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Chartered Membership Examination

Wednesday 24 January 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 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 wireles 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.

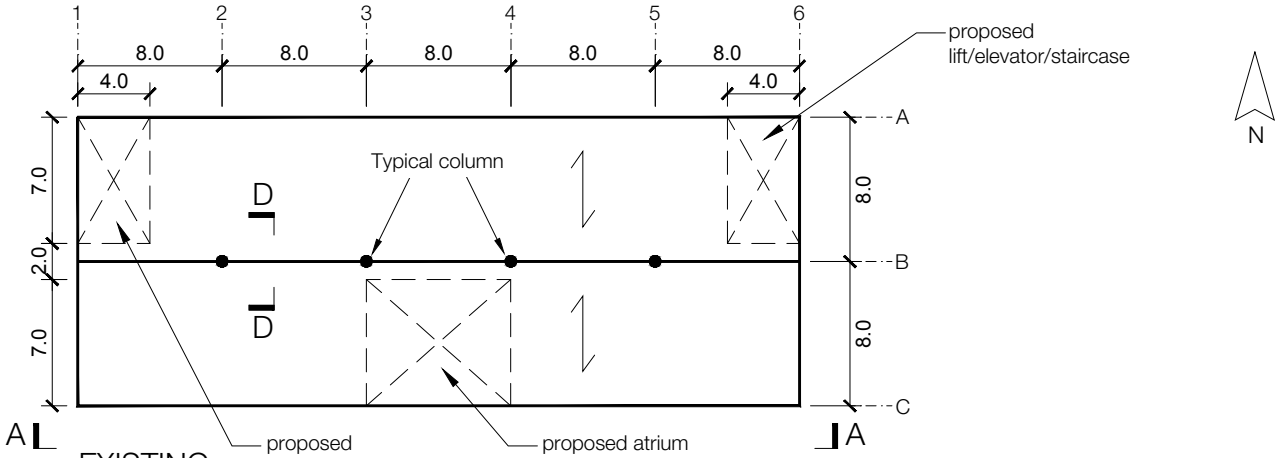
In selecting and developing your design you should also remember the guidance given in the Institution's report, Structural design - achieving excellence, and in particular:

(1) "the structure must be safe",

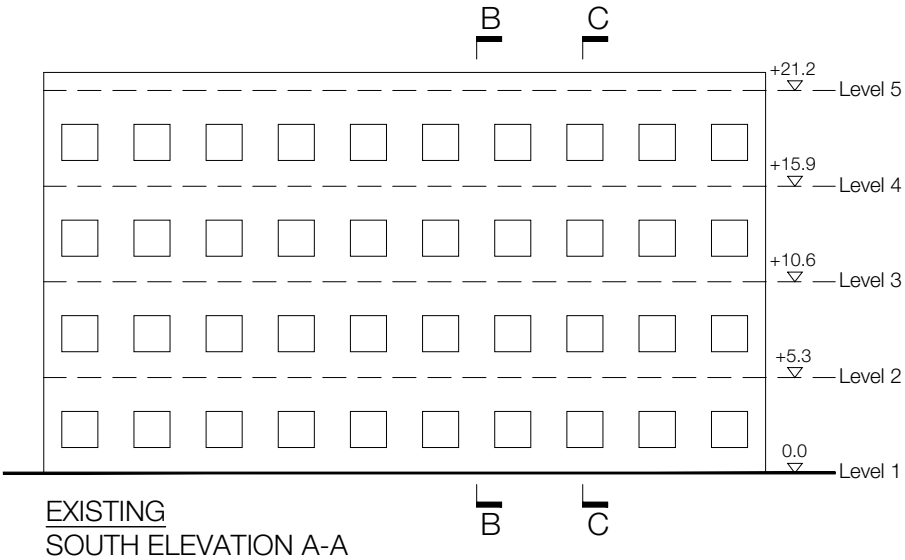
(2) "a good design has certain typical features – simplicity, unity and necessity",

(3) "the structure must fulfil its intended function".

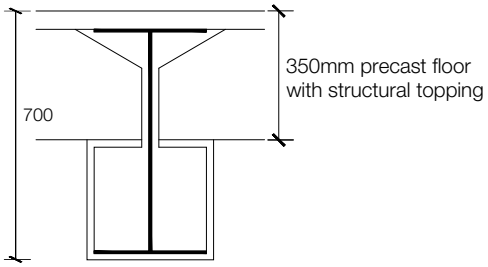
If you have difficulty in deciding the correct interpretation of a question, pay particular attention to point 6. notes to candidates, on the front cover. The examiners will take into account your interpretation – and the design you base on this – if this is clearly stated at the beginning of your answer.



EXISTING
PLAN

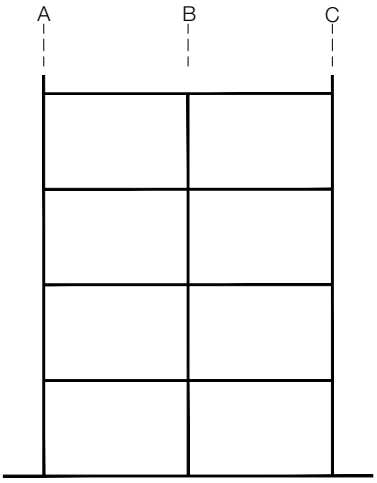


EXISTING
SOUTH ELEVATION A-A

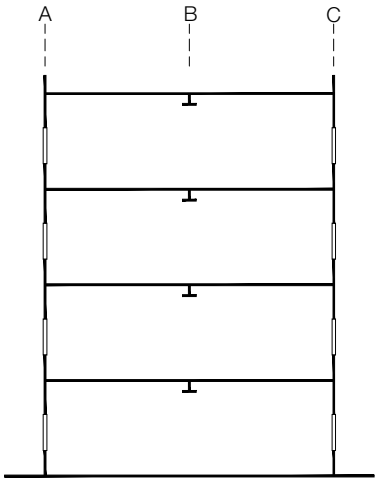


DETAIL D-D

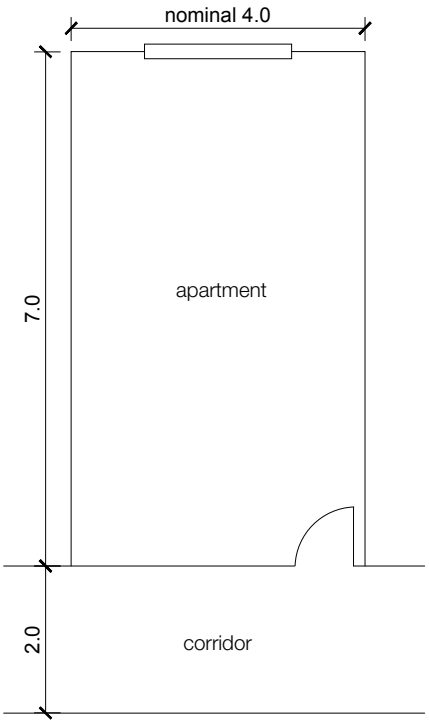
NOTE: Dimensions are in mm.



SECTION B-B



SECTION C-C



TYPICAL APARTMENT

NOTE: All dimensions are in metres unless otherwise noted.

FIGURE Q1

Q1. Conversion of industrial building to apartments

Client's requirements

1. An existing vacant four-storey industrial building is to be converted into residential apartments, see Figure Q1. Two levels of sixteen apartments are to be constructed on each existing floor, providing a total of 128 apartments over eight storeys. The flat roof has a 1m high perimeter parapet.
2. A typical apartment is nominally 4m wide by 7m long with access to a 2m wide corridor. A clear floor-to-ceiling height of 2.3m is to be provided within the apartments. Each apartment is to have a 2m wide x 1m high window at 1m above finished floor level.
3. The existing building has solid brick external walls 0.45m thick. The perimeter walls have reinforced concrete spread foundations 1.5m wide. The existing north and south elevations have windows 2m high by 2m wide at 1m above each existing floor and a clear horizontal space of 2m between windows.
4. Floors are of precast concrete with structural topping spanning on to steel beams with fire protection, which in turn are supported by steel columns. The type and size of foundations to the columns are unknown. Site measurements: Steel beams overall depth 610mm (24 inches), flanges width 305mm (12 inches) and thickness 19.7mm (3/4inch approx), web thickness 11.8mm (1/2 inch approx). Elastic modulus Zxx = 4110cm^3, Zyy = 611cm^3, Mass = 149kg/m (100 pounds per foot). Steel minimum yield stress = 355N/mm^2 (MPa) = 51ksi approx (Grade S355).
5. A full height atrium is to be provided with a glazed roof and a glazed external elevation as shown in Figure Q1. The atrium is to incorporate a lift/elevator and staircase for access to all floors. The atrium and the lift/elevator/staircase areas should be clear of structure to allow for following works such as stair and lift/elevator installation.
6. A further internal lift/elevator and staircase to all floors is to be provided at each end of the building as shown in Figure Q1. The existing external staircases at each end of the building have been removed as part of the preparatory work.

Imposed loading

7. Apartment floors 1.5kN/m^2
   Corridor floors 2.5kN/m^2
   Roof 1.0kN/m^2
   The unfactored imposed load capacity of the existing floors is 6.0kN/m^2.

Site conditions

8. The site is located on the outskirts of a large city. Basic wind speed at sea level is 46.0m/s on a 3-second gust; the equivalent mean hourly wind speed is 23.0m/s.
9. Ground conditions

Ground level – 0.3m	Fill
0.3 – 6.0m	Dense sandy gravel. N = 50
Below 6.0m	Sandstone, characteristic compressive strength 3500kN/m^2

No groundwater was recorded in the soil investigation.

Omit from consideration

10. Stairs and lifts/elevators and atrium glazed roof and glazed elevation secondary steelwork.

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 is complete, the Client asks you to suggest ways in which the brief could be altered to reduce material usage whilst maintaining the total number of apartments and an atrium. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the rest of the design. (10 marks)

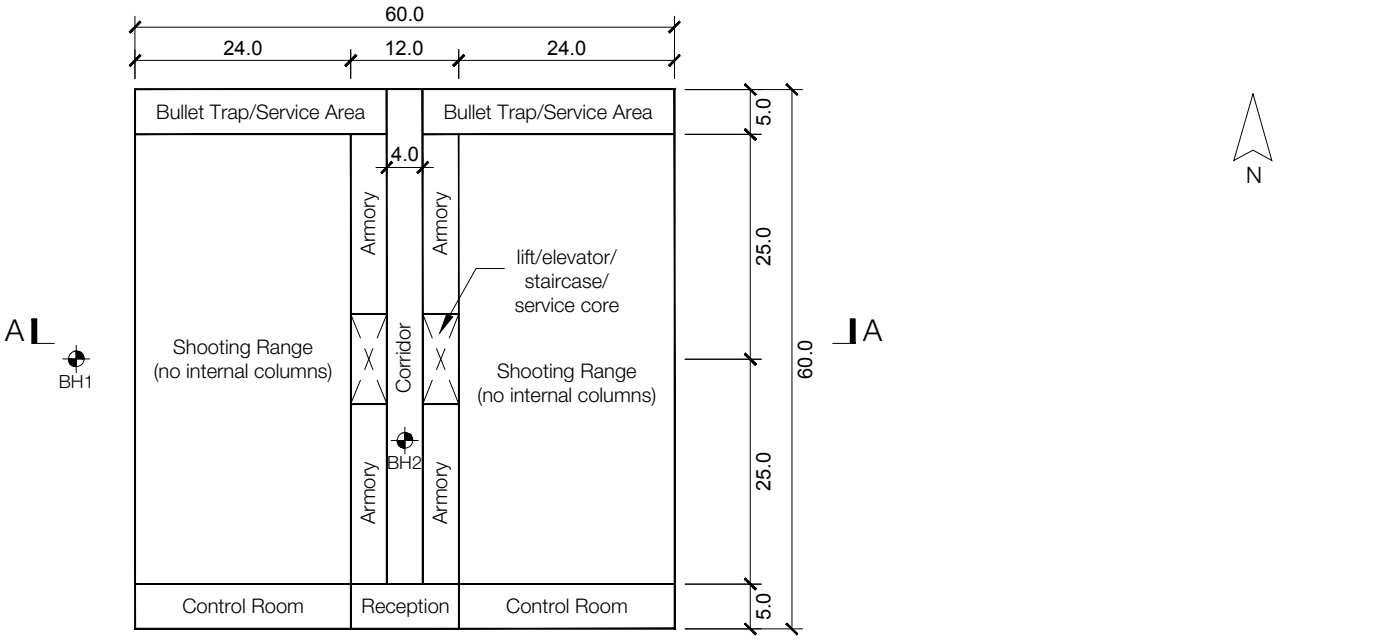
SECTION 2 (50 marks)

For the solution recommended in Section 1(a):

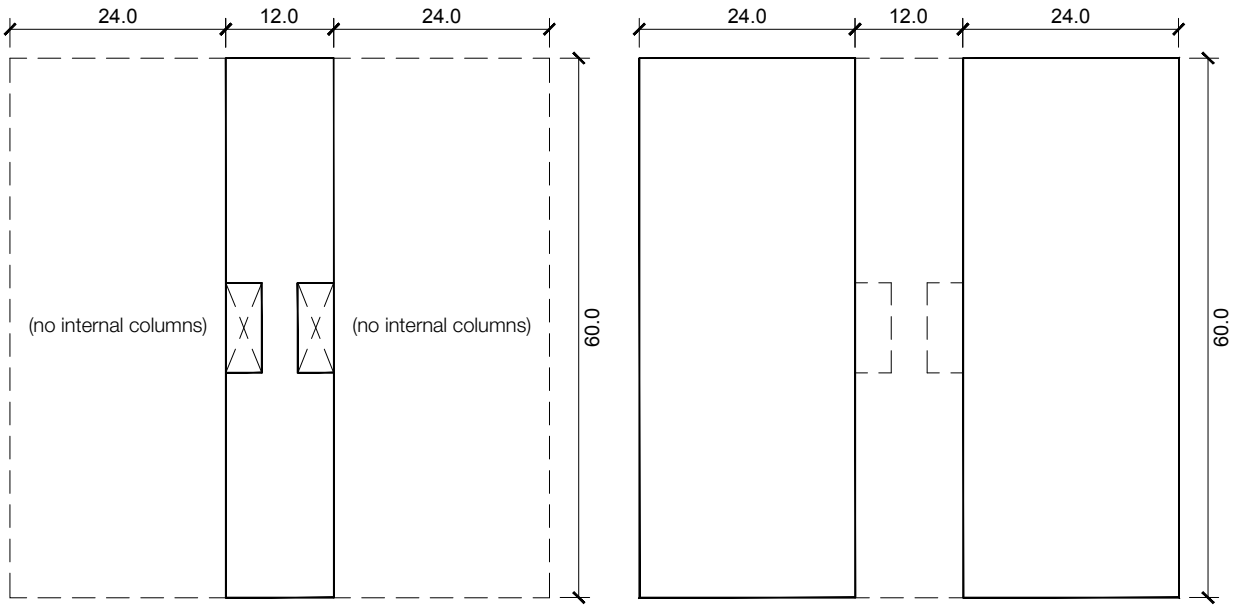
c) Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. Include approximate A1-A3 carbon calculations for each of your principal elements. (22 marks)

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)

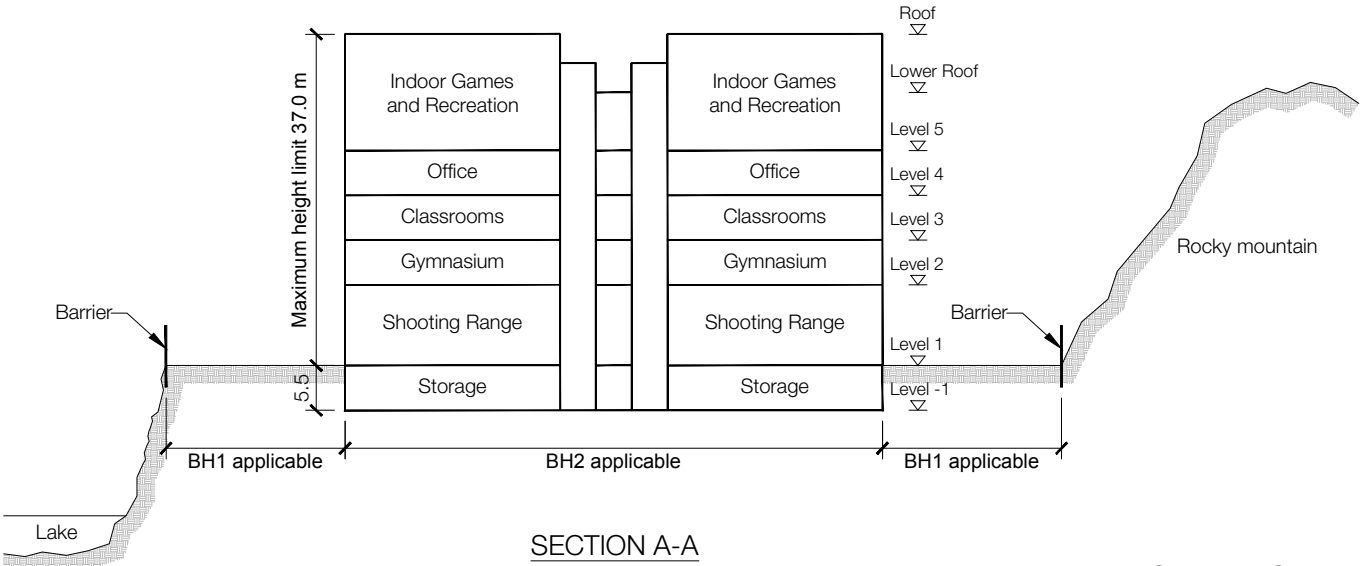


PLAN AT LEVEL 1



PLAN AT LOWER ROOF
(MECHANICAL FLOOR)

PLAN AT ROOF



SECTION A-A

NOTE: All dimensions are in metres.

FIGURE Q2

Q2. Defence Facility

Client's requirements

1. A new defence facility is to be constructed for the provision of military training to new recruits. The building is square on plan with 60.0m long sides. It has a single basement with five floors above it. See Figure Q2.
2. Two 10.0m x 4.0m lift/elevator/stair/service cores are to be provided to serve all floors.
3. Internal columns are not allowed within the shooting ranges at Level 1 and within spaces for indoor games and recreation at Level 5. Internal column spacing should not be less than 8m at all other levels. External column spacing should not be less than 8m except from corners where additional shear walls or vertical bracing could be placed.
4. Clear floor-to-ceiling height is to be 4.0m at Level 1 and 12.0m at Level 5. All other levels, including the basement, are to have a clear floor-to-ceiling height of 3.5m. A structure-free ceiling zone of 0.9m is required at Level 1. A structure-free ceiling zone of 0.4m is required at all other levels, including the basement.
5. The overall height of the building must not exceed 37.0m above Level 1.
6. No internal vertical bracing or shear walls are permitted except at lift/elevator/stair/service core positions.
7. Level 1 façades shall have stone cladding, and the remaining facades are to have 75% glazing. The roof shall be clad metal sheeting.

Imposed loading

8. Roof = 1.0 kN/m^2 (allowance included for solar panel)
   Lower roof = 5.0 kN/m^2 (Mechanical floor)
   Level 1 to Level 5 Basement = 4.0 kN/m^2
   Level -1 = 7.5 kN/m^2
   Loadings include allowances for finishes, ceiling and services.

Site conditions

9. The site is situated in an easily accessible hilly area facing a large lake in the outskirts of a city. Basic wind speed is 40m/s based on a 3-second gust; the equivalent mean hourly wind speed is 20m/s.

Ground conditions

10. Borehole 1
    Ground Level to - 1.0m - Topsoil
    -1.0m to -3.5m - Loose sand N = 8
    Below -3.5m - Granite rock, allowable bearing strength = 3200 kN/m^2
    Borehole 2
    Ground Level to - 1.0m - Topsoil
    -1.0m to -3.5m - Loose sand N = 10
    -3.5m to -14.0m - Medium dense sand N = 12
    -14.0m to -21.0m - Sandstone, allowable bearing strength = 1500 kN/m^2
    Below -21.0m - Granite rock, allowable bearing strength = 3000 kN/m^2
    No ground water was observed in either borehole.

Omit from consideration

11. Detailed design of staircase, glazed façade and 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. 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) In order to reduce project costs, your client asks you to suggest ways in which the brief could be altered to reduce material usage, whilst maintaining the same size internal spaces. Write to your client proposing possible changes. As part of any proposals made explain the effect this may have on the rest of 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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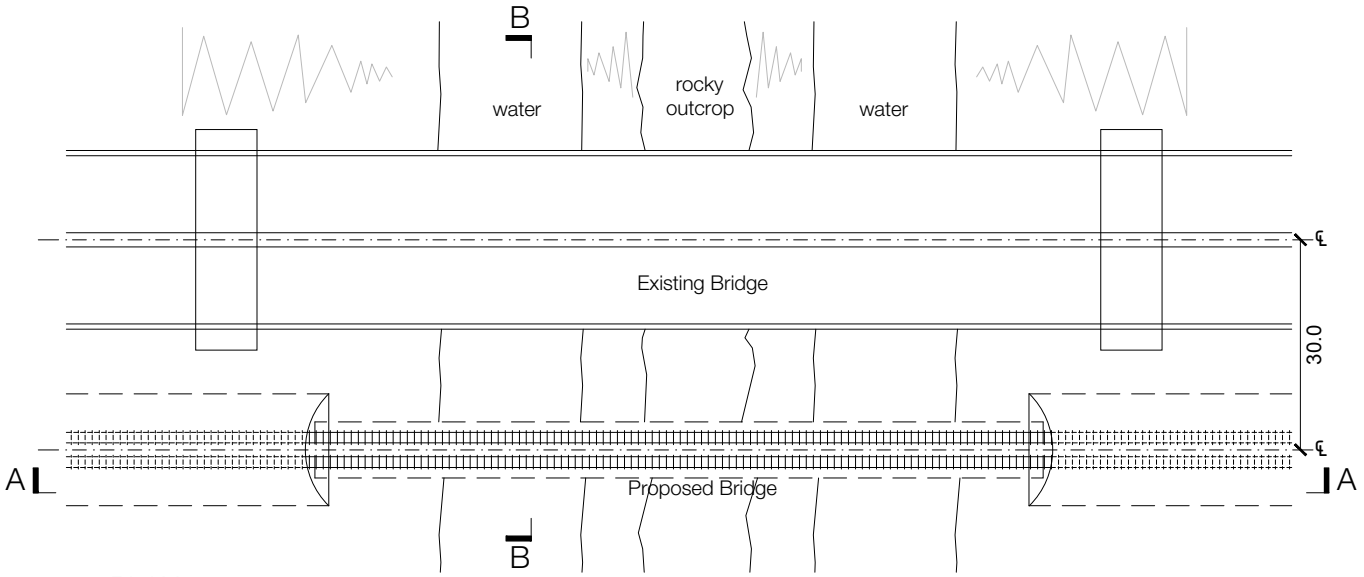
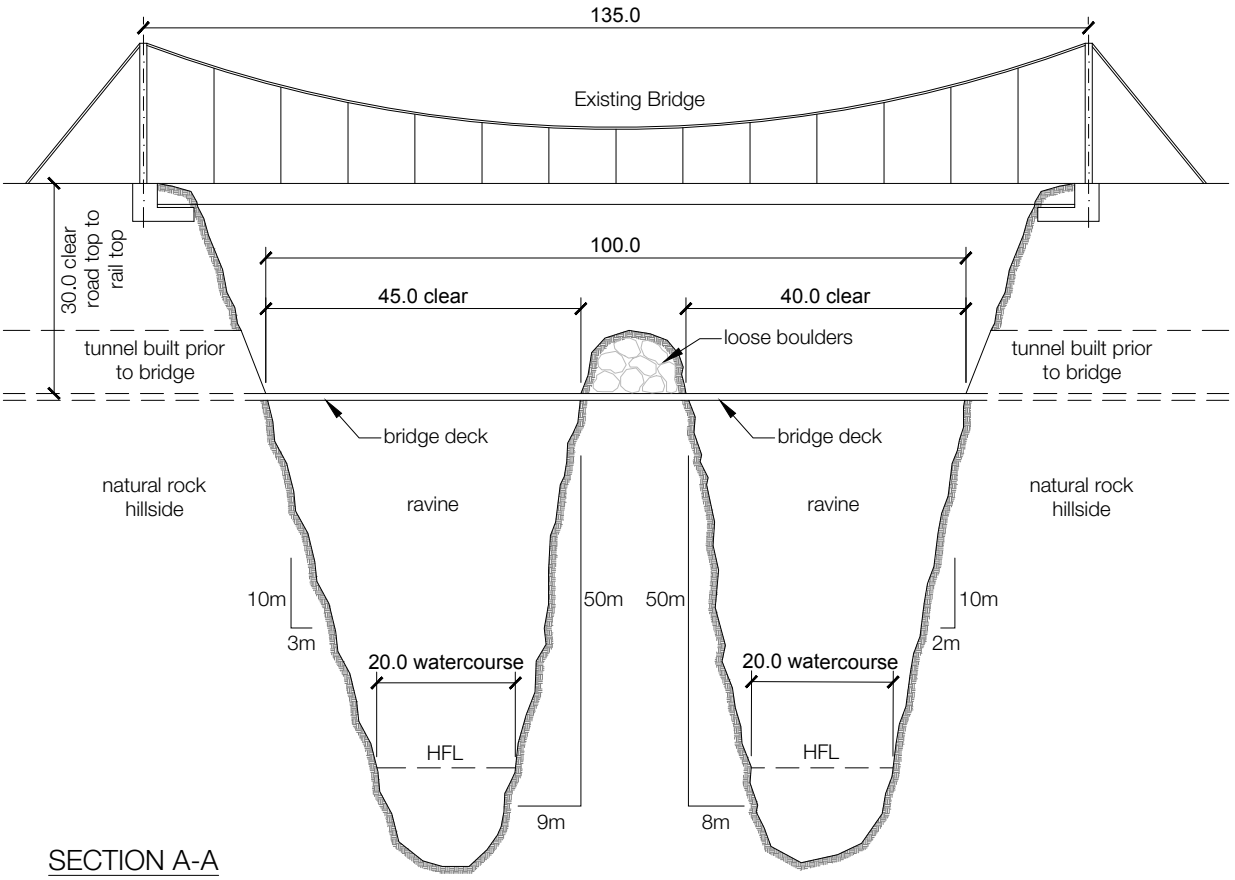
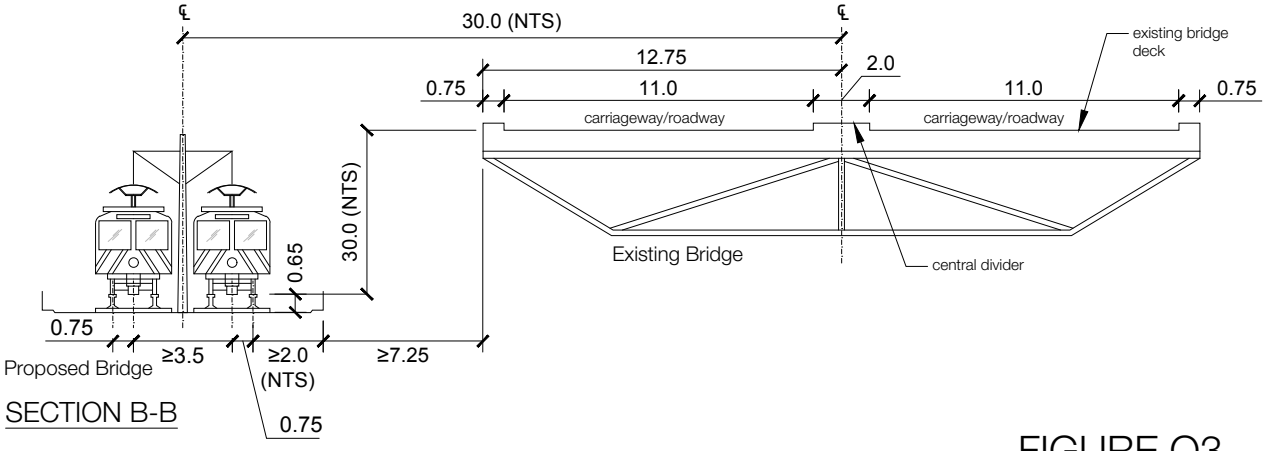


PLAN



SECTION A-A



SECTION B-B

NOTE: All dimensions are in metres.

FIGURE Q3

Q3. New Railway Bridge

Client's requirements

1. As part of a high-speed rail project, a new bridge is required to carry a 2-track railway over a deep ravine with steep sides located in a rural area, see Figure Q3.
2. Both ends of the bridge will be connected to a 9m high and 18m wide tunnel which will be built before the bridge is built. The existing road bridge is located to the North and at a higher level to the track level of the proposed railway bridge - see Figure Q3.
3. Traffic on the existing road bridge may be restricted for 2 periods of 4 consecutive days in each year as well as overnight closures at weekends.
4. No temporary or permanent piers or foundations are permitted in the waterway at or below the highest recorded flood level.
5. Sleepers/ties may be fixed directly to the deck to avoid additional load from ballast. An amplification factor of 1.8 may be used.

Imposed loading

6. Vertical traffic loading 100kN/m per track. Braking and Traction loading from a train 1500kN.

Site condition

7. The site is on a natural rock hillside. The rock has a typical compressive strength of 4000kN/m^2.
8. The river in the ravine is not navigable.
9. Basic wind speed is 46m/s based on a 3 second gust; the equivalent mean hourly wind speed is 23m/s.

Omit from consideration

10. Design of vehicle containment parapet.
11. Stability of rock slopes, which are to be considered stable for the intended construction.

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) Your client asks you to suggest ways to reduce the amount of material used on the bridge, whilst maintaining the functional requirement and minimising alterations to the project constraints. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the rest of 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.

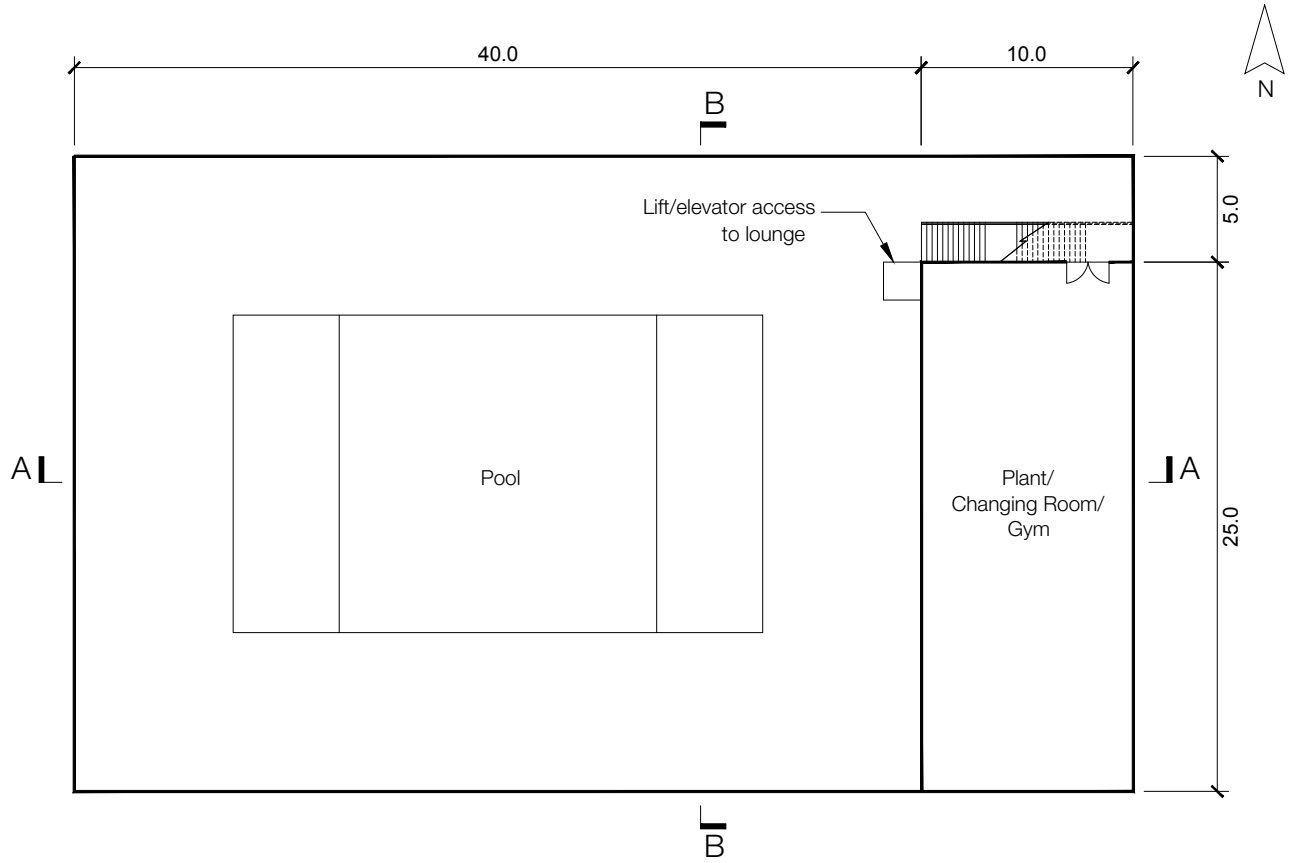
(22 marks)

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.

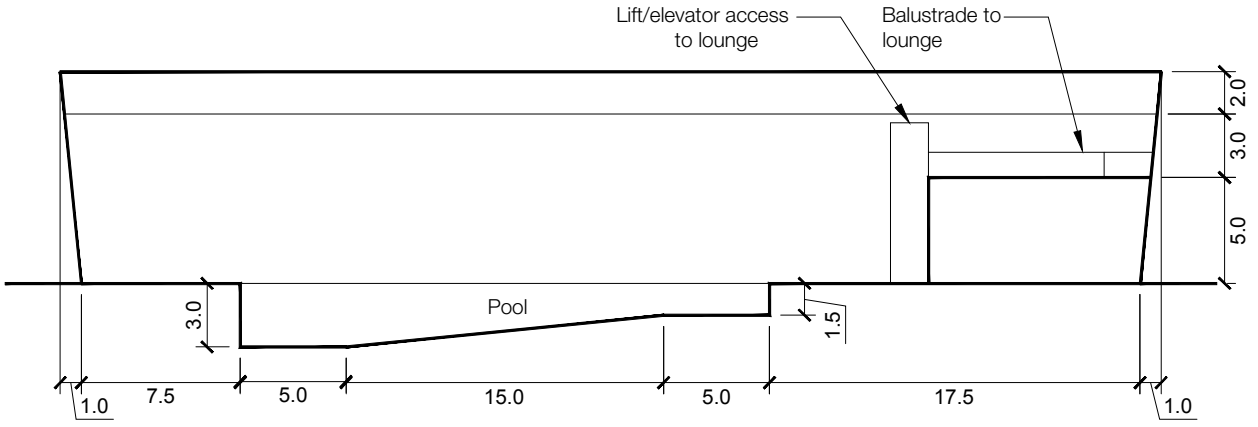
(20 marks)

e) Prepare a detailed method statement for the safe construction of the works.

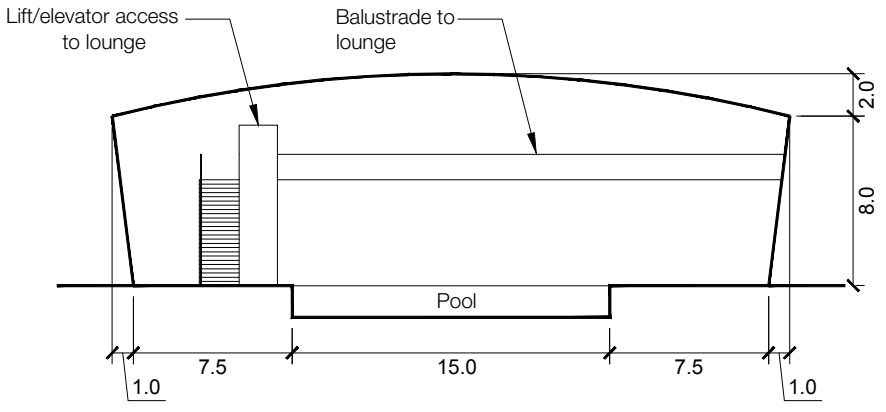
(8 marks)



GROUND FLOOR PLAN



SECTION A-A



SECTION B-B

NOTE: All dimensions are in metres.

FIGURE Q4

Q4. Private Leisure Facility

Client's requirements

1. A new leisure facility consisting of a swimming pool, changing area, and gym. See Figure Q4.
2. The building is to have a clear internal height of 8.0m and is to be column free. Additionally, there are to be no columns placed outside the footprint of the building. The client would like the structure to be exposed and aesthetically pleasing.
3. The changing/gym area is to have a clear internal floor-to-ceiling height of 4.0m and is to be column free, but columns are permitted around the perimeter of this space. The floor above this area is to be a lounge/bar accessed by a staircase and lift/elevator.
4. The pool is to be a deck level pool with the water skimmed via a channel on the outside of the pool structure.
5. The building is to be clad with glass curtain walling with the columns at a minimum spacing of 5.0m. The internal walls to the changing/gym area are to be of fair-faced masonry blockwork.
6. The roof is to be clad with an insulated composite sheeting.

Imposed loading

7. Roof 0.75kN/m^2
8. Pool / gym floor 4.0kN/m^2
9. Lounge / bar floor 2.5kN/m^2

Site conditions

10. The site is level and located on the outskirts of a large city. Basic wind speed is 40m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20m/s.
11. Ground conditions:

    Ground level – 1.0m top soil

    1.0m – 5.0m sand and gravel N value 10

    5.0m - 10.0m stiff to very stiff clay C = 250kN/m^2

    Standing ground water was encountered at 3.5m below ground level.

Omit from consideration

12. Detail design of the stairs and lift/elevator shaft to lounge.

SECTION 1 (50 marks)

a) Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the pool and 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, identify the design you recommend, giving reasons for your choice.

(40 marks)

b) After the scheme design has been approved, the Client asks whether changes could be made to it to reduce the usage of materials, while maintaining the effective use of the space within the leisure centre. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the rest of 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 pool and foundations. Include approximate A1-A3 carbon calculations for each of your principal elements.

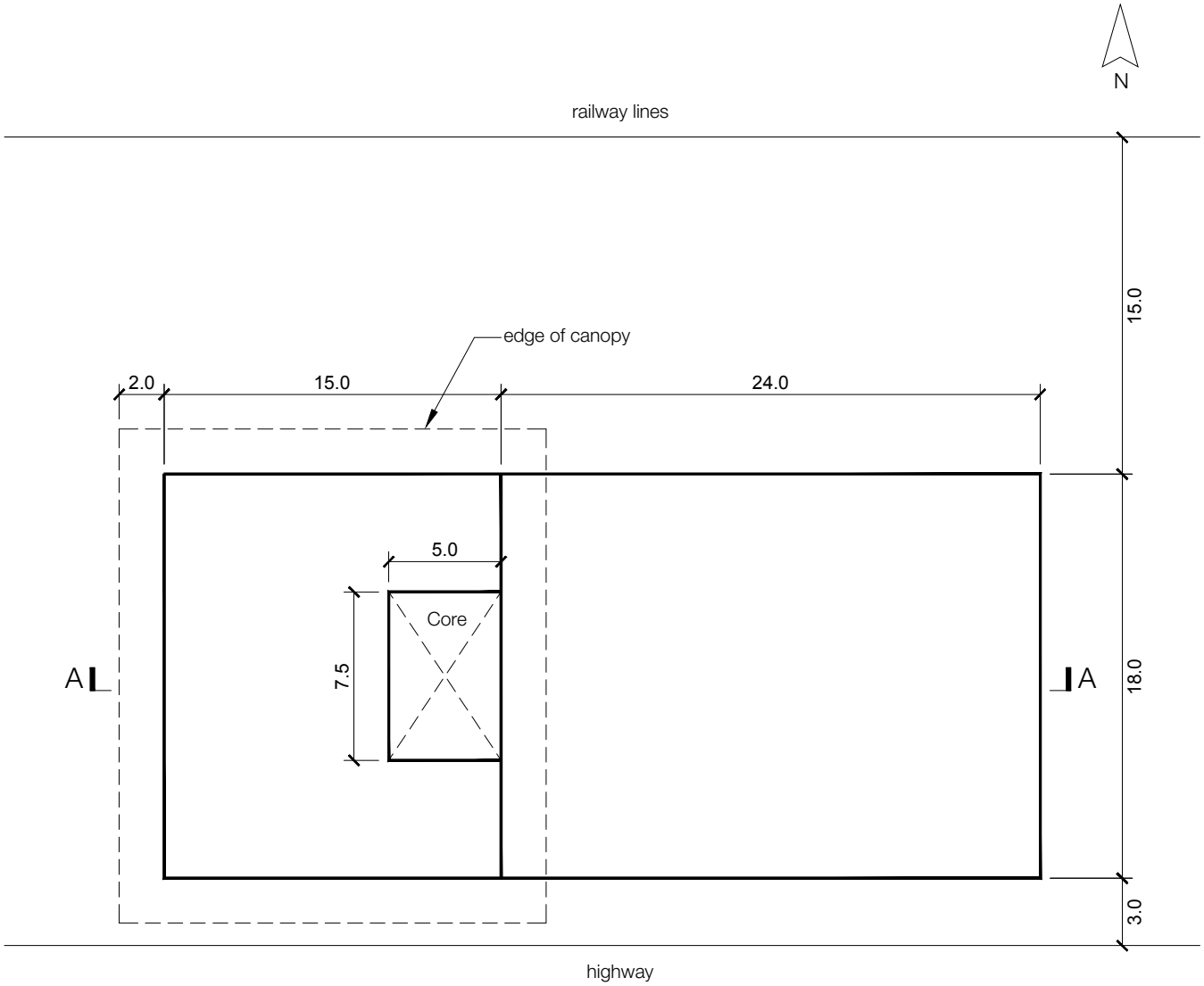
(22 marks)

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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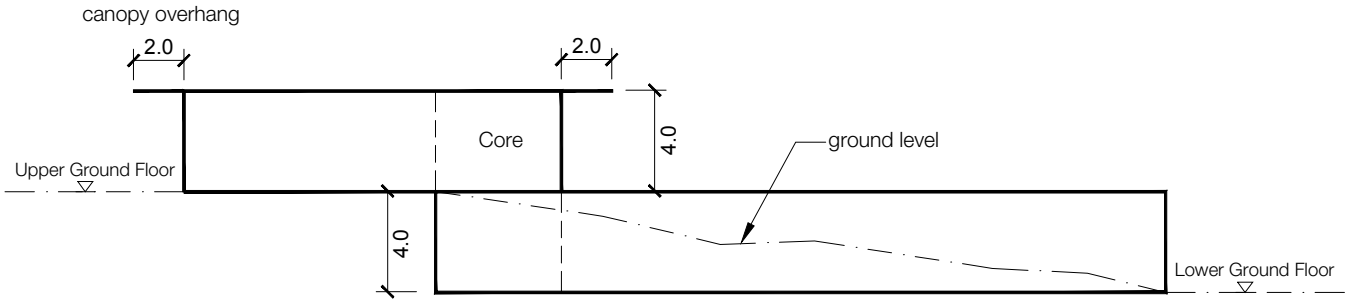

SECTION A-A

NOTE: All dimensions are in metres.

FIGURE Q5

Q5. Community Centre Building

Client's requirements

1. A two-storey community centre is to be constructed to provide flexible arts & teaching space. See Figure Q5.
2. The building is to be located on a previously developed site, within a large city.
3. A minimum clear internal height of 3m is required to each floor, the finished floor-to-floor height for the building is 4.0m. Consideration of services integration is required.
4. The upper ground floor level is to be open plan (no internal columns), with glazed façades (no bracing permitted). The lower ground floor requires provision for four teaching space classrooms. Columns are permitted within classroom walls with a minimum spacing of 6m.
5. The upper ground floor is to incorporate a slim profile and a projecting canopy with no supporting columns below.
6. Access is to be provided to allow for use of lower ground floor roof structure as external garden terrace.
7. The site is bounded by a highway to the south and lies within 15m of railway lines to the north.

Imposed loading

8.	Upper Ground Floor Roof	0.6kN/m^2
9.	Lower Ground Floor Roof	5.0kN/m^2 plus allowance of 2.0 kN/m^2 for green roof system.
10.	All internal floors	10.0kN/m^2

Site conditions

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

General site conditions

Ground level – 1.0m	Made ground
1.0m – 1.5m	Soft clays, C = 10kN/m^2
1.5m – 8.0m	Stiff clays, C = 50kN/m^2
Below 8.0m	Mudstone, C = 150kN/m^2

No ground water was encountered.

Omit from consideration

13. Detail design of lift/elevator and stair cores.

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) In order to reduce project costs, your client asks you to suggest ways in which the brief could be altered to reduce material usage, whilst maintaining the predominantly column free internal spaces. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the rest of 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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