

Chartered Membership Examination

Tuesday 16 July 2024

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 on the question paper, 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.

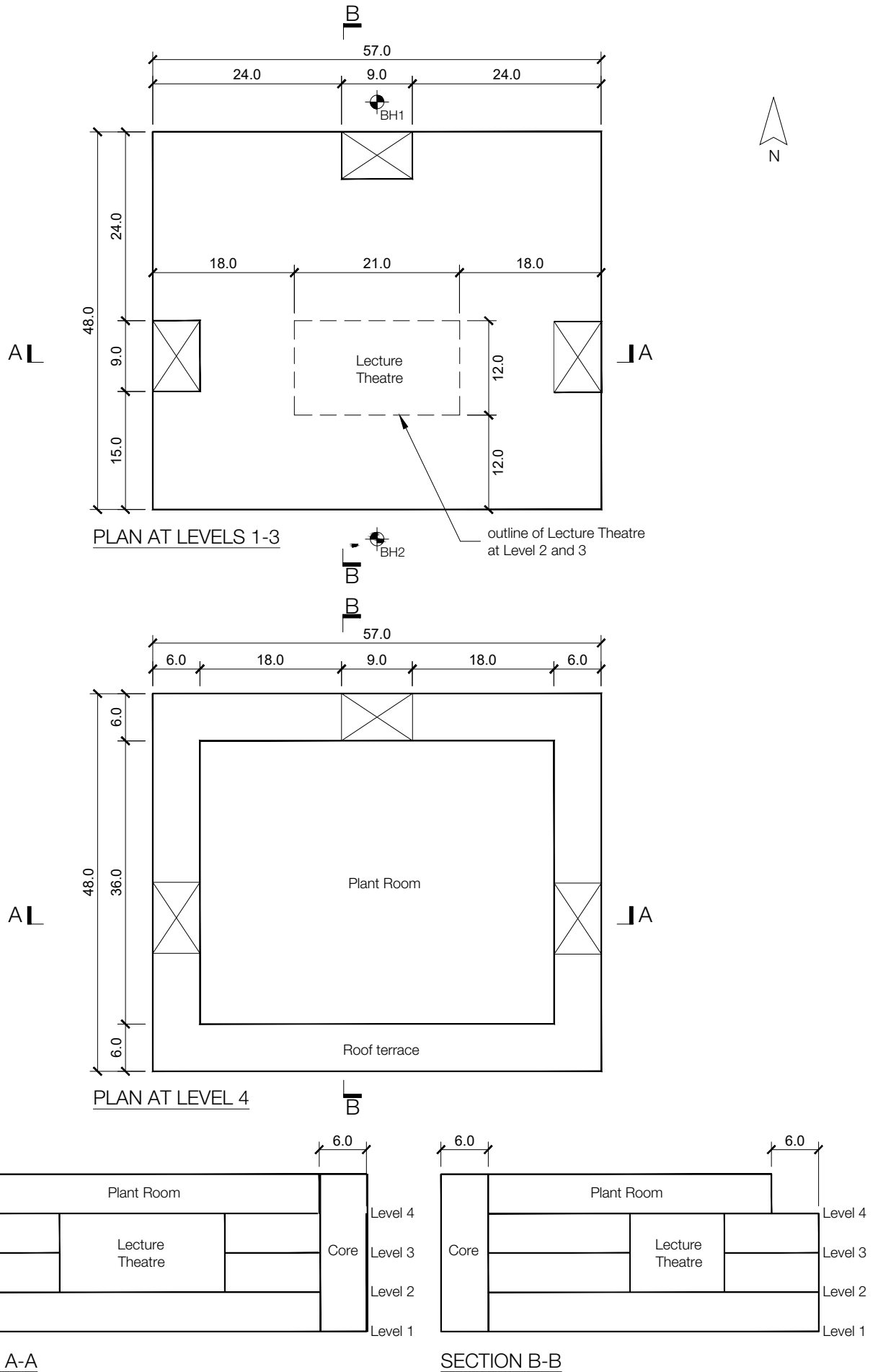


FIGURE Q1

Q1. University teaching hub

Client's requirements

1. A 4-storey teaching hub building is to be constructed on the outskirts/edge of a city. See Figure Q1.
2. The building up to Level 4 is masonry-clad with vertical strip windows occupying at least 25% of the elevational area, while the plant room is clad entirely with a lightweight cladding panel system. No visible bracing is permitted on any elevation.
3. On Levels 1, 2, & 3 internal columns must have a minimum spacing of 6.0m centre to centre as well as from external walls and stair/lift/elevator cores, there is no restriction on external column spacing. For the plant room at Level 4, there must be no more than 6No. internal columns to facilitate the spatial planning of plant and equipment, with a minimum spacing of 9.0m centre to centre.
4. The lecture theatre on Level 2, which measures 21.0m x 12.0m on plan, is to have no internal columns.
5. At Levels 1, 2, & 3 the floor-to-floor height is to be 4.5m, with a floor to ceiling height of 2.7m and a 0.6m service zone. The only variation to this is in the lecture theatre where the floor to ceiling height is to be 6.0m in addition to a 0.6m service zone. At Level 4 the height to the underside of the roof structure must be 3.8m.

Imposed loading

6. General floor loading 4.0kN/m²
Plant room 7.5kN/m²
Roof (general) 1.5kN/m², roof (plant room) 0.75kN/m²

Site conditions

7. The building is located on a relatively flat inland site. Basic wind speed is 40.0m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20.0m/s.
8. The ground conditions are as follows, which may be linearly interpolated between the boreholes:

Borehole 1

Ground – 1.0m	Soft clay (C=75kN/m ²)
1.0m – 4.0m	Stiff clay (C=250kN/m ²)
Below 4.0m	Rock, characteristic bearing strength = 4500 kN/m ²

Borehole 2

Ground – 3.0m	Soft clay (C=75kN/m ²)
3.0m – 10.0m	Stiff clay (C=250kN/m ²)
Below 10.0m	Rock, Rock, characteristic bearing strength = 4500 kN/m ²

No groundwater is present.

Omit from consideration

9. Design of the lifts/elevators and stairs

SECTION 1

(50 marks)

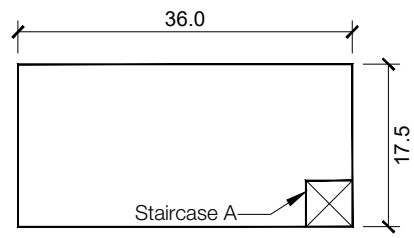
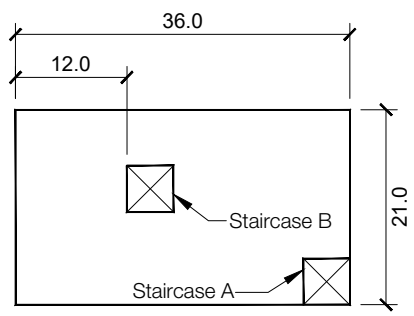
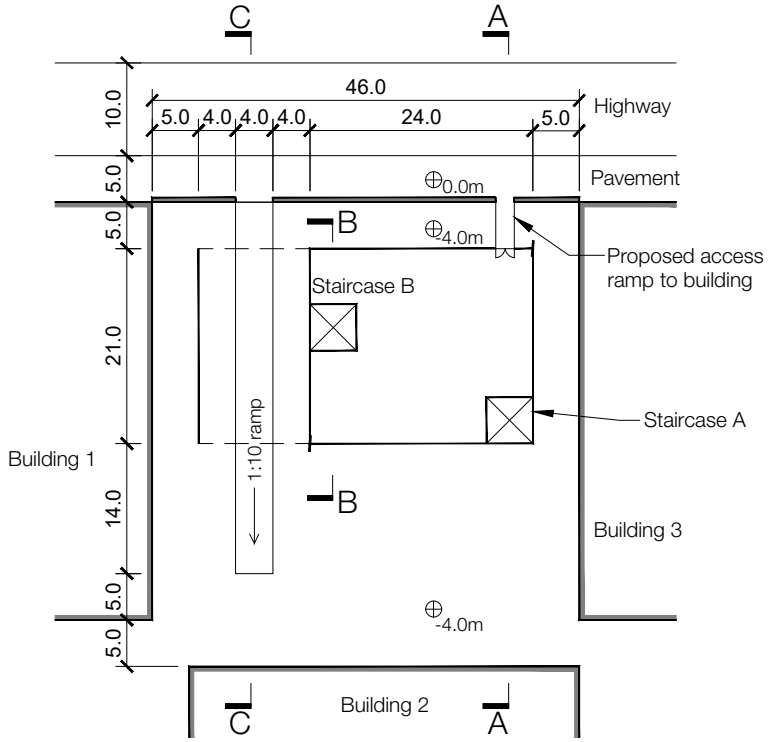
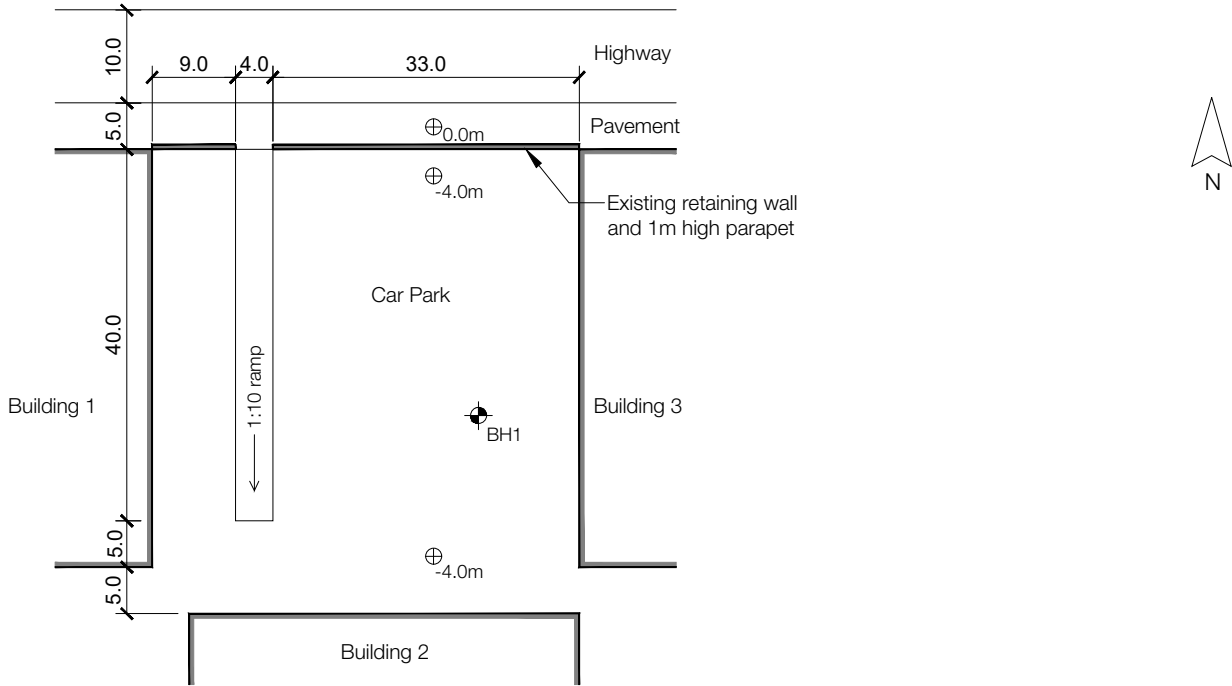
- a) Prepare a design appraisal with appropriate sketches indicating two distinct, viable, and sustainable solutions for the proposed structure including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability 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 usage of materials, whilst maintaining the number of floors as indicated. As part of any proposals made, explain the effect this may have on the design. (10 marks)

SECTION 2

(50 marks)

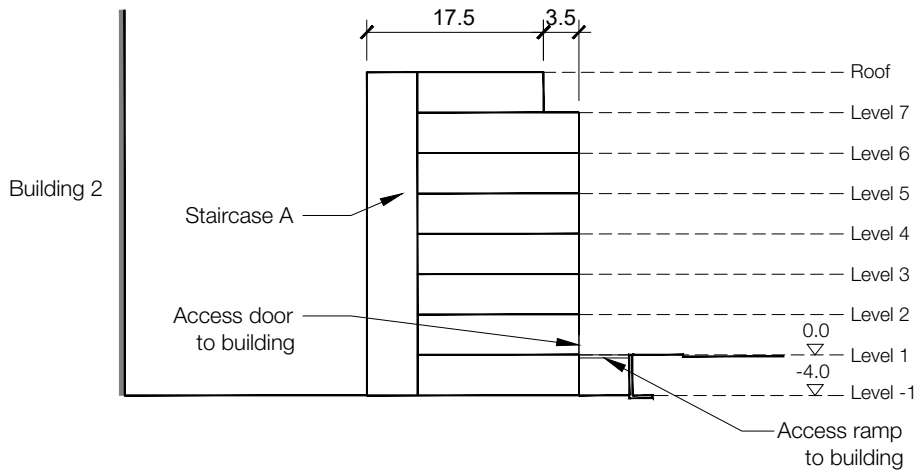
For the solution recommended in Section 1(a):

- 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)

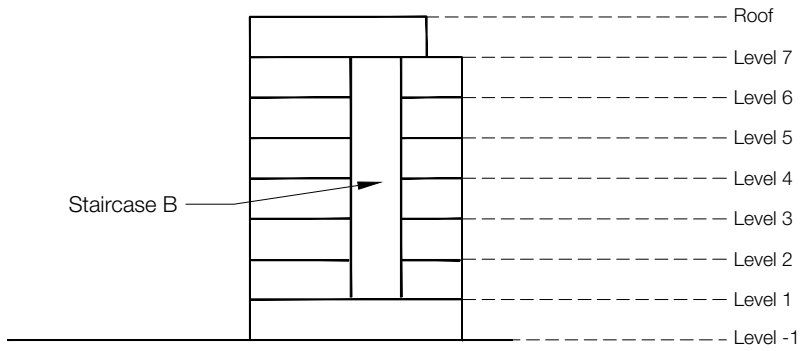


NOTE: All dimensions are in metres.

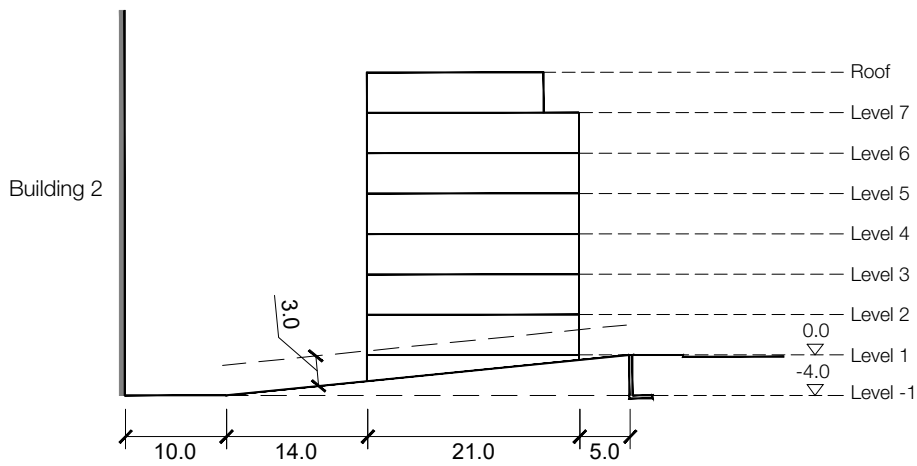
FIGURE Q2



SECTION A-A



SECTION B-B



SECTION C-C

NOTE: All dimensions are in metres.

Q2. Multi-storey residential/student accommodation development

Client's requirements

1. The client requires a new 8-storey student accommodation building within a city centre surrounded by multi-storey buildings of similar height to be built. Level L1 is to serve as a communal area and reception, see Figure Q2. Access to the building at Level L1 will be via a bridge constructed after the building is completed by others.
2. An existing vehicle ramp from the highway level, which provides secondary access down to a car park area into Level L-1 of Building 2, is to be retained in the permanent condition and during construction except for restricted periods. A minimum 2m clear gap shall be left between the new building and both sides of the ramp, and no columns are permitted in this zone.
3. Staircase A has a lift/elevator and staircase within it and serves all floors. Staircase B contains a staircase that provides access to Level L1 through to Level L7 only. The size of Staircases A and B is a minimum of 16m², their locations are indicated on Figure Q2. The North to South location of Staircase B can be selected to suit the structural layout. The building is to be clad in masonry in all elevations. There are no windows to the eastern and western facing walls due to the proximity of the neighbouring buildings and 40% glazing of the elevational area to all other elevations.
4. Foundations to the existing ramp and retaining wall are within their footprint and are 1m below Level L-1.
5. Column spacing to be no closer than 4m, which includes distance to shear walls. No internal bracing or walls are permitted away from stair cases within the floorspace.
6. Columns on the northern elevation adjacent to the highway are to be designed to withstand a vehicular impact of 250kN at 375mm above the finish floor of Level L1.
7. All adjacent buildings have a single-storey basement that is at Level L-1.
8. The finish floor level of Level L2 is 5m above the finished floor level of Level L1. The minimum clear height from the finish floor level of Level L1 to the ceiling of Level L1 is to be 3m to allow for vehicle access. The minimum clear floor to ceiling height between all other floors is to be 2.75m and the maximum height of the building is 30m from Level L-1 basement.
9. The basement at Level L-1 acts as a plant room that serves the entire building.

Imposed loading

10. Roof	1kN/m ²
Floors	1.5kN/m ² + 1kN/m ² for internal partitions
Plantroom	7.5kN/m ²

Site conditions

11. The site contains a car park where the proposed development is to be constructed. Basic wind speed is 42.0m/s based on a 3-second gust; the equivalent mean hourly speed is 21.0m/s.
12. Ground Conditions:
Borehole 1 log indicates the following soil profile:
0m-0.5m – Made Ground (N=5)
0.5m-5m – Medium dense sand (N=25)
Below -5m – Dense sand (N=45)
Ground water was encountered at 10m below Level L-1

Omit from consideration

Design of the staircases and façade cladding.
Design of the ramp at L1 to the pavement.

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.

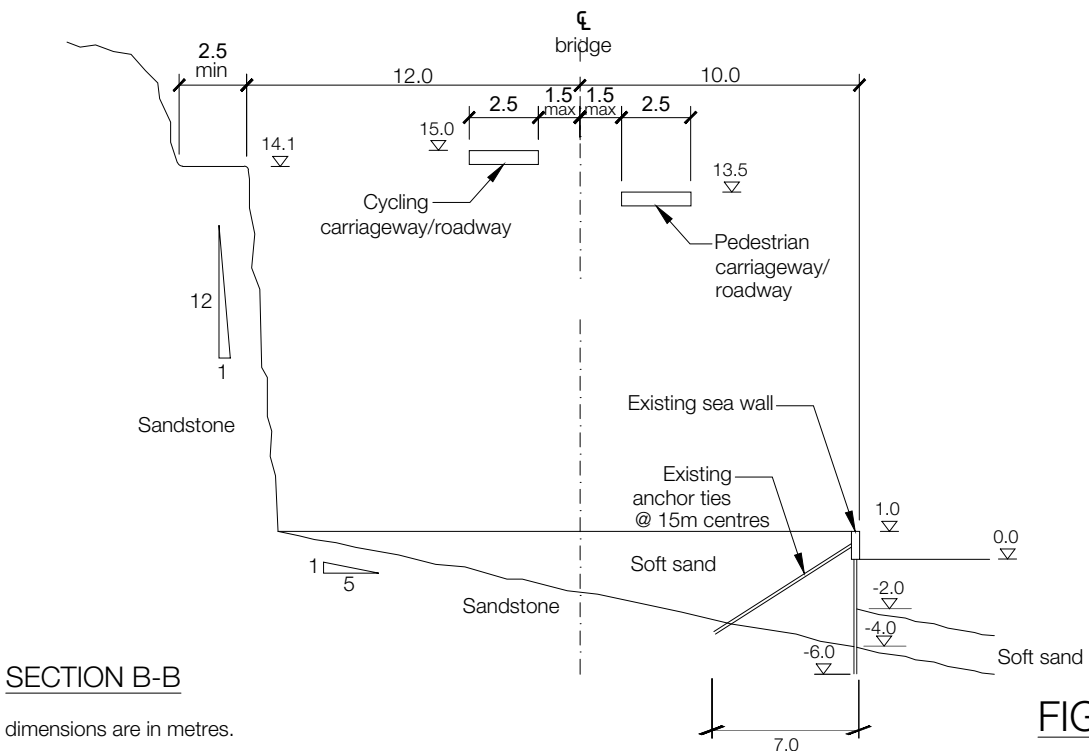
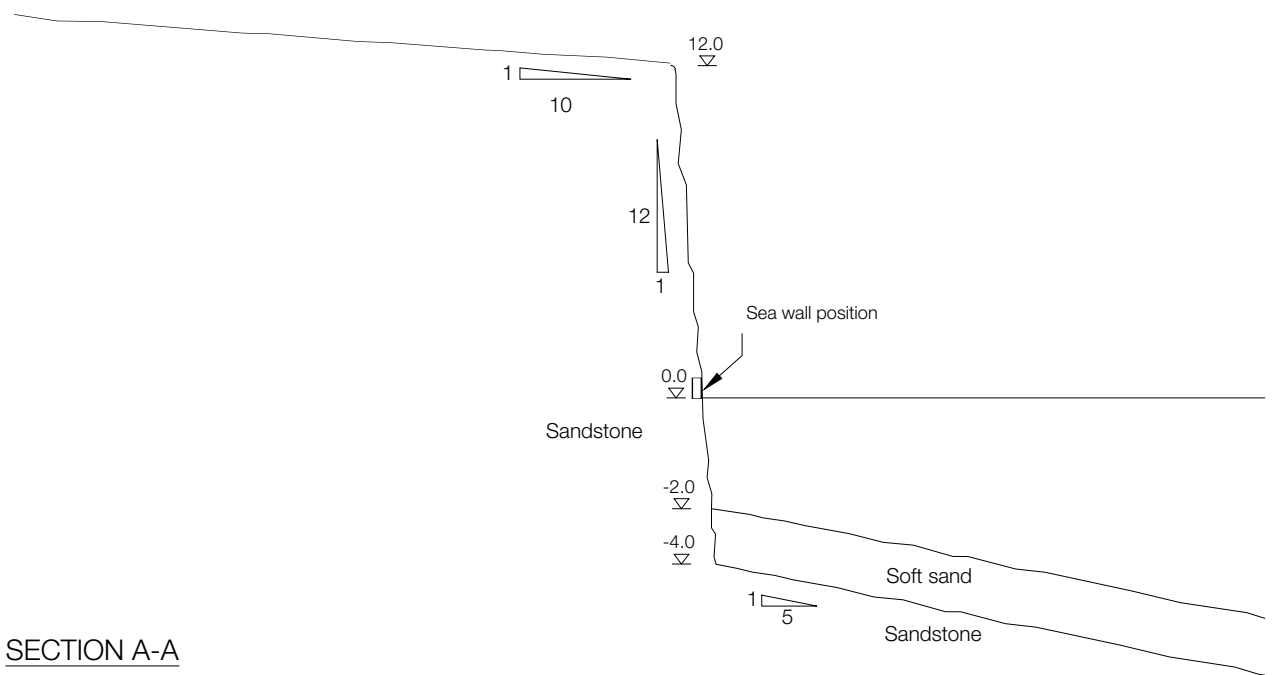
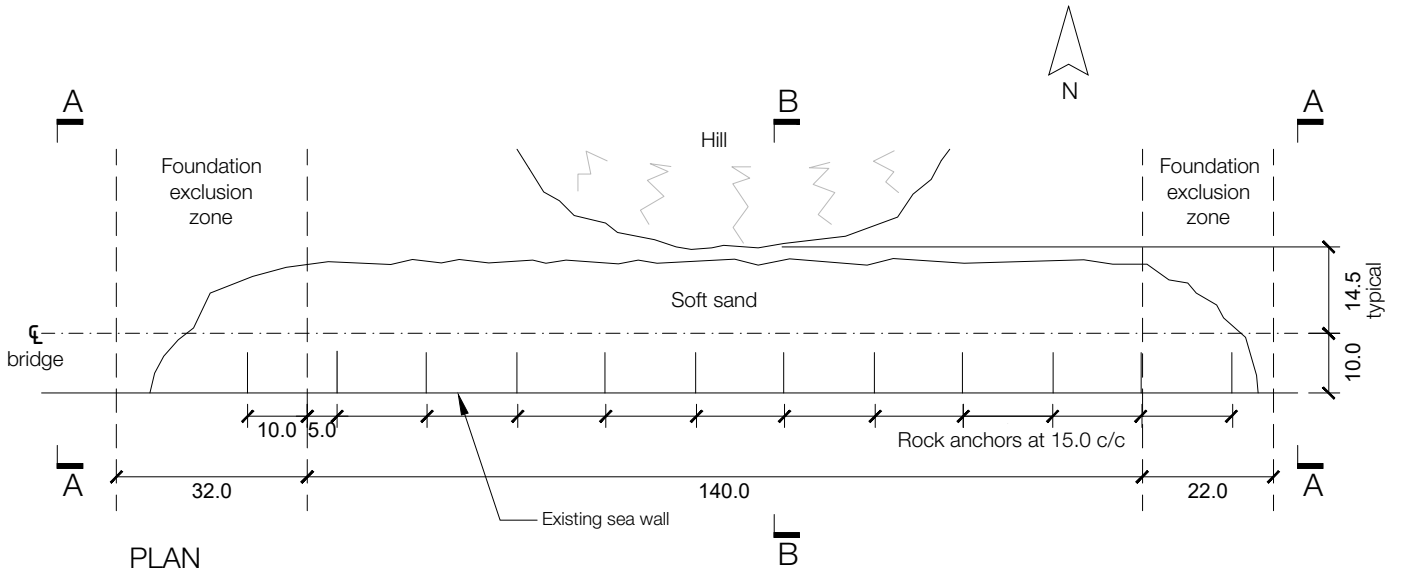
(40 marks)
- b) After the scheme design has been completed, the client asks whether changes could be made to the brief in order to reduce usage of materials, whilst maintaining the floor plan as indicated. Write to your client proposing possible changes explaining the effect this may have on the design.

(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)



NOTE: All dimensions are in metres.

FIGURE Q3

Q3. New coastal path cycleway and pedestrian bridge

Client's requirements

1. An existing path runs around the edge of an ancient slope failure from a coastal cliff system. Access around the back of the slope failure is limited by a hill and has been deemed to be unsafe to users due to rockfall risk from the steep hill slopes. The client requires that a new pedestrian and cycle bridge is designed to span across the slope failure zone.
2. The material from the slope failure has long since eroded away and has left a sandy shelf that has been protected by an existing sheet pile wall that is supported by rock anchors at 15m centres. Owing to limited knowledge of the construction of these anchors, no temporary or permanent load may be placed above any rock anchor, or 4m laterally either side of the rock anchor centreline. The extent of the anchors is shown on the plan view and Section B-B of Figure Q3.
3. The site is also one of high environmental interest and therefore the client requires that the footprint of the new bridge must be reduced to the barest minimum, both permanently and temporarily.
4. The edge of the slope failure runs parallel to the coast and has been found to be stable except at the east and west edges where zones of exclusion have been defined. These are shown on Figure Q3. The zones of exclusion contain rock strengths of variable quality and therefore no structure may be supported in these zones either permanently or temporarily. Abutments must be placed outside these zones.
5. The new bridge is to contain two carriageways/roadways, the northern one for cyclists and the southern one for pedestrians: each is to be 2.5m wide. To maximise the view from the carriageways/roadways, both are to be staggered in elevation such that the southerly carriageway/roadway is 1.5m in elevation below the northern carriageway/roadway for the spans of the bridge between the zones of exclusion. Each carriageway/roadway may be offset laterally from the bridge centreline by up to 1.5m in plan.
6. Parapet/handrail heights are to be 1.4m for the cycleway and 1.1m for the pedestrian deck.

Imposed loading

7. Both carriageway/roadways: Live Load intensity 5 kN/m²

Site condition

8. Basic wind speed is 40.0m/s based on a 3-second gust; the equivalent mean hourly speed is 20.0m/s.

Ground conditions

9. The sandstone is of a uniform bearing condition with an allowable bearing pressure of 2000 kN/m² in any direction. The soft sands have $N = 5$

Omit from consideration

10. Design of parapets/handrails.

SECTION 1

(50 marks)

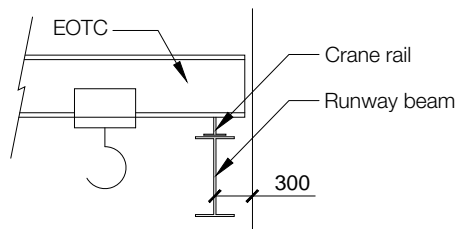
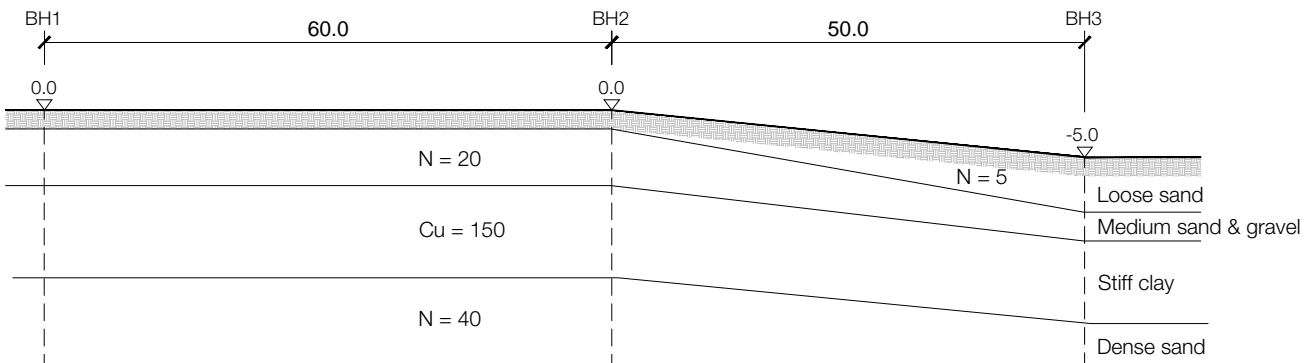
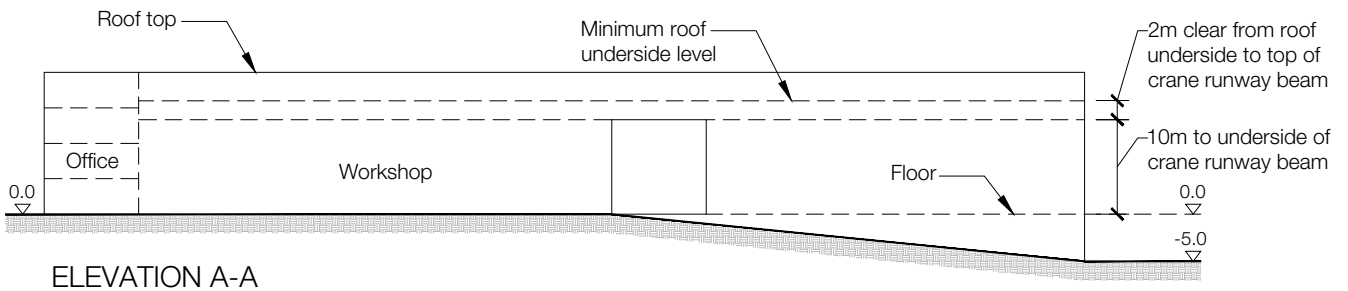
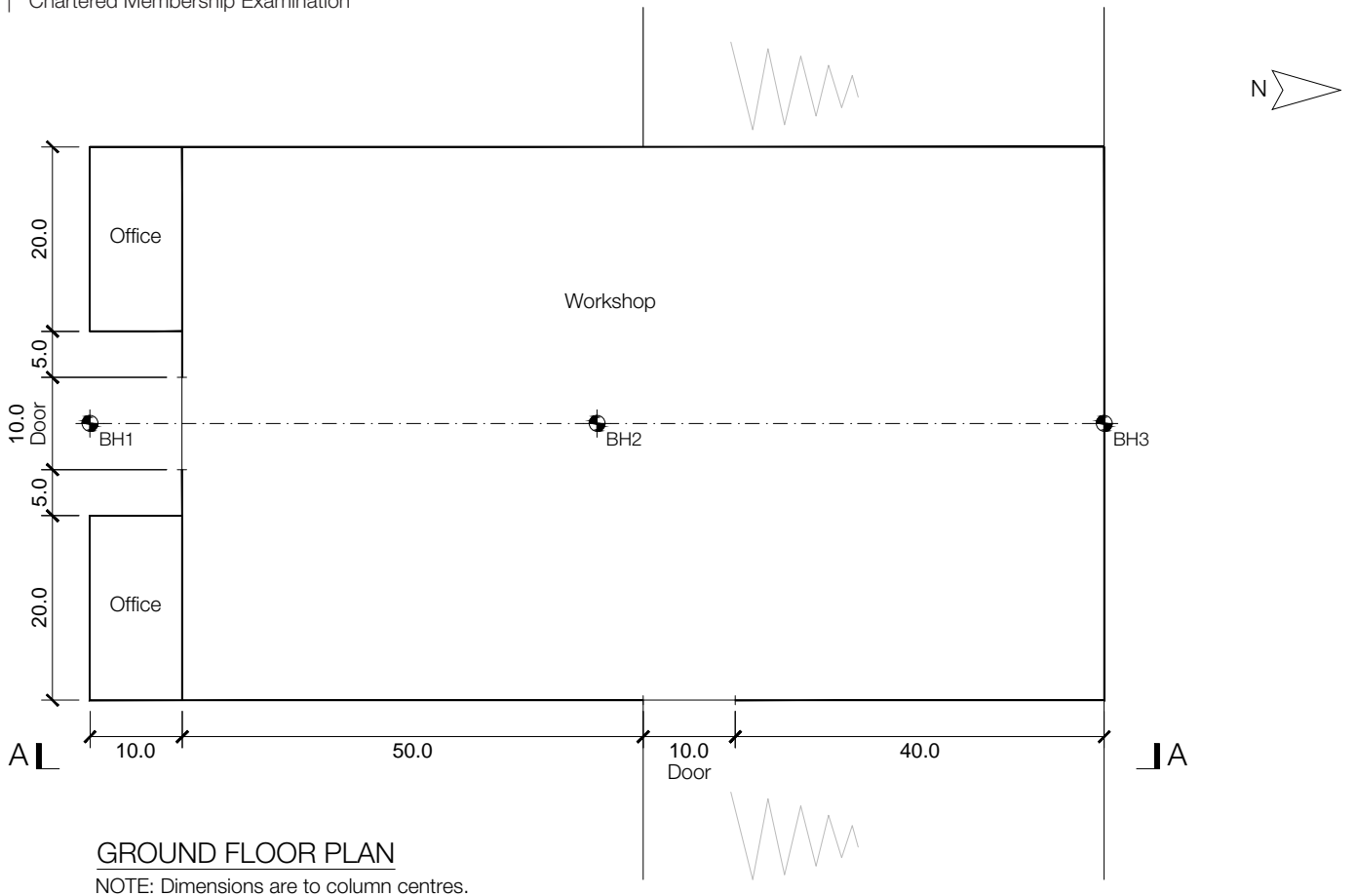
- a) Prepare a design appraisal with appropriate sketches indicating two distinct, viable, and sustainable solutions for the proposed bridge including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability as 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 material usage while maintaining the bridge requirements. Write to your client proposing possible changes explaining the effect these might 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. Industrial building with overhead cranes

Client's requirements

1. A single-storey rectangular workshop building on a sloping site, see Figure Q4.
2. The level ground floor is to have four single-girder Electric Overhead Travelling Cranes (EOTC) arranged in three 20m wide bays 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 20kN. The outer bays are to have a lifting capacity of 50kN and the central bay a lifting capacity of 100kN. All cranes can be used independently at the same time and are stored at the ends of the building when not in use. Internal columns at ground floor level shall have a minimum spacing of 10m centre to centre.
3. Each end of the crane girders is supported on two wheels spaced 3.0m apart and 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.
4. The clear height beneath the crane runway beams shall be 10m and a clear height of 2.0m shall be provided between top of crane runway beam and underside of roof structure to allow operating space for the cranes.
5. Two-storey offices are located at the southeast and southwest ends of the building. A 2.5m clear height is required for each floor level. Plant is located above the second floor to the offices.
6. An external horizontally sliding door 10.0m high by 10.0m wide is required on the east and on the south elevations.
7. The building cladding to walls and roof need to minimise maintenance and energy consumption.

Imposed loading

8. Roof including services	2.0kN/m ²
Plant	5.0kN/m ²
Ground floor	50.0kN/m ²
Overhead crane imposed load effects	
Vertical impact allowance	25%
Longitudinal surge	10%
Transverse surge	5%

Site conditions

9. The site is on an industrial estate outside a town on an uneven surface. Basic wind speed is 40.0m/s based on a 3-second gust; the equivalent mean hourly speed is 20.0m/s.

Ground conditions

10. Boreholes 1 and 2	
Ground level – 0.3m	Loose Sand. N = 5kN/m ²
0.3m – 2.0m	Medium Sand and Gravel. N = 20
2.0m – 5.0m	Stiff Clay. Cu = 150
Below 5.0m	Dense Sand. N = 40
Borehole 3	
Ground level – 2.0m	Loose Sand. N = 5kN/m ²
2.0m – 3.0m	Medium Sand and Gravel. N = 20
3.0m – 5.0m	Stiff Clay. Cu = 150
Below 5.0m	Dense Sand. N = 40

The soil profile can be assumed to vary linearly between the boreholes and is representative of the whole site. Groundwater was encountered at 5.0m below ground level.

Omit from consideration

11. Design of horizontally sliding doors.

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 material usage while maintaining the primary workshop requirements. Write to your client proposing possible changes explaining the effect these might have on the design. (10 marks)

SECTION 2

(50 marks)

For the solution recommended in Section 1(a)

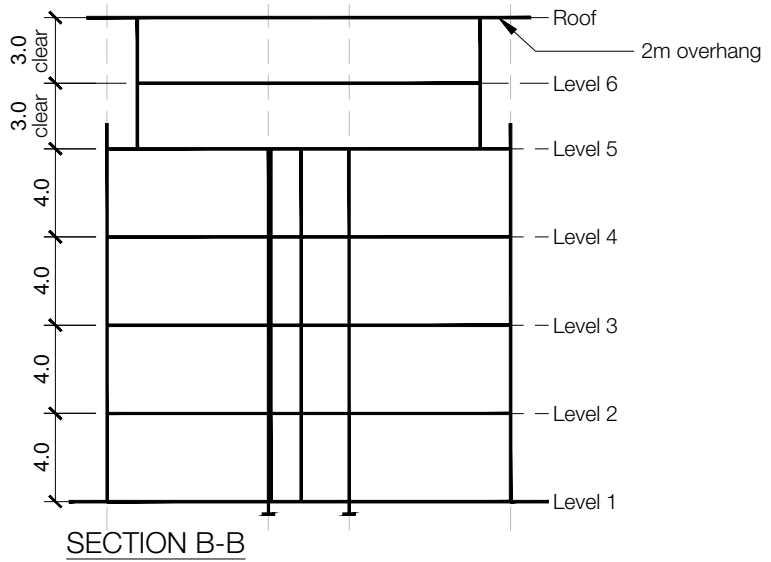
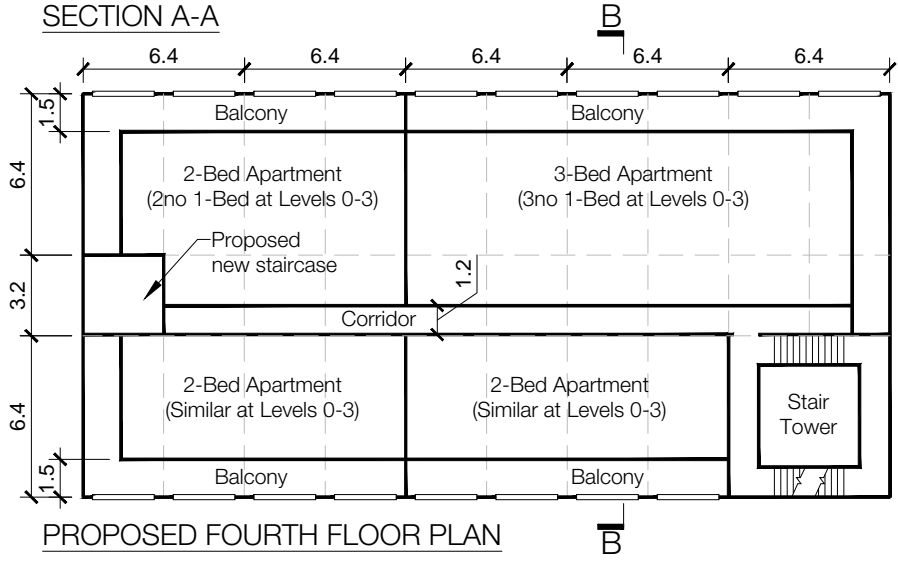
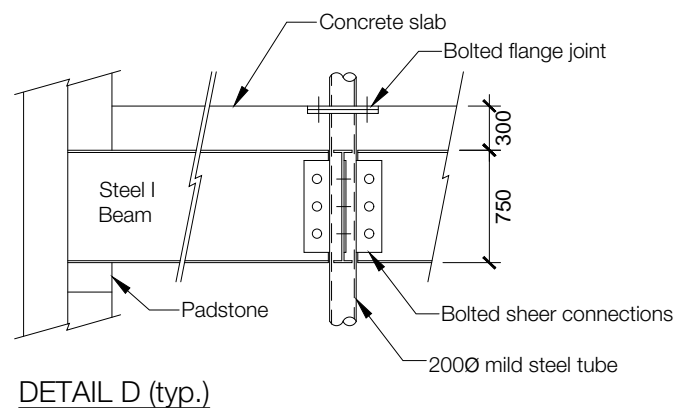
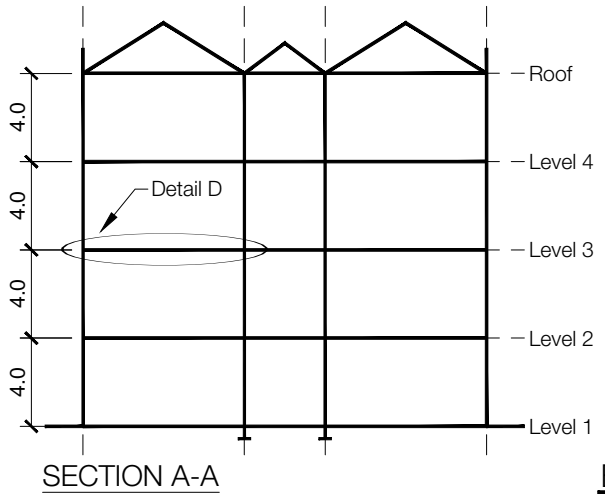
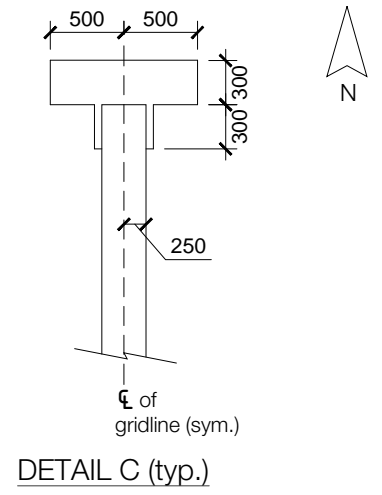
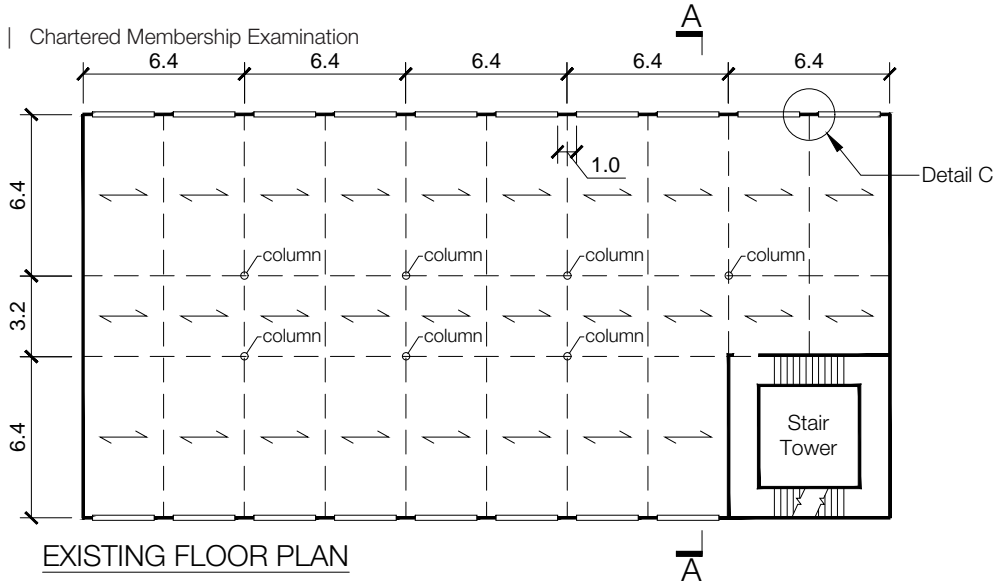
- c) Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. Include approximate A1-A3 carbon calculations for each of your principal elements.

(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)

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

FIGURE Q5

Q5. Conversion and extension of existing warehouse building

Client's requirements

1. The client has purchased an existing four-storey warehouse and would like to convert it to residential use with one, two, and three-bedroom apartments. It is also proposed to add a two-storey extension with a flat roof to house 4No two-storey apartments, each with their own internal staircases and with set-back façade and roof-top balconies to replace the existing pitched roof; see Figure Q5.
2. The existing building is of steel internally framed construction with concrete floors and 300mm-thick load bearing masonry perimeter walls which act as the global stability system. The floors act as diaphragms to distribute loads into the walls. The details of the floor construction are shown on Detail D. Piers between windows on the long elevations are 1000mm wide and 300mm thick with a 300mm x 500mm outstand over the full height of the building (see Detail C). Existing internal structure may be replaced with lighter materials to increase the capacity of the structure but this must be absolutely minimised.
3. The building has an existing stair tower at the south-east corner that is to be extended upwards to provide access to the first additional storey. A new lift/elevator will be installed within the centre of the stair tower. An additional new staircase will be added to the western end of the building as shown on Figure Q5.
4. Existing floor to ceiling height is 4.0m and minimum floor to ceiling height of new two-storey construction to be 3.0m.
5. The building is to have a 90-minute fire rating between floors.

Loading

6. Research has determined the existing warehouse floors to be in good condition and were originally designed to safely support a variable load of 7.5 kN/m² and the permanent self-weight load of the existing floors is 6 kN/m². The existing roof self-weight is 3 kN/m². The stair tower was found to have capacity to support a single floor extension of the same construction as the original without modification.
7. All floors, including the additional storeys, are to support a variable total load of 2.5 kN/m². The new flat roof is to support a variable load of 0.75 kN/m² as was for the existing pitched roof.

Site conditions

8. An existing strip concrete foundation of 600mm width is present beneath walls and the column foundations are 2m x 2m square. The base of all foundations is at 1.5m below ground level.
9. Sandstone is present at a depth of 10m below ground level overlain by Dense Sand with an N of 50.
10. Basic wind speed is 43.0m/s based on a 3-second gust; the equivalent mean hourly speed is 21.5m/s. The site is in a built-up city-centre location.

Omit from consideration

11. Detailed design of the stair extension, new stairs (internal and additional main staircase) and new lift/elevator.
12. The existing building structure is sufficiently robust for disproportionate collapse when assessed against code and statutory requirements. This applies to current and proposed arrangements.

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, including sequencing of construction. Reusing existing structures where required, clearly indicate the functional framing, load transfer, serviceability, and temporary and permanent 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 usage of materials, whilst maintaining the net floor area and function 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 1(a):

- c) Prepare sufficient design calculations to establish the form and size of all the principal structural elements including any necessary checks on existing structural elements. Include approximate A1-A3 carbon calculations for each of your new 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, including connections to existing structure. (20 marks)
- e) Prepare a detailed method statement for the safe construction of the works, including how temporary stability of the existing building will be maintained. (8 marks)

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