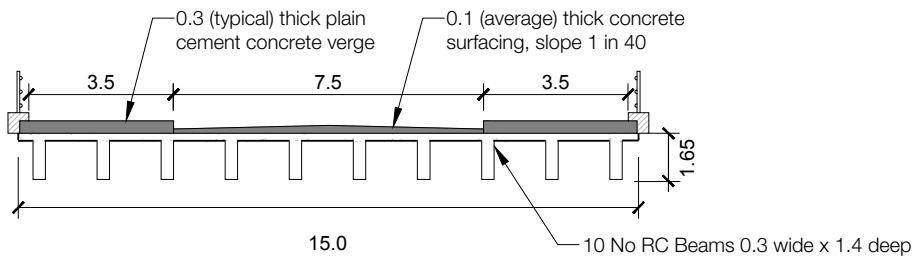
For the solution recommended in Section 1(a):

- c) Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. Include approximate A1-A3 carbon calculations for each of your principal elements. (22 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. (8 marks)

EXISTING BRIDGE LAYOUT:

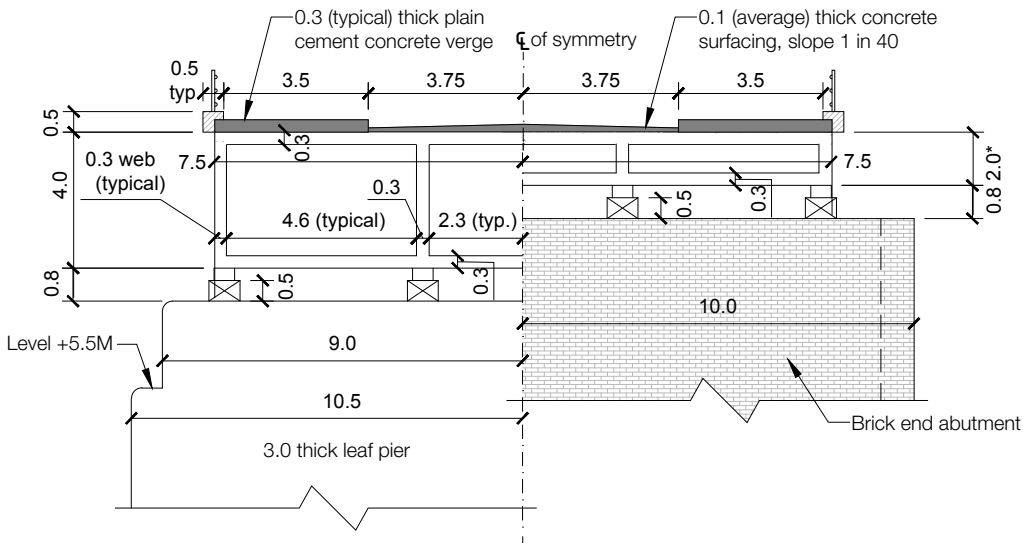


ELEVATION



SECTION A-A  
SUSPENDED SPAN CROSS SECTION

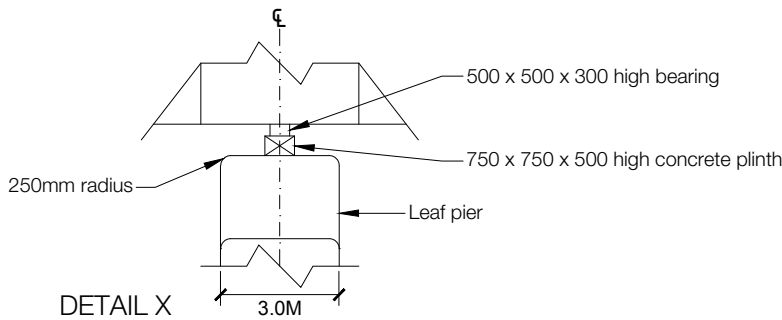
NOTE: Detailed dimensions are from as-built drawings, including associated text.



SECTION B-B  
HALF X-SECTION AT PIER

SECTION C-C  
HALF X-SECTION AT ABUTMENT

NOTE: \*Same super structure depth at half joint.

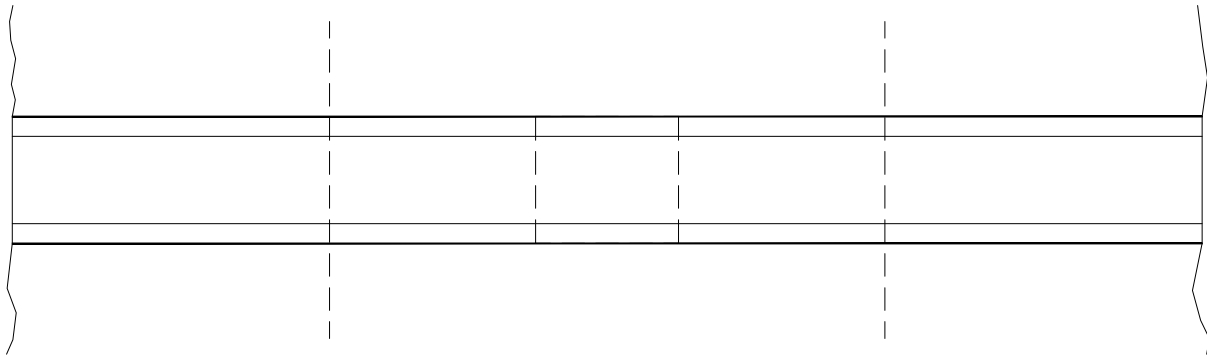


DETAIL X

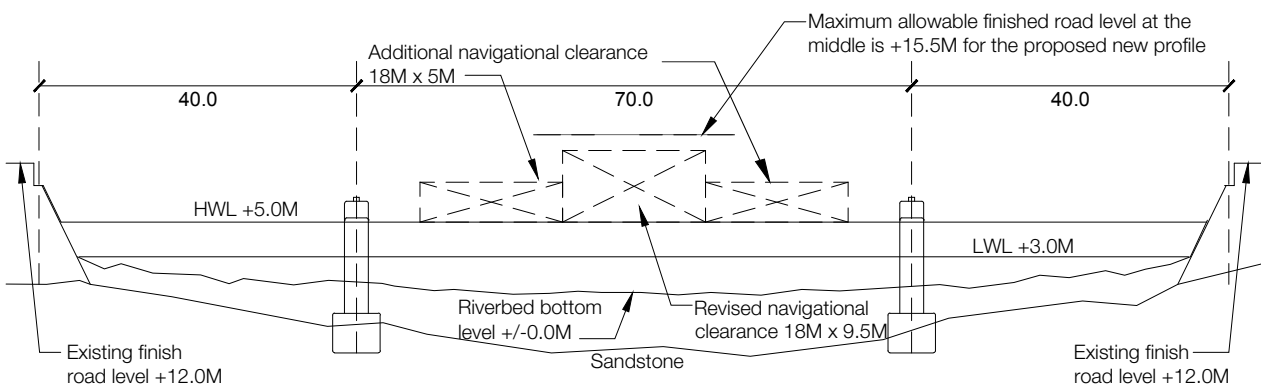
NOTE: All dimensions on details are in millimetres. All other dimensions are in metres.



PROPOSED BRIDGE LAYOUT:

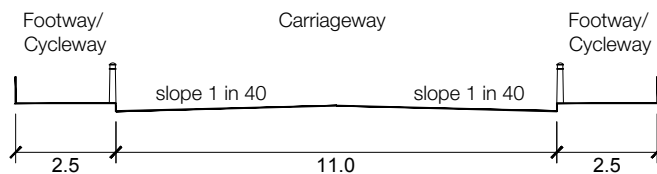


PLAN  
OUTLINE PLAN OF THE BRIDGE OVER THE RIVER



ELEVATION

NOTE: Intermediate pier may be reused, but abutment must be reused as shown in cross section of the river. Features (not shown) on side face of concrete box girder must be retained / reproduced on the new bridge.



SECTION

PROPOSED OUTLINE CROSS SECTION OF THE NEW / UPDATED BRIDGE

NOTE: Bollard shown / similar protection must be used. Kerb height minimum 0.2 metres.

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## Q3. Improvements to an existing bridge

### Client's requirements

1. An existing reinforced concrete box girder bridge over the main river of a large city needs to be replaced or refurbished to make it safer for pedestrians to use and to increase the navigational clearance envelope between the central piers as shown in Figure Q3.
2. The proposed configuration for the revised deck layout includes two 2.5m traffic lanes, two 3m bus lanes and two 2.5m pedestrian/cycleway lanes in total, also shown in Figure Q3.
3. The River Authority will not permit any new foundations in the watercourse; however, if it can be demonstrated that the new applied load is less than that originally designed for, substructures may be reused with necessary alteration. Total closure/shut down for construction is possible but the period must not exceed a total of six weeks over a year.

### Imposed loading

4. Footways 5.0kN/m<sup>2</sup>.
5. Carriageway 15kN/m<sup>2</sup> was used for design of existing bridge.  
10kN/m<sup>2</sup> may be used for design of bridge for proposed use.

### Site conditions

6. The site is in an urban area. Basic wind speed is 46.0m/s based on a 3-second gust, the equivalent mean hourly wind speed is 23.0m/s.

### Ground conditions

7. Sandstone, safe bearing capacity 1,000kN/m<sup>2</sup>.

### Omit from consideration

8. Design against loads from ship impact.

## SECTION 1

**(50 marks)**

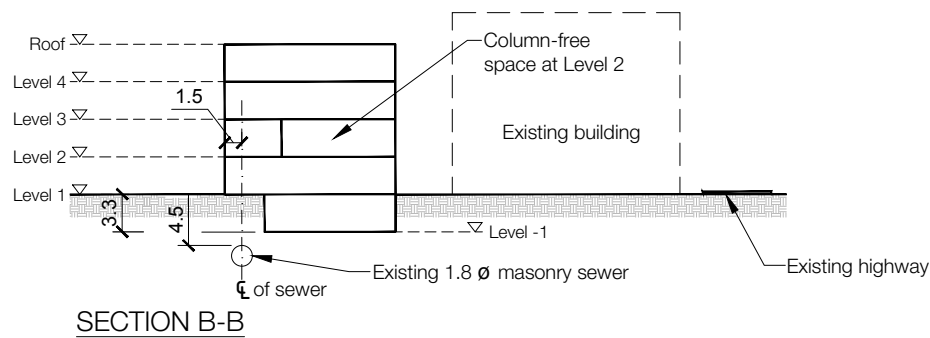
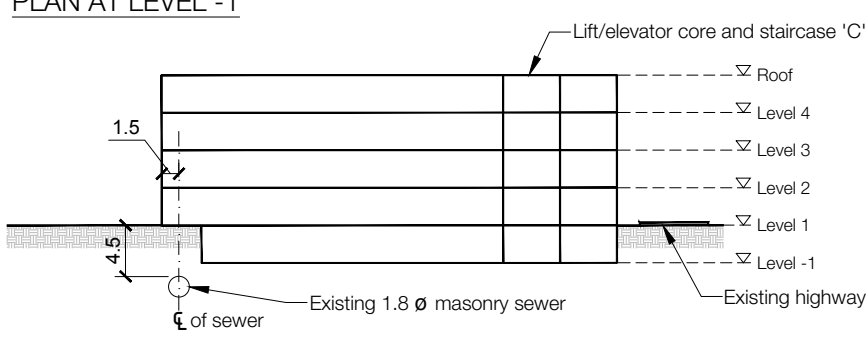
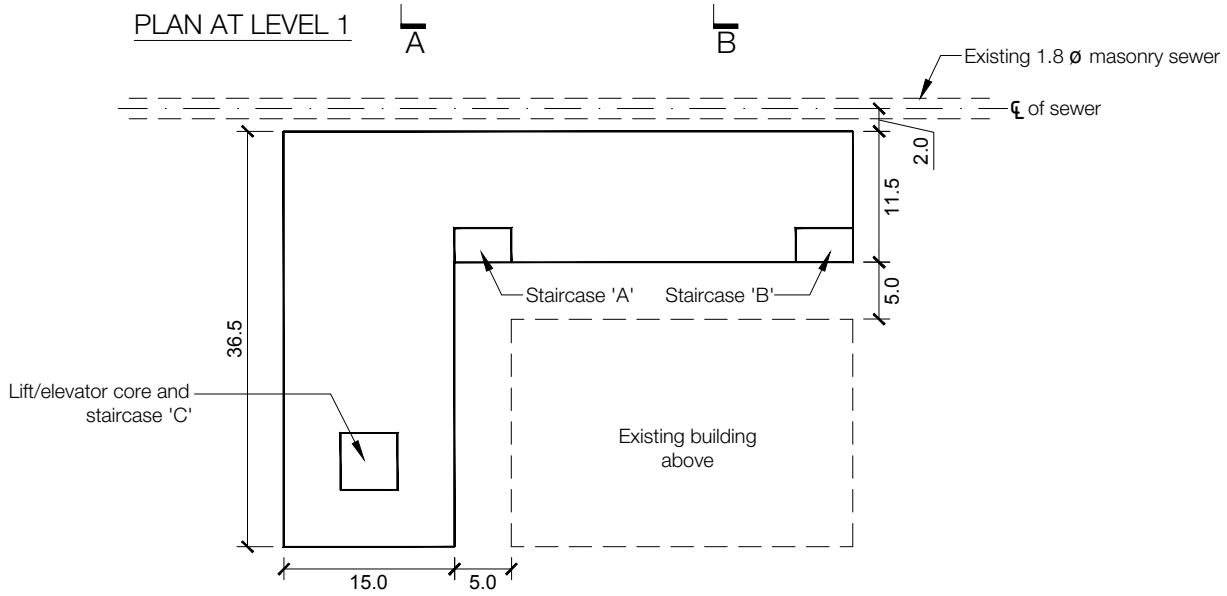
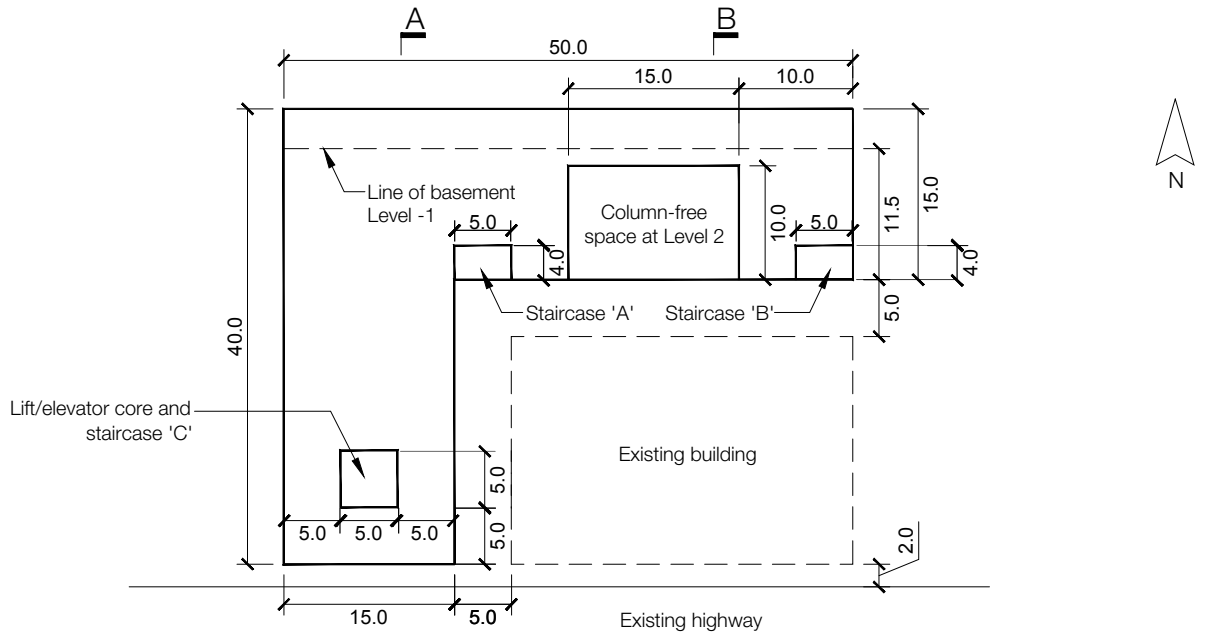
- a) Prepare a design appraisal with appropriate sketches indicating two distinct, viable and sustainable solutions for the proposed structure including the foundations. Reusing existing structures where required, clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability as a key criterion, review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b) After the scheme design has been completed, the client asks whether changes could be made to the brief in order to reduce the material usage while maintaining the increased navigational clearance. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have 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. Include approximate A1-A3 carbon calculations for each of your principal elements. (22 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. (8 marks)



NOTE: All dimensions are in metres.

FIGURE Q4

# Q4. Multi-storey library and study hall

## Client's requirements

1. The client requires a new 5-storey library and study hall building within a city centre to be constructed.
2. The building is located over an existing masonry sewer that cannot have any additional vertical load applied to its crown.
3. Column spacing to be a minimum of 5m centres. There are to be no columns within a portion of Level 2 where an open plan study hall is to be placed – see Figure Q4.
4. No excavations deeper than 300mm are permitted over the crown of the sewer.
5. The minimum clear floor-to-ceiling height is to be 2.75m and the services zone is to be 300mm deep.
6. The depth of the basement sub-structure is to be 3.3m from Level 1.
7. Access to the building is via the highway to the south of the structure.
8. The basement acts as a plantroom that serves the entire building.

## Imposed loading

- |           |   |
|-----------|---|
| 9. Roof   | 1kN/m <sup>2</sup>  |
| Floors    | 5kN/m <sup>2</sup> (storage) + 1kN/m <sup>2</sup> for internal partitions |
| Plantroom | 7.5kN/m <sup>2</sup>  |

## Site conditions

10. The site is flat. Basic wind speed is 42m/s based on a 3-second gust, the equivalent mean hourly wind speed is 21m/s.

## Ground Conditions:

0-2m	Made Ground
2-10m	Weak silty clay ( $C_u=$ )75kN/m <sup>2</sup>
10-15m	Firm Clay ( $C_u=$ )125kN/m <sup>2</sup>
15 to 30m	Stiff clay ( $C_u=$ )200kN/m <sup>2</sup>

Ground water was encountered at 2m below Level -1.

## Omit from consideration

11. Design of the staircase and lifts/elevators, and façade cladding.

## SECTION 1

**(50 marks)**

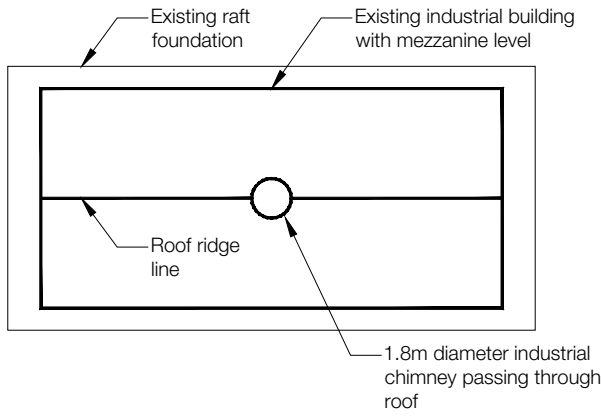
- a) Prepare a design appraisal with appropriate sketches indicating two distinct, viable and sustainable solutions for the proposed structure including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability as a key criterion, review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b) After the scheme design has been completed, the client asks whether changes could be made to the brief to reduce the material usage while maintaining the total plan floor area of the building. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the design. (10 marks)

## SECTION 2

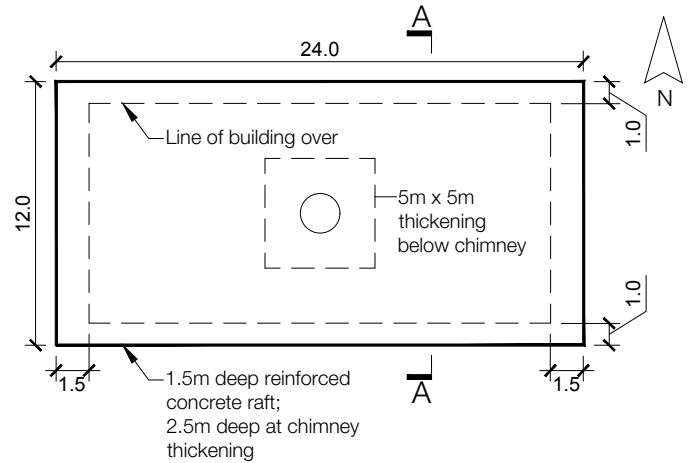
**(50 marks)**

For the solution recommended in Section 1(a):

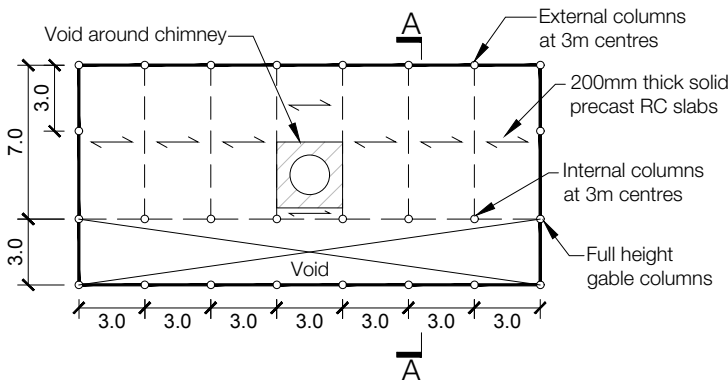
- c) Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. Include approximate A1-A3 carbon calculations for each of your principal elements. (22 marks)
- d) Prepare general arrangement drawings which may include plans, 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. (8 marks)



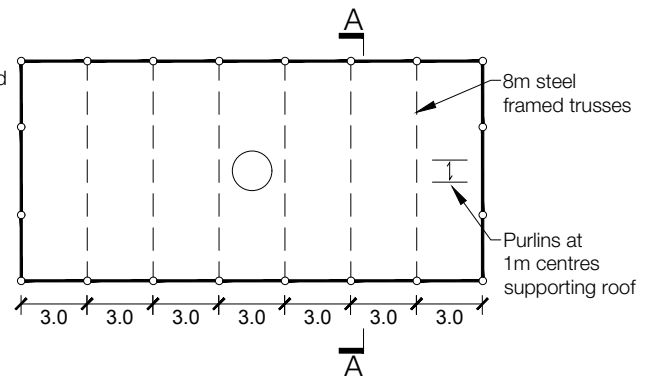
PLAN ON EXISTING BUILDING



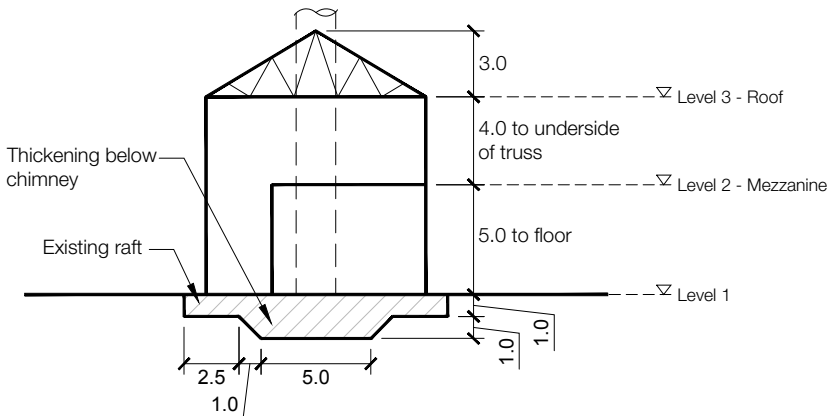
PLAN ON EXISTING FOUNDATIONS LEVEL 1



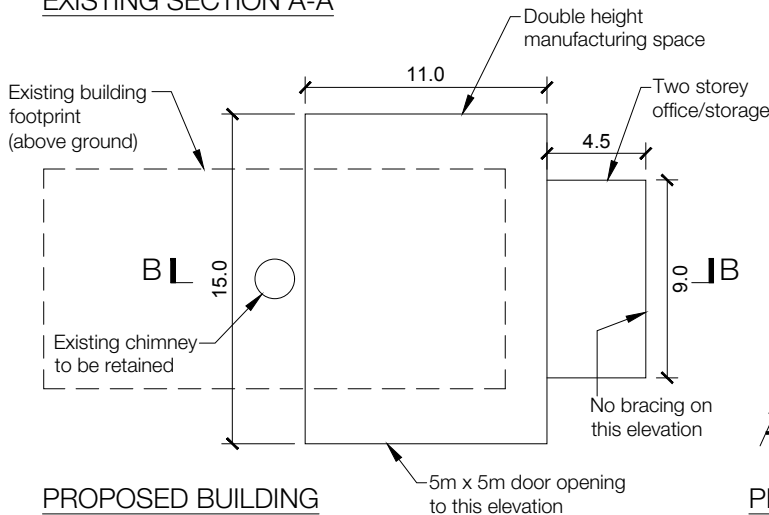
PLAN ON EXISTING BUILDING LEVEL 2



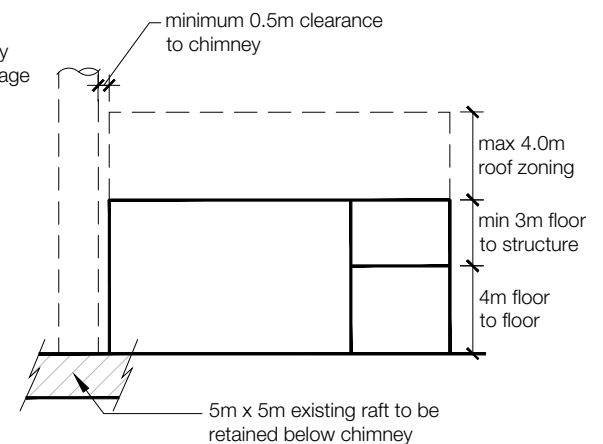
PLAN ON EXISTING BUILDING LEVEL 3 (ROOF)



EXISTING SECTION A-A



PROPOSED BUILDING



PROPOSED SECTION B-B

NOTE: All dimensions are in metres.

FIGURE Q5

## Q5. New industrial building on existing site

### Client's requirements

1. The client has an existing factory facility on the edge of a town. The existing building consists of a double-height steel frame, with a mezzanine floor that was added 10 years after the original construction. A chimney is situated in the middle of the building, and is structurally independent from the steel frame, other than a shared raft foundation. See Figure Q5.
2. Due to a requirement for a more efficient building, the client wishes to demolish the existing building and build a new facility. The client no longer needs the chimney for the industrial facility, but the chimney can not be demolished as it is a locally protected landmark. As a result, the client would like to construct a new building adjacent to the chimney. See Figure Q5.
3. The new building will consist of a double-height manufacturing space, and a 2-storey office/storage space. Access to the upper floor of the 2-storey section will be via a staircase from the adjacent double-height space. See Figure Q5.
4. The double-height space cladding is to be insulated composite cladding panels. No internal columns are permitted within the double-height space. A large door opening is required at one end of the building.
5. The 2-storey space is to be clad in brickwork on the 3 external faces, and a single skin of blockwork on the edge of the double-height space. No openings are allowed in one elevation due to window and door openings.

### Loading

6. Research has determined the existing structure to be in good condition. Level 1 was originally designed to safely support a variable load of 50 kN/m<sup>2</sup>, and the mezzanine floor was originally designed to safely support a variable load of 15 kN/m<sup>2</sup>. The existing roof cladding and services self-weight is 1.5 kN/m<sup>2</sup>.
7. Level 1 of the new building double-height space is to support a variable total load of 15 kN/m<sup>2</sup>. Both levels of the 2-storey space are to support a variable total load of 7.5kN/m<sup>2</sup>. The new building roof is to support a services load of 0.25 kN/m<sup>2</sup>.

### Site conditions

8. Basic wind speed is 40m/s based on a 3-second gust; the equivalent mean hourly speed is 20m/s.

### Ground conditions

- |                        |                                |
|------------------------|--------------------------------|
| 9. Ground level – 0.5m | Variable fill material         |
| 0.5m – 1.5m            | Medium Sand and Gravel. N = 20 |
| Below 1.5m             | Stiff Clay. Cu = 150           |

No ground water encountered.

### Omit from consideration

10. Design of access to upper level of 2-storey space.
11. Existing chimney, other than foundations.

## SECTION 1

**(50 marks)**

- a) Prepare a design appraisal with appropriate sketches indicating two distinct, viable and sustainable solutions for the proposed structure including the foundations. Reusing existing structures where possible, clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability as a key criterion, review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 marks)
- b) After the scheme design has been completed, the client advises that he now has permission to demolish the chimney, so that no longer provides a constraint. Advise the client on whether changes could be made to the brief in order to reduce the material usage while maintaining the proposed floor space of the new build development. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have 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. Include approximate A1-A3 carbon calculations for each of your principle elements. (22 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. (8 marks)

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