The Institution of
StructuralEngineers

International HQ,
47-58 Bastwick Street,
London EC1V 3PS, UK

T +44 (0)20 7235 4535
E membership@istructe.org

www.istructe.org

Incorporated-Member 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 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.

Incorporated-Member 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.

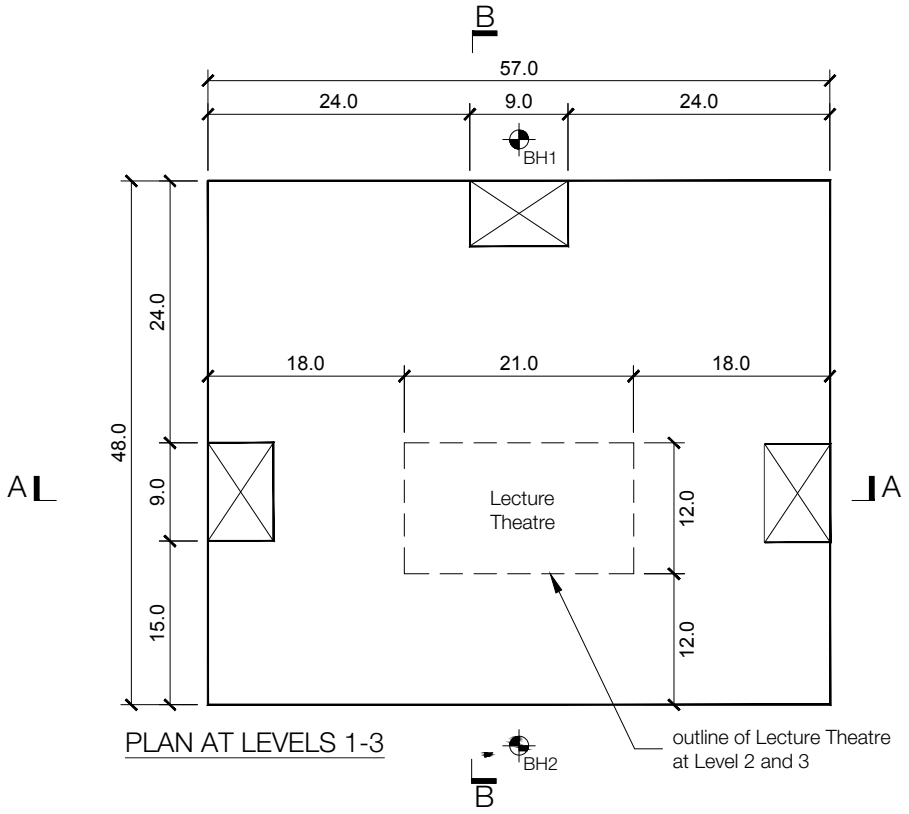
In selecting and developing your design you should also remember the guidance given in the Institution's report, Structural design - achieving excellence, and in particular:

(1) "the structure must be safe",

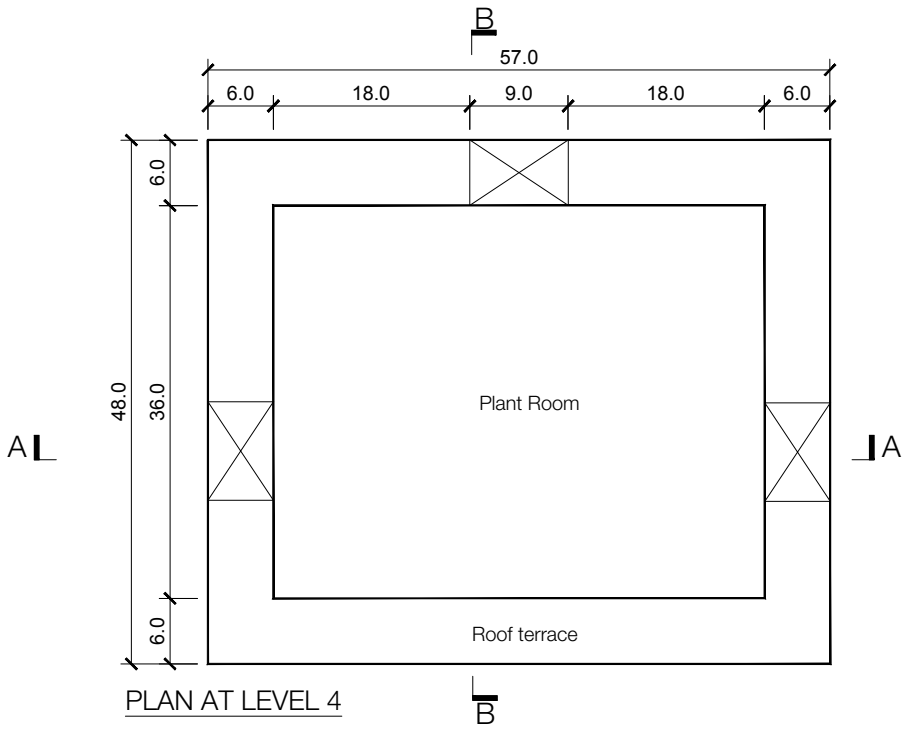
(2) "a good design has certain typical features – simplicity, unity and necessity",

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

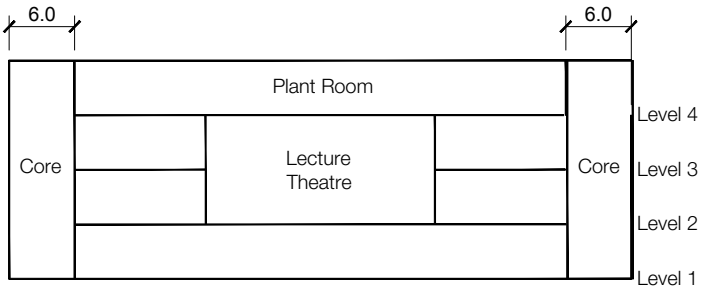
If you have difficulty in deciding the correct interpretation of a question, pay particular attention to point 6. notes to candidates, on the front cover. The examiners will take into account your interpretation – and the design you base on this – if this is clearly stated at the beginning of your answer.



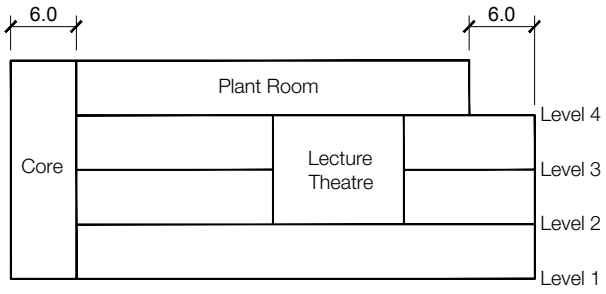
PLAN AT LEVELS 1-3



PLAN AT LEVEL 4



SECTION A-A



SECTION B-B

NOTE: All dimensions are in metres.

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/m^2
   Plant room 7.5kN/m^2
   Roof (general) 1.5kN/m^2, roof (plant room) 0.75kN/m^2

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, characteristic bearing strength = 4500 kN/m^2

No groundwater is present.

Omit from consideration

9. Design of the lifts/elevators and stairs

SECTION 1 (30 marks)

a) Prepare a design appraisal with appropriate sketches indicating a viable and sustainable solution for the proposed structure including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of the scheme. Using sustainability as a key criterion, justify the reasons for your solution. (20 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)

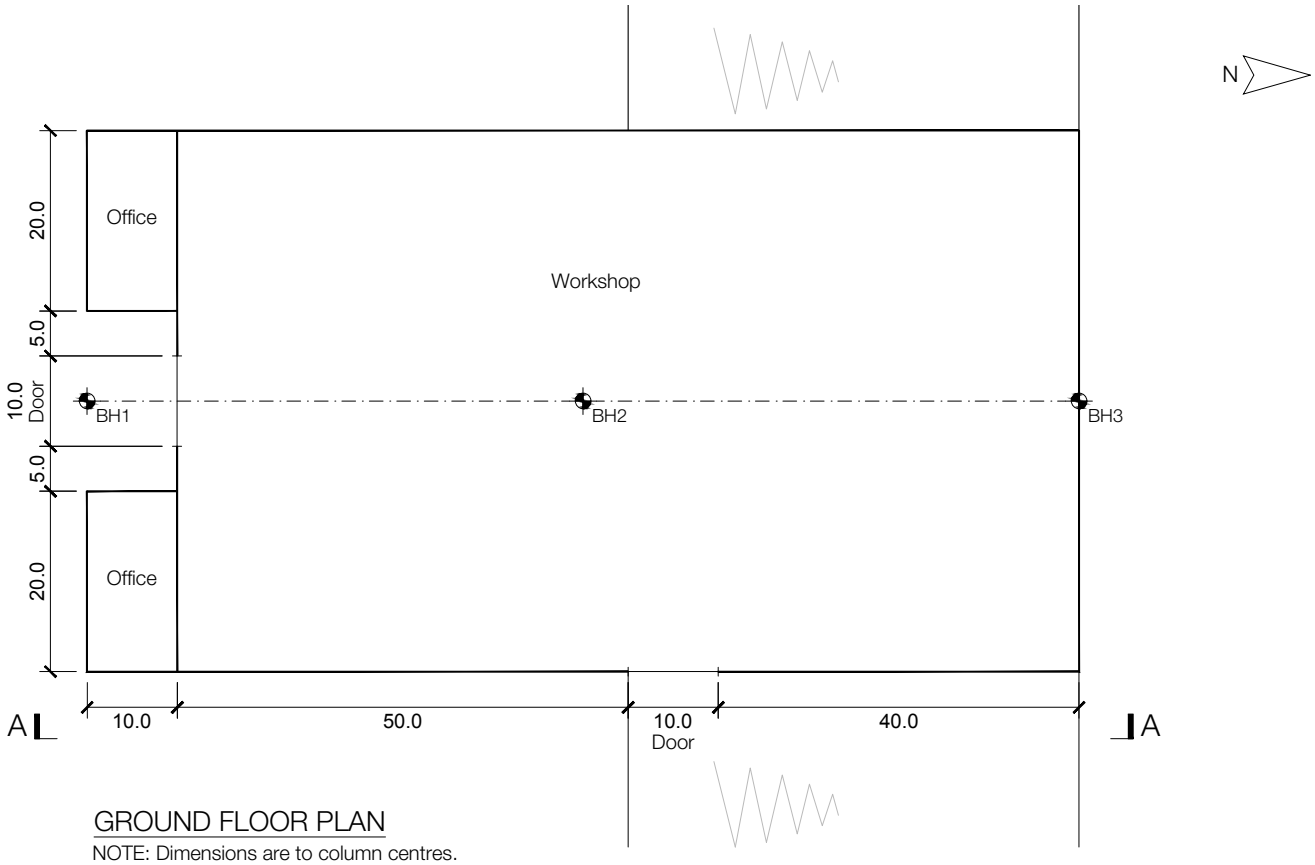
SECTION 2 (70 marks)

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. (30 marks)

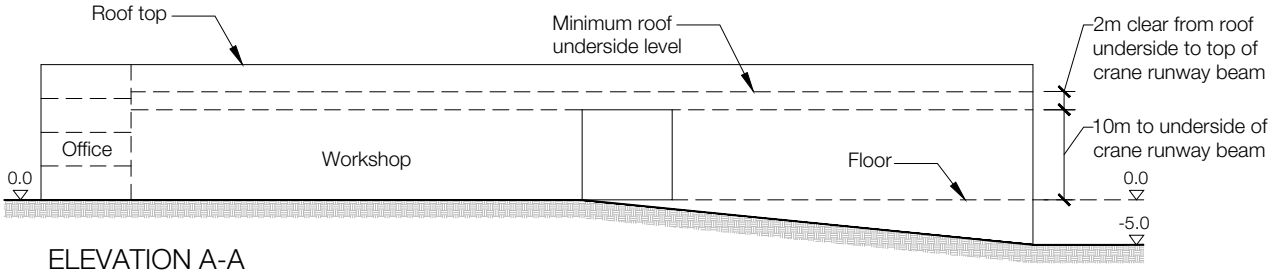
d) Prepare general arrangement drawings, which may include plans, sections and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes. Prepare clearly annotated sketches to illustrate details of:
   a) Plant room roof structure to the vertical support structure
   b) The perimeter foundation, ground slab and vertical support structure (30 marks)

e) Prepare a detailed method statement for the safe construction of the works. (10 marks)

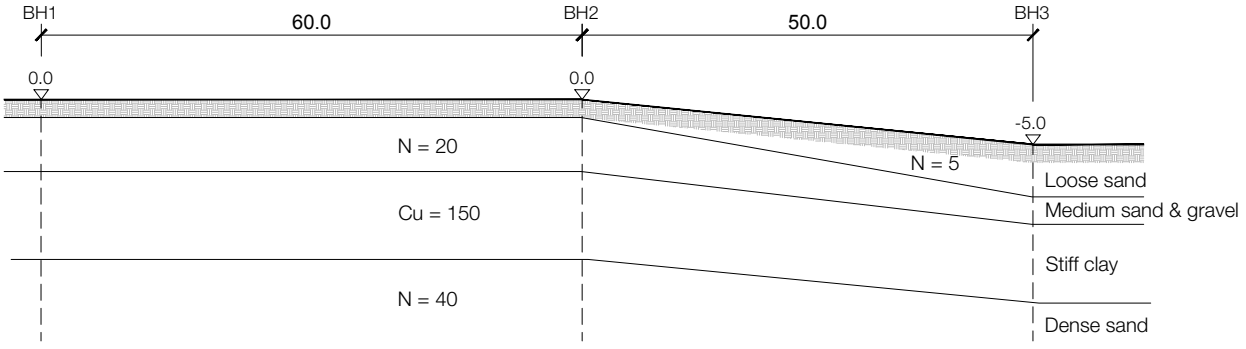


GROUND FLOOR PLAN

NOTE: Dimensions are to column centres.

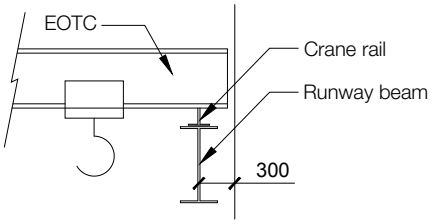


ELEVATION A-A



SOIL PROFILE

NOTE: Dimensions are to column centres.



CRANE DETAIL

NOTE: Detail dimensions are in mm.

NOTE: All dimensions are in metres.

FIGURE Q2

Q2. Industrial building with overhead cranes

Client's requirements

1. A single-storey rectangular workshop building on a sloping site, see Figure Q2.
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 along the north to south 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, when operating the cranes together, 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. The ends of each crane girder are 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/m2
   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 (30 marks)

a) Prepare a design appraisal with appropriate sketches indicating a viable and sustainable solution for the proposed structure including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of the scheme. Using sustainability as a key criterion, justify the reasons for your solution. (20 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 your design. (10 marks)

SECTION 2 (70 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.

(30 marks)

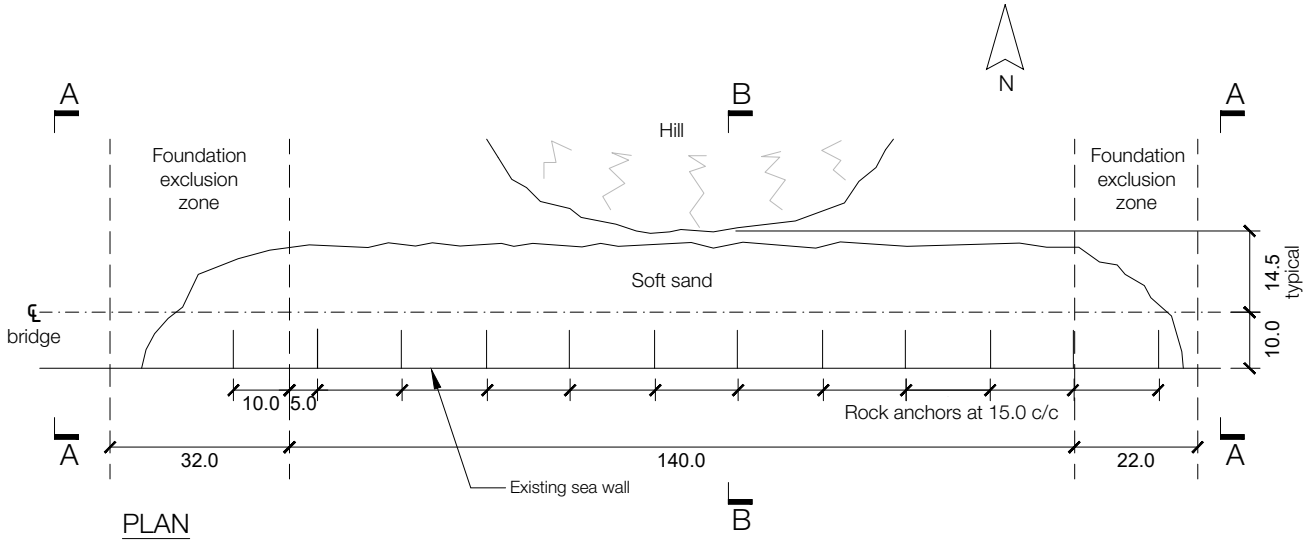
d) Prepare general arrangement drawings which may include plans, sections and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes. Prepare clearly annotated sketches to illustrate details of:
a) The roof structure at the perimeter and its vertical support including the crane runway beam
b) The perimeter ground slab and the main structures foundation at the North end of the building

(30 marks)

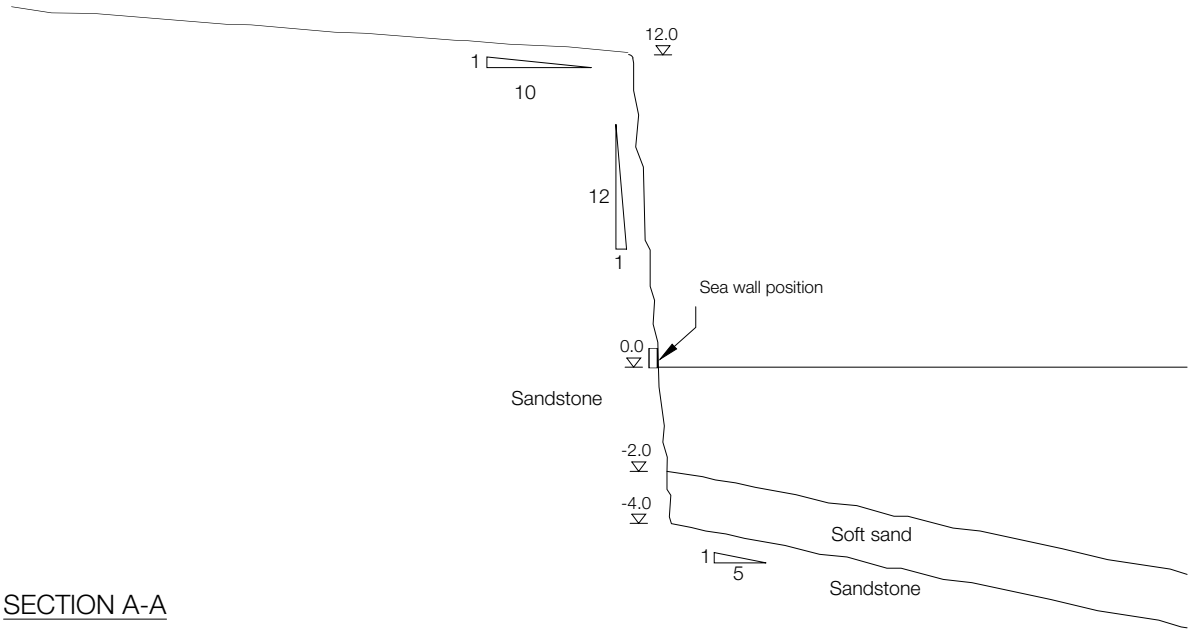
e) Prepare a detailed method statement for the safe construction of the works.

(10 marks)

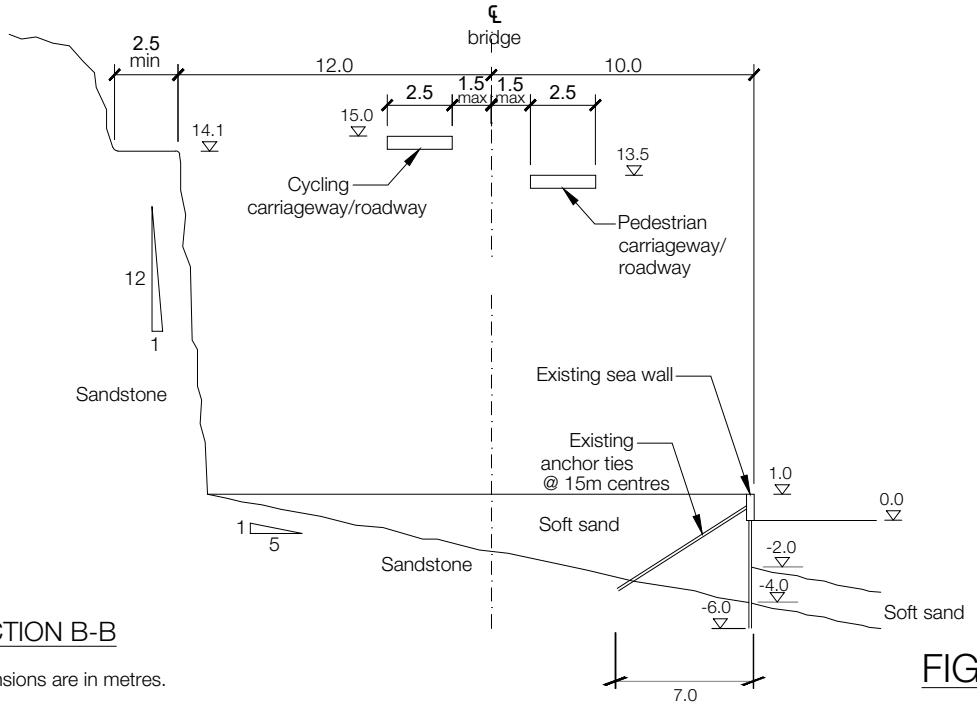
Blank page



PLAN



SECTION A-A



SECTION B-B

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 carriageways: Live Load intensity 5 kN/m^2

Site conditions

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/m^2 in any direction. The soft sands have N = 5

Omit from consideration

10. Design of parapets/handrails.

SECTION 1 (30 marks)

a) Prepare a design appraisal with appropriate sketches indicating a viable and sustainable solution for the proposed bridge including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of the scheme. Using sustainability as a key criterion, justify the reasons for your solution. (20 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)

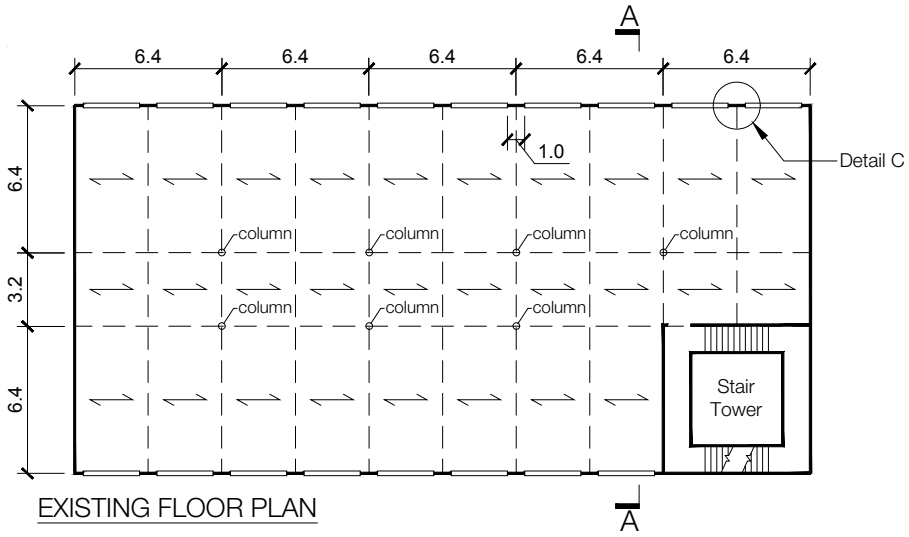
SECTION 2 (70 marks)

For the solution recommended in Section 1(a)

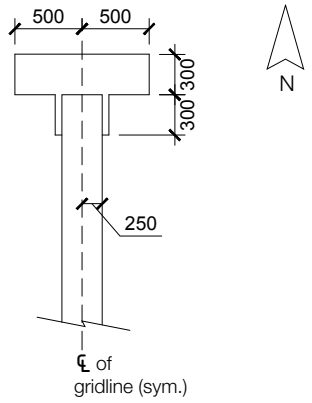
c) Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. Include approximate A1-A3 carbon calculations for each of your principal elements. (30 marks)

d) Prepare general arrangement drawings which may include plans, sections and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes. Prepare clearly annotated sketches to illustrate details of:
   a) Connection of the bridge structure to the abutments
   b) Vertical structure to the foundations (20 marks)

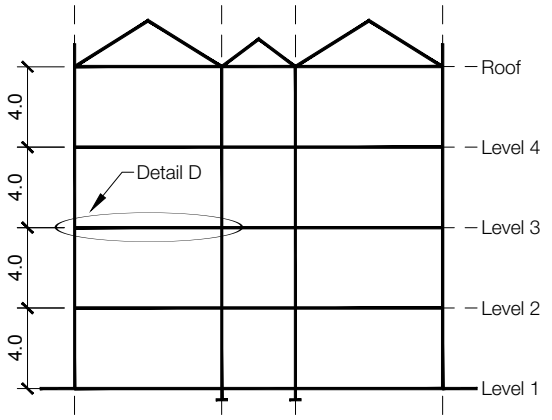
e) Prepare a detailed method statement for the safe construction of the works. (10 marks)



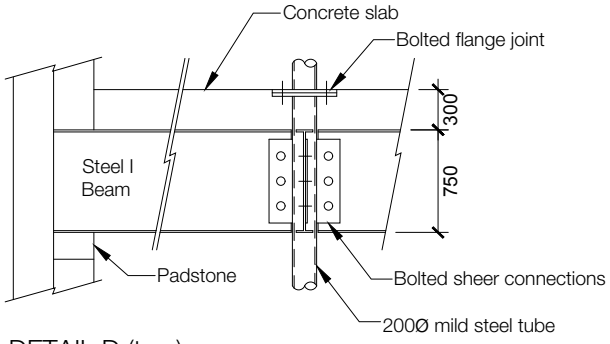
EXISTING FLOOR PLAN



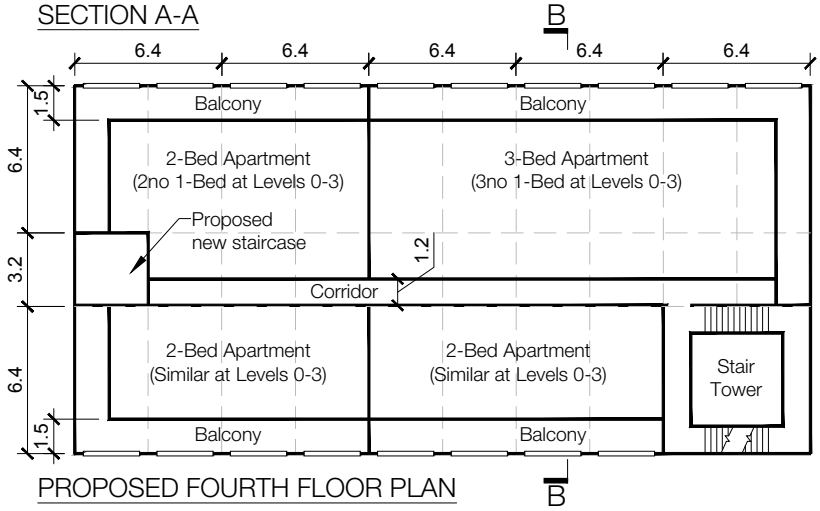
DETAIL C (typ.)



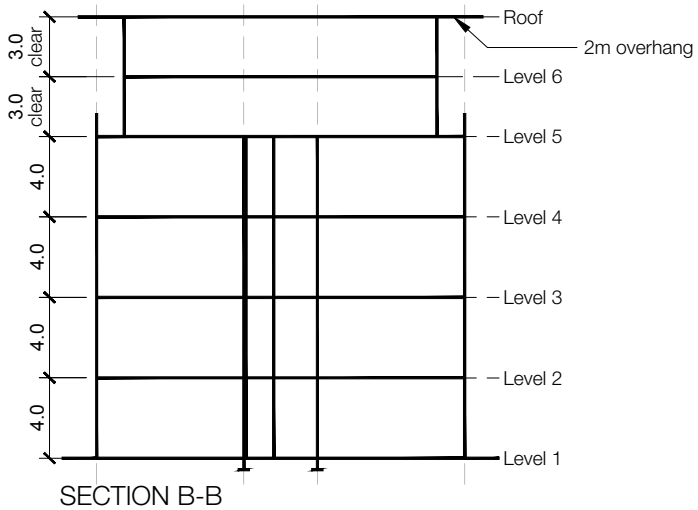
SECTION A-A



DETAIL D (typ.)



PROPOSED FOURTH FLOOR PLAN



SECTION B-B

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

FIGURE Q4

Q4. 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 Q4.
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 500 mm 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 Q4.
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/m^2 and the permanent self-weight load of the existing floors is 6 kN/m^2. The existing roof self-weigh is 3 kN/m^2. 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/m^2. The new flat roof is to support a variable load of 0.75 kN/m^2 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 (30 marks)

a) Prepare a design appraisal with appropriate sketches indicating a viable and sustainable solution 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 the scheme. Using sustainability as a key criterion, justify the reasons for your solution. (20 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 (70 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. (30 marks)

d) Prepare general arrangement drawings which may include plans, sections, and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes. Prepare clearly annotated sketches to illustrate details of:
   a) The connection of the new extensions vertical structure with its support member
   b) The connection of the new horizontal support member at Level 5 with the perimeter wall (30 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 at all stages of construction. (10 marks)

Blank page

Blank page

International HQ,
47-58 Bastwick Street,
London EC1V 3PS, UK

T +44 (0)20 7235 4535
E membership@istructe.org

www.istructe.org