The Institution of Structural Engineers

Possible solution to past CM examination question

# Question 3 - January 2016

# Taxiway Bridge

by Saprava Bhattacharya

# Question 3. Taxiway Bridge

## Client's requirements

1. An existing motorway is to be connected with the main access road to the airport as shown in Figure Q3 and a bridge is required to support the taxiway over the new road. The existing maintenance hangar should remain in position and the taxiway connection to the hangar is to be interrupted as little as possible.
2. The airport will allow a maximum of seven days' continuous closure of the taxiway to the hangar once in a year. No other closure will be allowed. However a temporary taxiway route (as shown in Figure Q3) may be built before the bridge construction, but the airport will charge the contractor a very high price if this option is chosen as it would disrupt aircraft landing and take-off.
3. Aircraft moving to and from the hangar should not have any obstruction 50.0m either side of the centreline of the existing taxiway.
4. Two 7.0m diameter concrete tubes, constructed on top of existing bed rock at 8.0m depth from the surface of the runway / taxiway, carry the underground railway service. This must remain uninterrupted at all times.
5. The taxiway bridge must achieve the clearance envelopes as shown in figure Q3.

## Imposed loading

6. Design Live load on bridge deck- 20.0kN/m$^2$ over entire deck.

## Site conditions

7. The site is located in open countryside. Basic windspeed is 44.0m/s based on a 3-second gust; the equivalent mean hourly wind speed is 22.0m/s.
8. Ground conditions

| | |
|---|---|
| Ground level – 8.0m | stiff clay, C= 200kN/m$^2$ |
| Below 8.0m | Rock, characteristic compressive strength 2,000kN/m$^2$ |

## Omit from consideration

9. Longitudinal braking load.

## SECTION 1 (50 marks)

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After the completion of the design, the client informs you that the deck should be checked for a single wheel load of 500kN over an area 500mm square. Write a letter to your client advising on the design implications and ways in which the design would need to be modified. (10 marks)

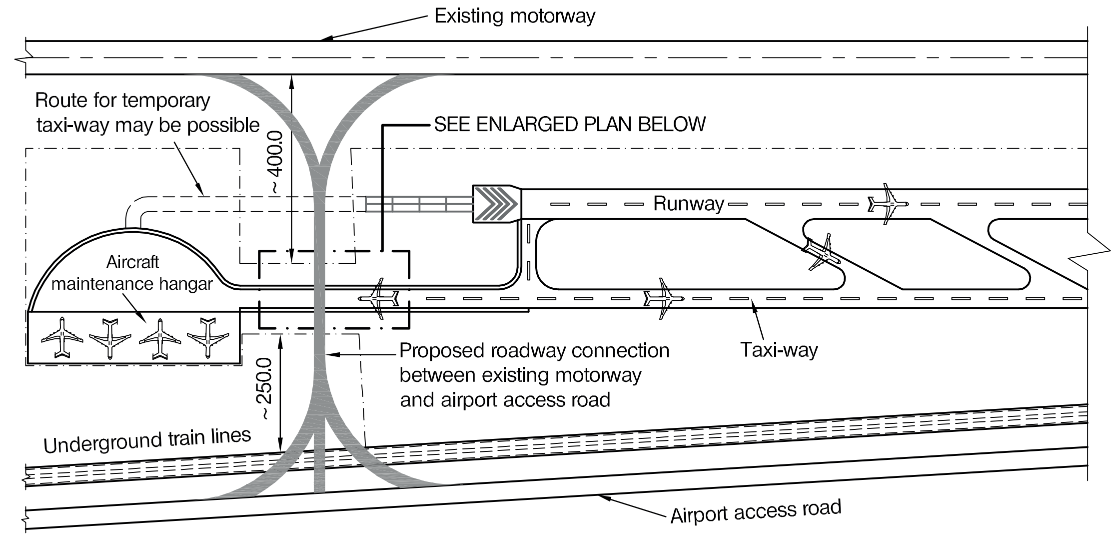
## SECTION 2 (50 marks)

For the solution recommended in Section 1(a):

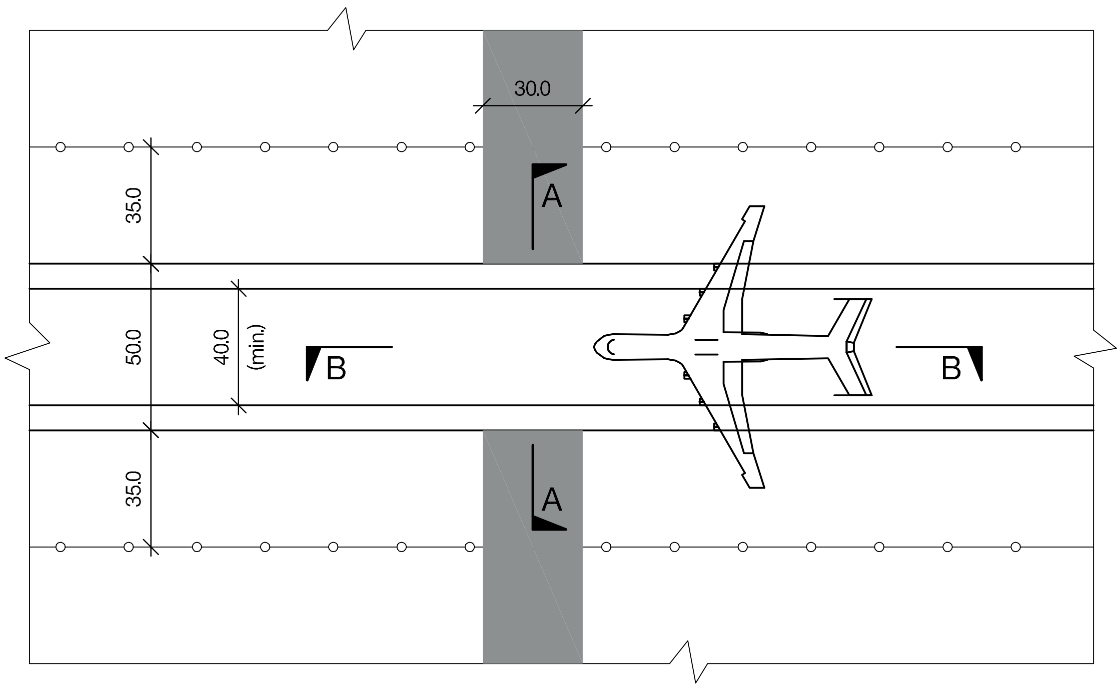
c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

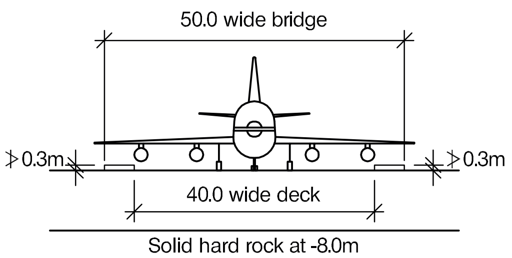
e. Prepare a detailed method statement for the safe construction of the works and an outline construction programme. (10 marks)



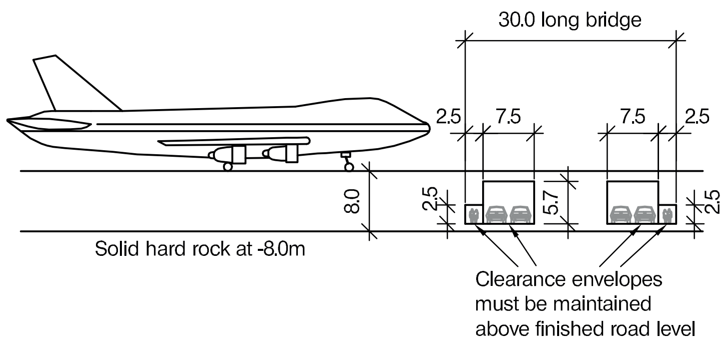

PLAN




ENLARGED PLAN




SECTION A - A




SECTION B - B

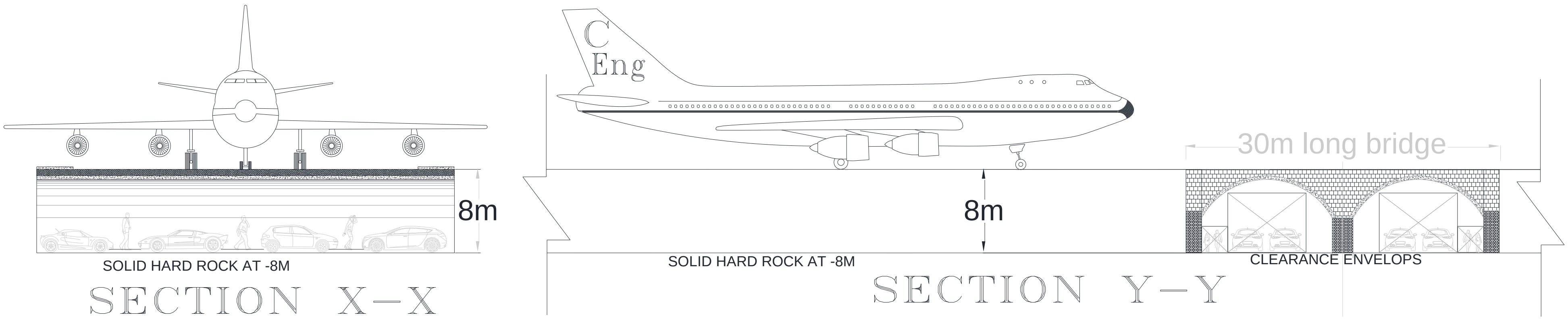
NOTE: All dimensions are in metres

FIGURE Q3

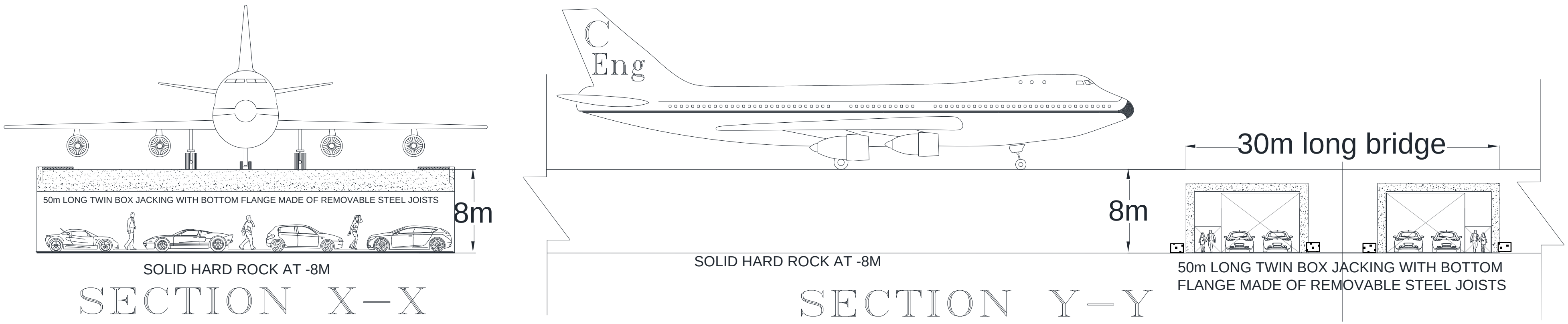
**Three possible solutions:**

**Solution 1:** Obviously the simple two span Taxiway Bridge shown in the photograph below could be an appropriate solution, only if it could be built off line and moved in position during the available possession time given in the question. Although the question requires 30m long and 50m wide bridge which may not look exactly like the bridge below, however the basic structural arrangement could be the same. Hence, lighter superstructure easy to move in place after offline construction.  For the structure below the end abutments are crucial, especially if they are cast on the bed rock, stability check against overturning is a must.

**Solution 2:** Twin Precast arch may be a more appropriate solution to meet client's requirements in the question especially they are very quick and easy to build.

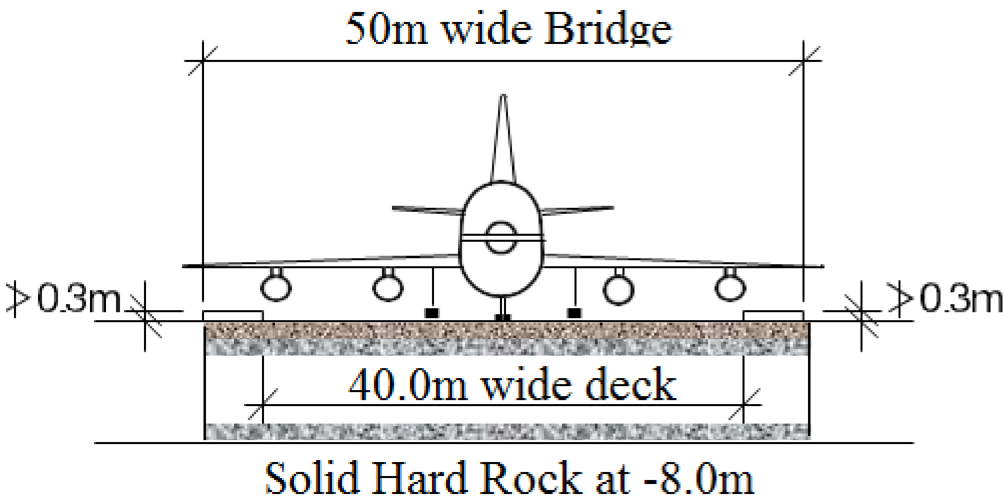



**Solution 3:** Most appropriate solution to meet client's requirements is twin portal built offline as shown below, lifted and placed with modular transporter.

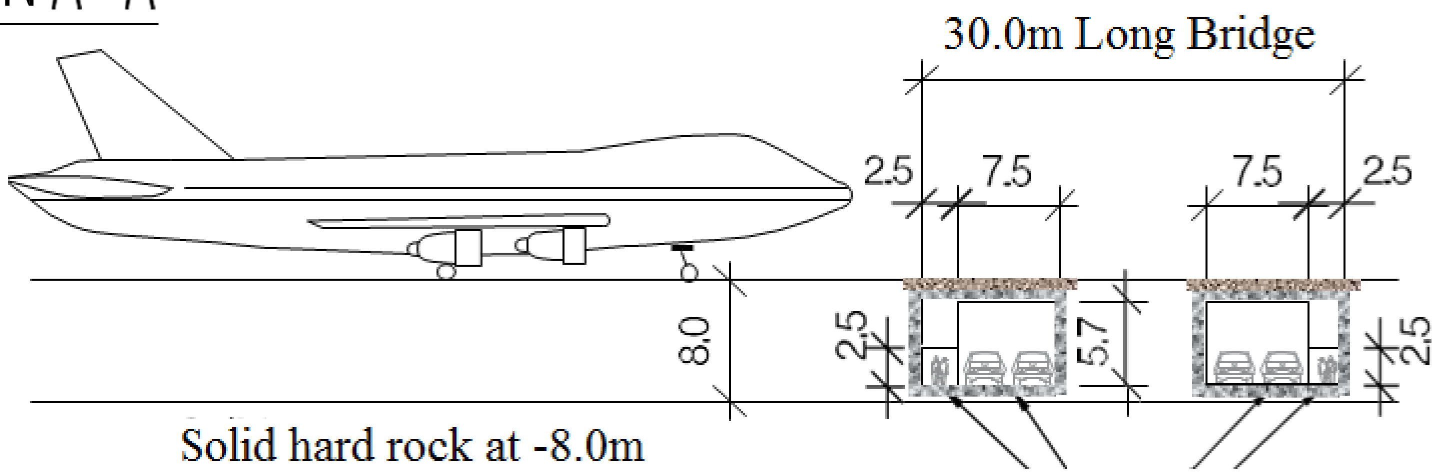



Two simple portal frames converting the taxiway bridge into two 50m long tunnels on top of which Aircrafts will drive on to the maintenance hangar.

**Solution 4:** Twin box jacked underneath may be appropriate to a practical solution but it is somewhat specialist approach for a mix of Structural and Geotechnical engineer, which is better to avoid for Part III examination of 7 hours. Even if anyone likes to propose this obvious solution as a discarded solution, the only way it could be discarded saying the uncertainty of the flat and even rock profile underneath.




SECTION A - A




Clearance envelopes
must be maintained above finished road level

SECTION B - B

**<u>Key observations from Client's requirement => *constraints*</u>**

- The existing maintenance hangar should remain in position and the taxiway connection to the hangar is to be interrupted as little as possible:
    - *Offline construction or precast segmental (in transverse direction) construction is essential.*
    - *Candidates should start writing method of statement soon after they decide two possible distinct solutions and the chosen one.*
- The airport will allow a maximum of seven days' continuous closure of the taxiway to the hangar once in a year
    - *Site construction activity and disruption to the existing taxiway can't exceed 7 days in a year.*
    - *Although a temporary taxiway connection to the maintenance hangar at the end of the runway is possible but not encouraged at all, for the safety reasons of landing and take-off operation.*
- Aircraft moving to and from the hangar should not have any obstruction 50.0m either side of the centreline of the existing taxiway:
    - *No construction activity should be taking place within 50m either side of centre line of existing taxiway connection*
    - *However offline construction and putting it/them at right place using modular transporter is a very simple possible solution.*
- Two 7.0m diameter concrete tubes, constructed on top of existing bed rock at 8.0m depth from the surface of the runway / taxiway, carry the underground railway service, which should be uninterrupted all time:
    - *Advantage of the rock profile along the length of the proposed new road and its required gradient should be beneficial.*
    - *One 30m long Bridge can be replaced by two bridges side by side with minimum clear span of 10m.*
- The taxiway bridge must achieve the clearance envelopes as shown in figure Q3:
    - *Box jacking option is the most obvious solution in practice; however precast arch with necessary cushion on top is easily available too.*
    - *Use of appropriate light weight cushion and backfill material may help in deigning reasonable thickness of the deck slab and the abutment walls.*
    - *High bearing capacity of the bed rock may reduce the size of the abutment base/ strip footing of the portal but clearance above road surface must not be compromised at all time.*

**The most appropriate two distinct viable solutions possible for this problem:**

For the two distinct and viable solutions out of four in above, they will be the second and the third for exam purpose. For design office 3rd may be replaced by its improved version as shown in 4th proposal. Out of those two, obviously the 3rd one will be the chosen solution to develop. The reasons are:

- Safest and easiest to construct offline, lift up and place it using modular transporter, particularly for this site. Alternatively each straight portal could be fully precast multiple segments and post-tensioned after placed in position.
- Aesthetically may be less attractive compared to the other precast Arch solution but it is the most appropriate solution to this particular problem.
- With appropriate cushion it'll eliminate problem arising from punching shear stress completely.
- Two separate portal bridge structure with integral abutment will eliminate the necessity of a wide base abutment. Many candidates failed to satisfy the basic overturning factor of safety for a cantilever retaining wall bridge abutment.

**Section 1b – letter to client:**

Though the proposed change mentioned in the question is unlikely to have any impact to the chosen solution, however it is eminent that client will expect technical advice in the reply. Hence it is essential for the engineer to demonstrate with statement rather than calculation, especially the load dispersion through surfacing and cushion layer on top of the deck slab. Knowledge of punching shear design is highly essential. Bigger the load dispersion depth effect of heavier load mentioned here in section 1b letter writing can become much easier as it will be closer to the standard design load.

**Section 2C: - Calculations.**

For this type of project calculations are generally basic Portal Frame analysis and design along with its base. Unfortunately basic stability calculation wasn't considered by the candidates who didn't succeed. However calculations must have enough to justify the behaviour of the portal frame sitting on top of bed rock at -8m level. Stability of structure is really important at all time, but choosing a portal frame, that is the deck is integral with abutments at either end, may not need to demonstrate it as the earth pressure either end will balance. On the other hand it will be essential to follow the design procedure of integral bridge.

Accurate calculation of load will govern the size of the deck thickness and the strip foundation which is highly essential.

**Drawings:**

As mentioned in the question the answer script must include general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimation purpose.

For the chosen solution above, drawn elevation sections in the form of sketch is needed to be improved and the plan view should be included, to make them complete engineering drawings.

If the construction to be done in segments then some post-tension detail has to be included. However for this extremely simple structure it is essential to provide reinforcement detail as part of the required detail along with appropriate notes.

**Method of Statement and outline construction programme:**

Finally the method of statement should have enough to justify the safety measures are adequately considered by the candidate. Offline construction and construction of the new road should be included. Emphasis has to be given on the restriction of 7 days period for site construction activity at the location of existing taxiway connection to aircraft maintenance hangar.

50 m clear distance is maintained at all time for offline construction activity nearby.

Appropriate construction program is highly essential for this type of project.

# Possible solution to past CM exam question

# Question 5 – January 2016

# Emergency Generator Building

by Rajavel Inbarajan

The information provided should be seen as an interpretation of the brief and a possible solution to a past question offered by an experienced engineer with knowledge of examiners' expectations (i.e. it's an individual's interpretation of the brief leading to one of a number of possible solutions rather than the definitive "correct" or "model" answer).

# Question 5. Emergency Generator Building

## Client's Requirements

1. Construction of a building to house an emergency electrical generator.
2. The building comprises a generator room and six electrical plant rooms; see Figure Q5. Eaves heights to the generator room are 4.5m, and to the plant rooms 3.0m.Exhaust ducting 0.5m diameter leads from the generator to an external flue.
3. The building and retaining wall are to be clad with brickwork, to match the aesthetics of the surrounding buildings.
4. Access 3.0m wide is required around the entire perimeter of the building, requiring a retaining wall on three sides, owing to the nature of the sloping site.
5. Cable trenches 1.0m wide and 0.8m deep are required to access each room.
6. A handrail 1.1m high is required to the perimeter access around the retaining wall.
7. A minimum of 1 hour fire resistance is needed.

## Omit from Design

8. The design of the support structure for the generator flue.

## Imposed loading

9. Ground floor 7.5kN/$m^2$
   Pitched roof 0.6 kN/$m^2$

## Site conditions

10. The site is situated on a heavily wooded site, which will need to be partly cleared of trees, and there are some cavities at a shallow depth in unknown positions caused by old mine workings. Basic wind speed is 46m/s based on a 3 second gust; the equivalent mean hourly wind speed is 23m/s.
11. The ground conditions at the south boundary of the site are:

| | |
|---|---|
| Ground level to 2.0m | Topsoil and made ground |
| 2.0m to 3.0m | Firm clay C = 75kN/$m^2$ |
| 3.0m to 4.0m | Stiff Clay C = 125kN/$m^2$ |
| Below 4.0m | Mudstone, presumed safe bearing capacity 400kN/$m^2$ |

Ground water was encountered at 3.0m below ground level.

## SECTION 1

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After you have completed your design, the client asks you to install a basement plant room under the entire area of the generator room (10m x 9m), with a clear headroom of 2.5m. Write a letter to your client explaining the implications of this potential change. (10 marks)

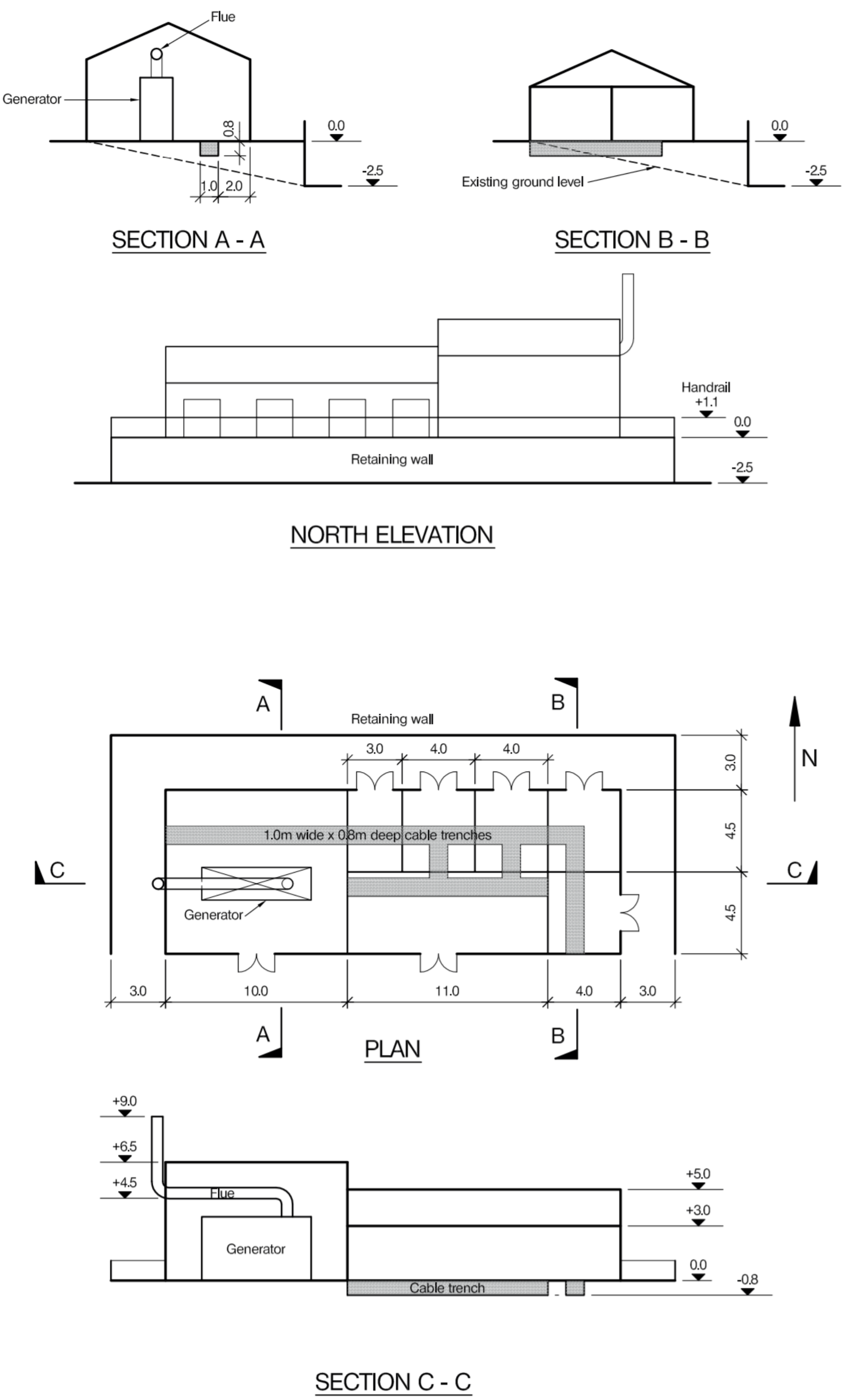
## SECTION 2

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 and the retaining wall. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

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




NOTE: All dimensions are in metres

FIGURE Q5

**It is brought to the attention of the candidates that the preparation of this possible solution is not carried out under examination conditions**. It is prepared to assist candidates in their Chartered Membership Examination preparation with respect to arriving at two distinct and viable solutions as required in Section 1(a) of the question. The annotated sketches provided were drawn using PowerPoint for better clarity and illustration purposes. However, in a design appraisal, candidates can convey their ideas in neat hand drawn annotated sketches in the context of Section 1(a), to illustrate the structural framing, load transfer and stability aspects. It is also vital to depict the stability aspects and both vertical and horizontal load transfers clearly in words. In the examination, candidates may use the A4 size answer sheets to draw the annotated sketches required to explain their design appraisal in Section 1(a).

Some guidance is given on the recommendation for scheme selection in Section 1(a).

This possible solution also explains the structural implications of constructing a basement plant room under the entire area of generator room and gives guidance to candidates in writing a letter to the client as required in Section 1(b).

# Introduction

This question deals with a single storey building to be constructed to house an emergency electrical generator on a heavily wooded site with sloping ground containing some cavities at a shallow depth as a result of old mine workings.

It is quite common that the Chartered Membership Examination tests a candidate's competency in aspects of geotechnical engineering in addition to structural engineering. This is one such question and demands competency in dealing with various type of foundations on a sloping site.

This question may therefore be daunting for those candidates that lack experience in geotechnical design and construction of different types of foundations. Nevertheless, it is not a difficult question for engineers experienced in dealing with the design and construction of various types of substructure, foundation and super structure systems.

# The issues

- Footprint of the building is 25m x 9m. The height of the generator room is 1.5m higher than electrical plant rooms.
- Retaining walls must be built in 3 sides to create access around the building. It implies that surcharge from the building and access areas needs to be taken care and considered in the design and construction of these retaining walls.
- Viable foundation systems are greatly influenced by ground conditions and by economically keeping their influence zones not to interfere with stems of the retaining walls at site boundaries to prevent the horizontal forces created by the surcharge of building.
- Water table is shallow, and it is below 3.0m from the ground level.
- The building and the retaining walls are to be clad with brick to suit the surroundings.

- 1-hour fire rating is required.
- It is important that the proposed schemes should be compatible with the construction sequence in order not to alter the design objectives. Therefore, in the context of this question, candidates should pre-plan the safe construction of building and retaining walls in a heavily wooded and slope site that possess cavities in unknown locations as ground probing for locating cavities, void grouting, earth excavation and earth filling are needed for the construction of foundations, retaining walls and forming the finished level around the building. Hence, in section 1(a) thought must be given to safe construction methods which would benefit candidates with the satisfactory preparation of a detailed method statement and construction programme in Section 2(e).
- Flue support details need to be included.

The following is worth noting.

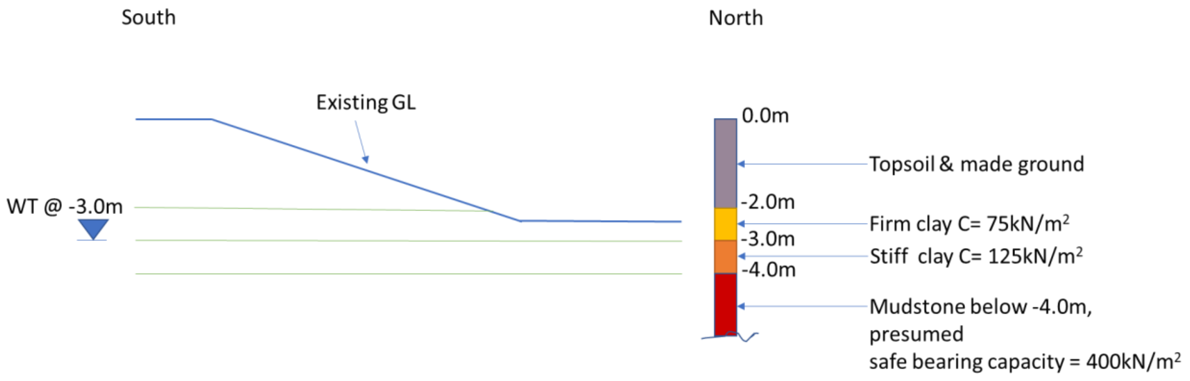
<u>Site boundary</u>

It is assumed that the retaining walls abut the site boundaries on the East, West and North sides of the plot although the site boundary is not indicated explicitly in the question.

<u>Site conditions</u>

The wind data is provided in terms of basic wind speed (46m/s) with a 3 second gust and equivalent mean hourly wind speed (23m/s). Candidates have the liberty to choose the basic wind speed or mean hourly wind speed values given in the question based on their local practice as it varies from country to country. The understanding on the effect of wind suction and pressure on the superstructure design should be demonstrated. Showing adequate calculations on the computation of wind forces for the design would reap good marks.

Ground conditions varies as follows;



The geotechnical design parameters should be worked out from the given ground conditions.

- The question states that ground water was encountered 3.00m below the ground level. The ground water level has been taken as shown in the above diagram at -3.0m level assuming the phreatic line stays within the existing slope.
- Densities of the topsoil/made ground and earth fill required to form the access in 3 sides could be taken as 19 $kN/m^3$.
- Allowable bearing capacities of firm clay and stiff clay can be calculated based on C values given.
- The safe bearing pressure capacity of mudstone should be taken as 400 $kN/m^2$.
- Retaining wall should be designed for a surcharge of 10 $kN/m^2$ applied in the access path.

Though the Chartered Membership Examination does not demand very complex geotechnical calculations, it is imperative that the candidates should demonstrate their understating of the exiting ground conditions and the remedial measures/precautions to be taken in the selection of viable and distinct foundation options. However, candidate should prepare sufficient calculations to show the load carrying capacities of different types of foundations to gain good marks. It is imperative to demonstrate the understanding on the following in the script.

- Further ground investigation should include ground probing to identify cavities for grouting to strengthen the ground conditions and to prevent ground settlement.
- Pile design should allow for negative skin friction above old mine workings if piling is done through old mine workings or have piles terminating above the grouted cavities.
- Clay heave should be considered in the design due to the presence of many trees in the heavily wooded site.

## Possible solution

The footprint of the single storey emergency generator building is not large, and its disposition is not very complex though it demands a double pitched roof at for the different levels of the generator room and electrical plant rooms. Therefore, the design appraisal of the superstructure for this building is relatively straight forward for experienced candidates that are familiar with portal frame and truss design. However, this question also tests the candidate’s knowledge and experience on the design and construction of foundations on sloping ground with varying soil conditions and in a heavily wooded site, with some cavities caused by old mining works at a shallow depth.

In fact, the design appraisal should explore and highlight various possible options and narrow them down to two distinct and viable schemes. The following tables shows various distinct and viable schemes for the superstructure and substructure/foundation.

## Options for superstructure schemes

| S. No | Options for superstructure | Remarks |
|---|---|---|
| 1 | *Duo pitched steel portal frames with pinned bases spanning in the shortest direction. Cross bracings on selected bays are placed in the sides of the longest direction.* | Better headroom. |
| 2 | *Duo pitched steel lattice trusses spanning in the shortest direction and connected to steel columns with pinned bases at edges. Cross bracings on selected bays are placed in the sides of the longest direction.* | Good headroom. |
| 3 | Flat steel portal frames with pinned bases spanning in the longest direction at edges and middle. Cross bracings on selected locations are placed on the shortest direction at gable ends and interface between GR and ERs. | Better headroom but span is longer in the longitudinal direction. |
| 4 | Flat steel lattice trusses spanning in the longest direction and connected with steel columns with pinned bases at edges and middle. Cross bracings on selected locations are placed on the shortest direction at gable ends and interface between GR and ERs. | Good headroom but span is longer in the longitudinal direction. |

## Options for substructure/foundation schemes

| S. No | Options for substructure/foundation | Remarks |
|---|---|---|
| 1 | *Shallow raft on piles and with sleeper walls/stumps on it to support ground floor, columns and brick walls.* | Building surcharge does not affect retaining walls. |
| 2 | *Deep filled trenches to support ground floor, columns and brick walls.*<br>*(Foundation should be deep enough not to cause surcharge loading from the building on retaining walls.)* | Building surcharge does not affect retaining walls. |
| 3 | Ground floor slabs and columns supported on RC beams resting on pile caps supported on piles. | Building surcharge does not affect retaining walls. |
| 4 | Shallow raft resting on engineered fill. | Surcharge from building should be considered in the retaining wall design. |

The question demands two distinct and viable solutions for the proposed emergency generator building. It is important that the candidates understand the real meaning of this requirement and at the same time recognise the intricacies of the question to enable them to score sufficient marks to pass the Chartered Membership Examination.

The first two options in the above tables are correspondingly selected as Scheme 1 and Scheme 2 for superstructure and substructure/foundation respectively. In this proposed solution, the distinctiveness of schemes is achieved by adopting different foundation and structural systems that exhibits dissimilar load transfer methods. Also, scheme 2 has a slightly different grid spacing in the generator room for supporting the generator compared to the grid spacing in scheme 1.

**Scheme 1 – Steel portal frames with pinned bases supported on sleeper walls/stumps resting on shallow raft on piles**

The structural system adopted for the scheme 1 is explained below.

This scheme uses two pinned duo pitched rigid steel portal frames arranged at 3m / 4m spacing across the building to suit the layout. Cross bracings are positioned in the longitudinal sides of the building and taken through roof to stabilise the building. However, it is not practical to provide cross bracings in the door locations. Therefore, cross bracing is terminated above the door and moment frames are introduced above the door in one location and symmetrically opposite side of the building (refer sketches) to maintain symmetry and keep the framing simple. Generator flue is supported using vertical ties connected to beam supported between the rafters of portal frames in the generator room.

The structural system adopted for the ground floor is shallow reinforced concrete raft resting on piles penetrated sufficiently below the raft to prevent surcharge on retaining walls. Sleeper walls are provided in the raft to support the suspended ground floor slabs and form the cable trenches using void formers and left-in formworks below the slab to reduce the self-weight of the ground floor/foundation. Stumps are provided below the portal columns in certain locations where the layout does not allow through cross sleeper walls between the columns on opposite locations (refer sketches).

**Load transfer**

- Vertical load transfer

The gravitational forces emanating from dead load, live load of the roof and the vertical load arising from wind load component acting on the roof are transferred to rafters of the portal frames through purlins by bending and shear actions. Portal frames transfer the loads to ground floor sleeper walls/stumps through frame action by axial compression, bending and shear actions. Also, the horizontal thrust generated at portal frame bases due to the dead load and live load by the frame action of portal frame is resisted by sleeper walls (if they are present between columns in the layout) or transferred to stumps that in turn transfer the loads to raft through bending and shear actions. Dead load of brick clad wall is transferred directly to raft through sleeper walls by axial compression.

The gravitational forces emanating from dead load, super imposed dead load and live load of the ground floor are transferred to sleeper walls from slabs through bending and shear actions. Sleeper walls/stumps transfer the vertical loads to the raft predominantly through axial compression.

The raft then transfers the loads to piles through bending and shear actions. Piles transfer the loads to ground by skin friction and end bearing.

- Lateral load transfer

➢ Lateral direction (North – South)

Horizontal wind load resisted by brick cladding and the horizontal component of the wind load resisted by roof are transferred to columns and rafters of the portal frames through secondary steel provided to laterally support the brick clad walls and roof purlins respectively by bending and shear actions. Portal frames, then, transfer the horizontal forces through frame action to sleeper walls/stumps by bending and shear actions.

The resultant horizontal force created by the wind load is resisted by cross sleeper walls/stumps through shear and bending actions and then transferred to raft.

The raft, then, transfer the loads to piles through bending and shear actions. Piles eventually transfer the resultant loads to ground by skin friction and end bearing.

The earth pressure acts in the outer sleeper walls is transferred to raft by bending and shear actions and then resisted by raft by diaphragm action.

➢ Longitudinal direction (East – West)

Horizontal wind load resisted by brick clad wall at the gable end is transferred to the portal frame by bending and shear actions through secondary steel provided to laterally support the brick clad wall. Then, the horizontal forces are resisted by the cross bracings and transferred to column bases by axial tension. Moment frames are required above the door in one location and in another location symmetrically opposite to transfer the loads from the bracing above to column bases in those locations.

The sleeper walls transfer the resulting load to raft that in turn transfers the load to piles.

**Robustness and stability**

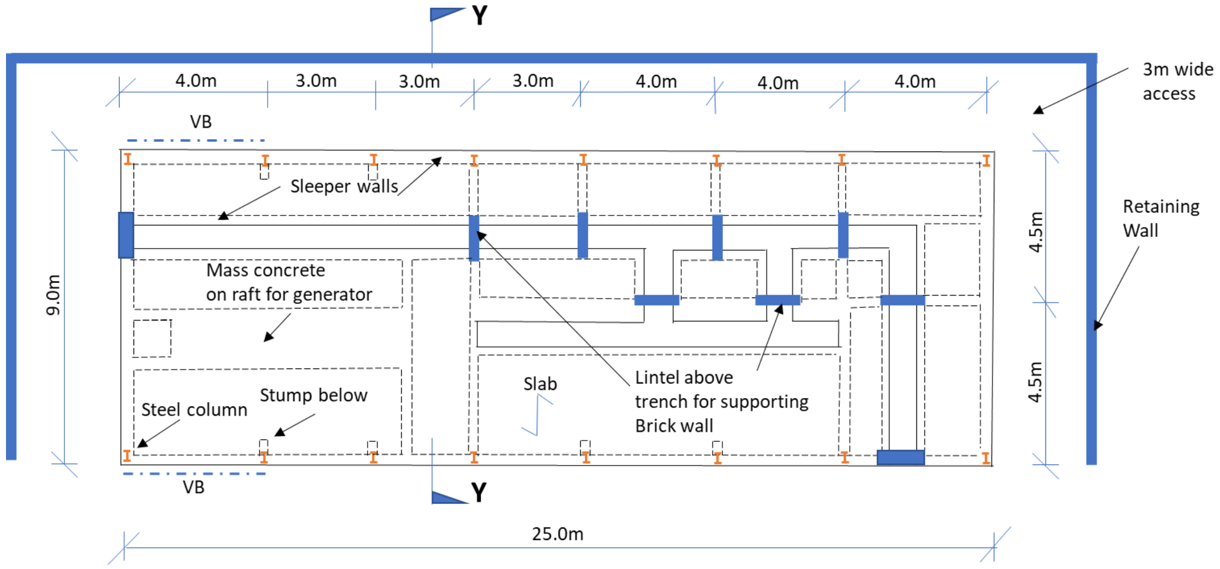
The building is sufficiently braced by rigid moment frames in the shortest direction and mainly by combination of cross bracing/moment frame in the longest directions as shown in the sketches to withstand vertical loads and horizontal loads including notional load. The shallow raft on piles facilitates the transfer of loads to mudstone strata and avoids building surcharge on the stem of retaining wall. The retaining wall base is positioned below the access path to improve the stability and to prevent sliding and over turning.

The earth filling and compaction between peripheral sleeper walls and retaining walls should be carried out uniformly without creating significant unbalanced earth pressure on the building foundation.

**Durability/Fire resistance**

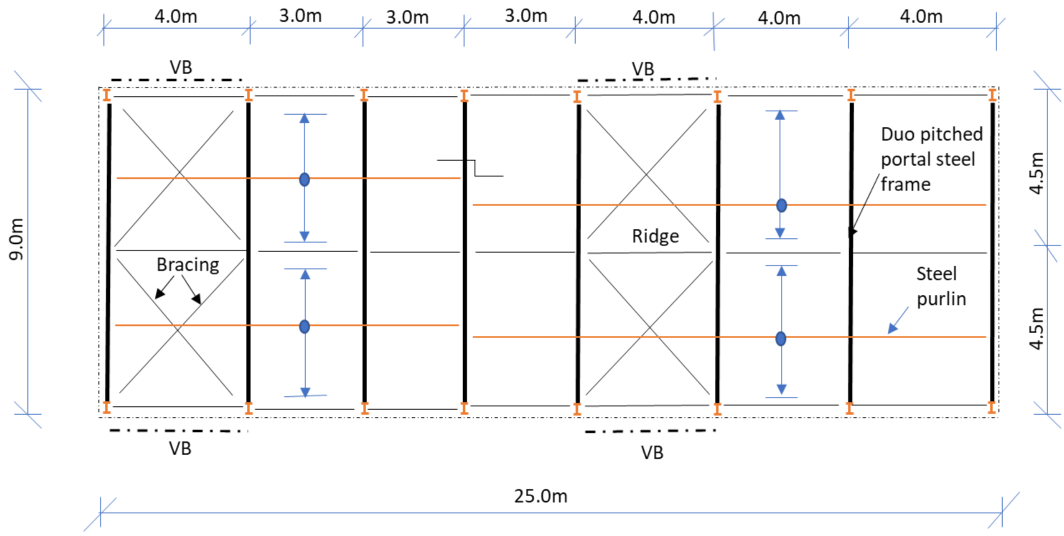
Achieving 1-hour fire rating for this building is not a challenge indeed. All the steelworks should be coated with intumescent coating to get 1-hour fire rating. All the reinforced concrete works should have the required minimum thickness and cover as per the code requirements.

The annotated sketches showing the plans, elevation and sections are attached below.



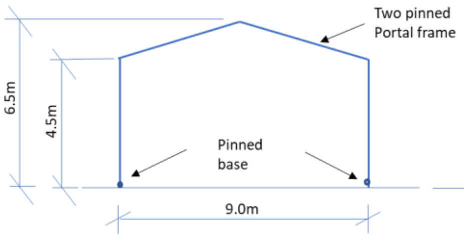

**Ground Floor Plan**

NTS

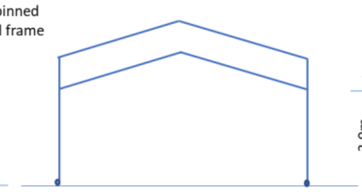



**Roof Plan**

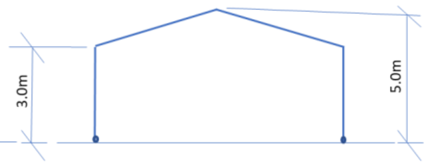
NTS



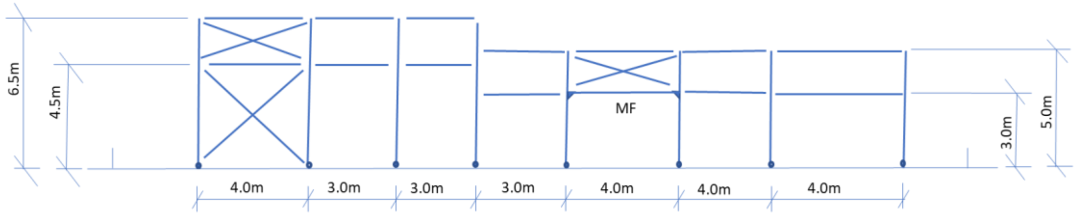

**Steel Portal Frame for Generator Room**
NTS



**Steel Portal Frame at Interface**
NTS

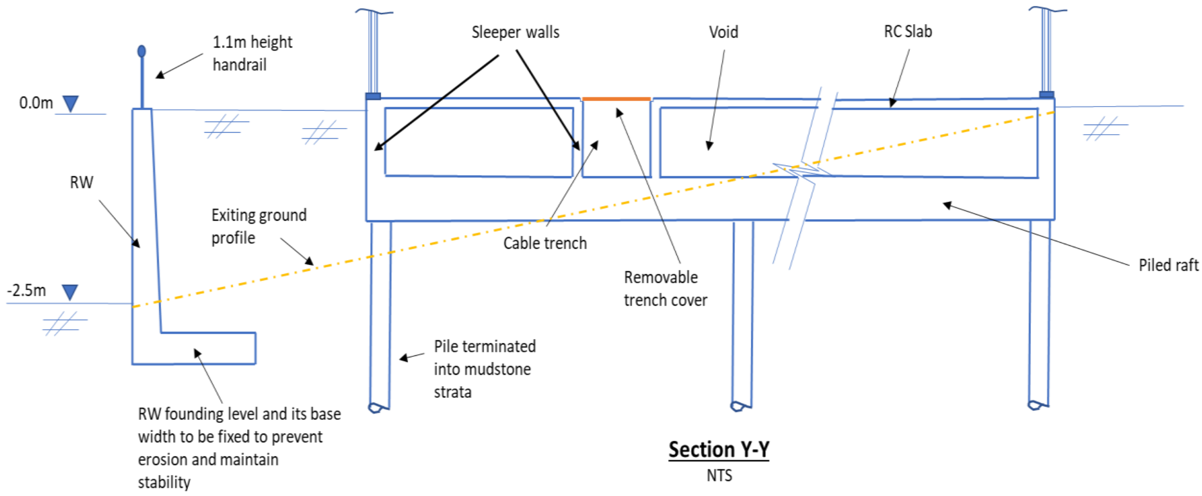



**Steel Portal Frame for Electrical Rooms**
NTS

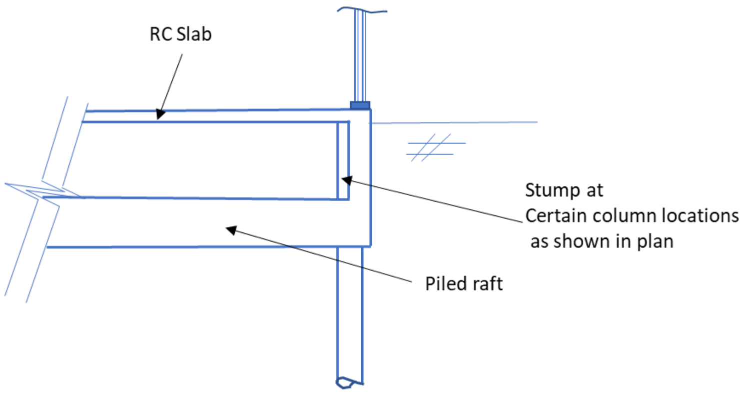



**Southside Frame**
NTS

Note: Secondary steel not shown




**Section Y-Y**
NTS



**Scheme 2- Steel lattice trusses connected to pinned bases supported on deep filled trench foundations**

The structural system adopted for the scheme 2 is explained below;

This scheme adopts duo pitched steel lattice trusses connected to steel columns pinned at their bases with truss spacing ranging from 3m to 4m along the building to suit the layout. Cross bracings are positioned in the longitudinal sides of the building and taken through roof to stabilise the building. However, it is not practical to provide cross bracings in the door locations. Therefore, cross bracing is terminated above the door and moment frames are introduced above the door in one location and symmetrically opposite side of the building (refer sketches) to maintain symmetry and keep the framing simple. Generator flue is supported using vertical ties connected to beam supported between the trusses in the generator room.

The structural system adopted for the ground floor is deep filled trenches adequately deep enough to prevent surcharge on retaining walls and to support the slab and beams. The depth of the deep filled trenches should be founded below the made ground. Also, engineered earth fill is required on the north side above the sloping ground (refer sketches).

**Load transfer**

- Vertical load transfer

The gravitational forces emanating from dead load, live load of the roof and the vertical load arising from wind load component acting on the roof are transferred to chords/booms of trusses through purlins by bending and shear actions. Trusses transfer the loads to columns predominantly through truss action (axial tension and compression). Columns transfer the loads to ground floor deep filled trenches through frame action by axial compression, bending and shear actions. Also, the horizontal out thrust generated at column bases due to the dead load and live load by the frame action of truss frame is resisted by deep filled trenches. Dead load of brick clad wall is transferred directly to ground through deep filled trenches by axial compression.

The gravitational forces emanating from dead load, super imposed dead load and live load of the ground floor are transferred from suspended slabs to deep filled trenches and cable trench beams spanning between deep filled trenches through bending and shear actions. Cable trench beams transfer the dead load, live load and super imposed dead load to deep filled trenches by bending and shear actions. Then, the deep filled trenches transfer the loads to ground by bearing.

- Lateral load transfer

➢ Lateral direction (North – South)

Horizontal wind load resisted by brick clad walls and the horizontal component of the wind load resisted by roof are transferred to columns and chords of the trusses through secondary steel provided to laterally support the brick clad walls and roof purlins respectively by bending and shear actions. Trusses transfer the loads to columns predominantly through truss action (axial tension and compression). Columns transfer the loads to ground floor deep filled trenches through frame action by axial compression, bending and shear actions.

The resultant horizontal force created by the wind load is resisted by deep filled trenches and then transferred to the soil.

- <u>Longitudinal direction (East – West)</u>

Horizontal wind load resisted by brick cladding at the gable end is transferred to the truss frame by bending and shear actions through secondary steel provided to laterally support the brick cladding. Then, the horizontal forces are resisted by the cross bracings and transferred to column bases by axial tension. Moment frames are required above the door in one location and in another location symmetrically opposite to transfer the loads from the bracing above to column bases in those locations.

The deep filled trenches transfer the resulting load to the soil.

**Robustness and stability**

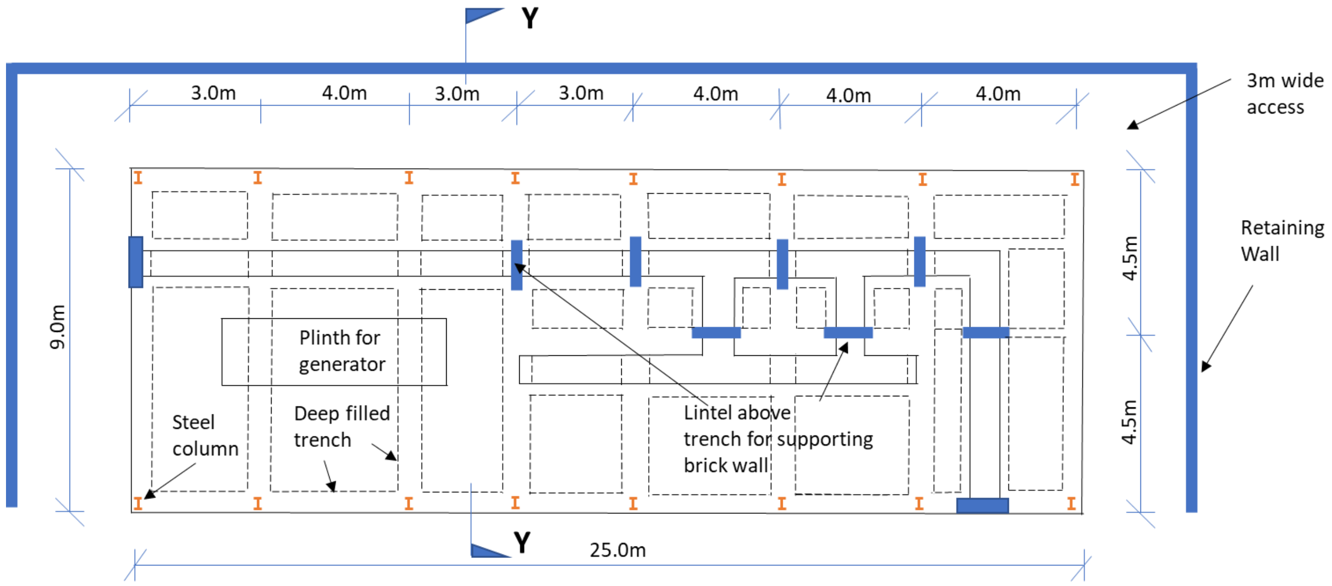
The building is sufficiently braced by trusses/frames in the shortest direction and mainly by combination of cross bracing/moment frame in the longest directions as shown in the sketches to withstand the vertical and horizontal loads including notional load. The deep filled trenches facilitate the transfer of loads to ground sufficiently below and to avoid building surcharge on the stem of retaining wall. The retaining wall base is positioned below the access path to improve the stability and to prevent sliding and over turning.

The earth filling and compaction between deep filled trenches and deep filled trenches and retaining walls should be carried out uniformly without creating significant unbalanced earth pressure on deep filled trenches.

**Durability/Fire resistance**

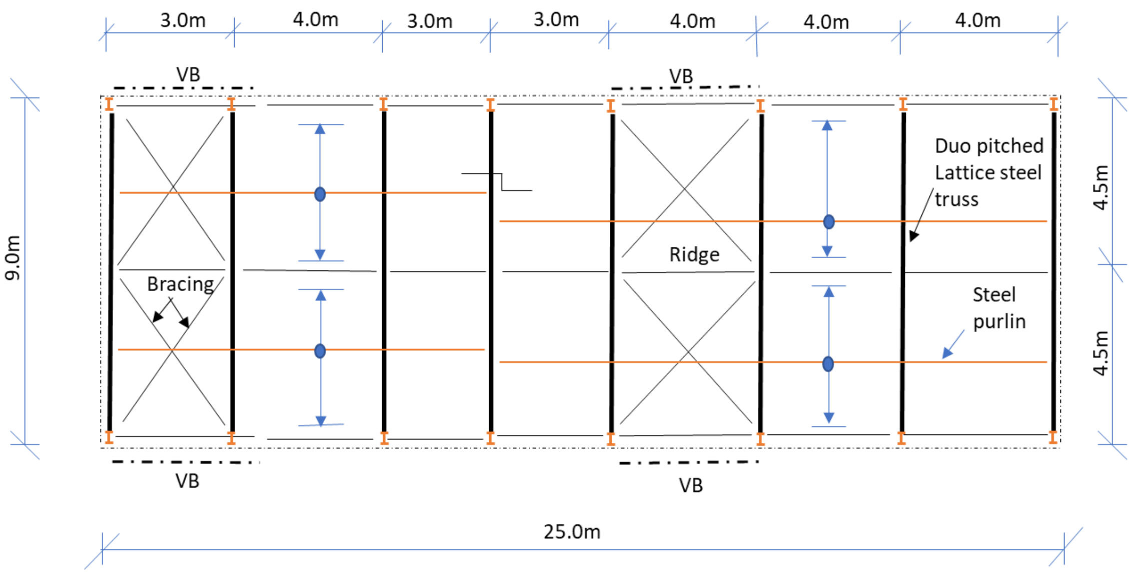
Achieving 1-hour fire rating to this building is not a challenge indeed. All the steelworks should be coated with intumescent coating to get 1-hour fire rating. All the reinforced concrete works should have the required minimum thickness and cover as per the code requirements.

The annotated sketches showing the plans, elevation and sections are attached below.



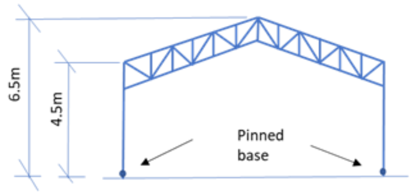

**Ground Floor Plan**

NTS

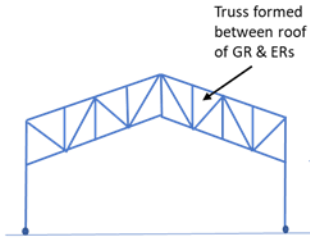



**Roof Plan**

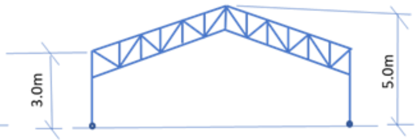
NTS



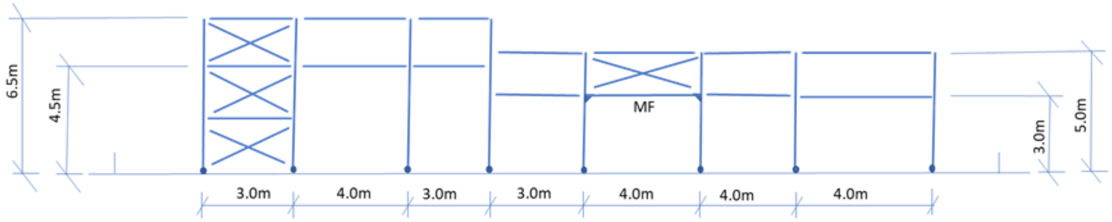

**Steel lattice truss for Generator Room**
NTS




**Steel lattice truss at interface**
NTS

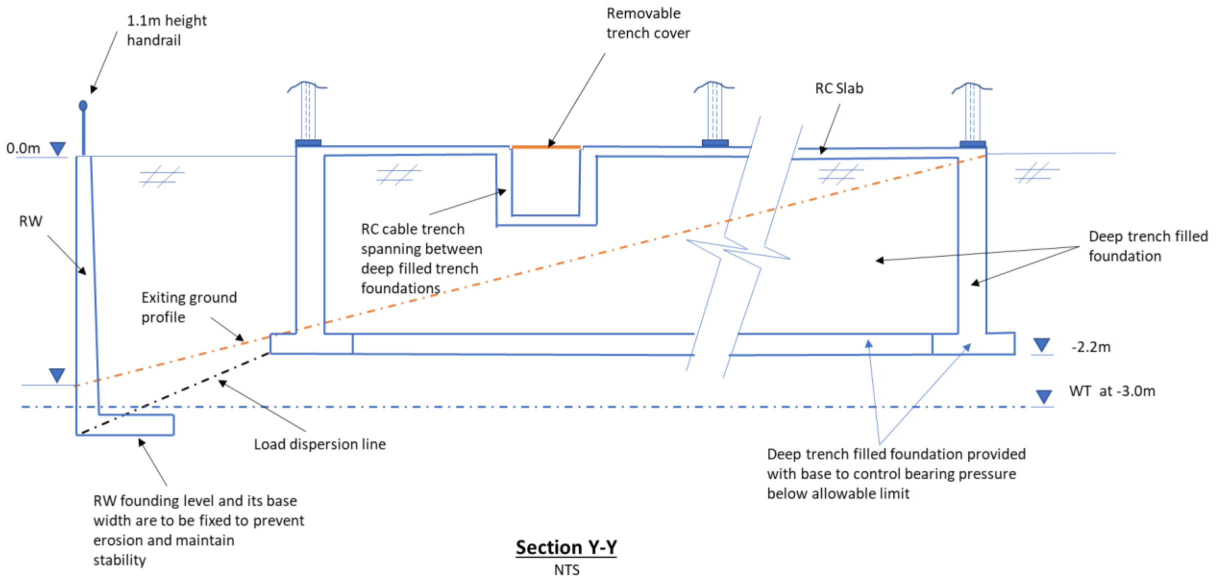



**Steel lattice truss for Electrical Rooms**
NTS




**Southside Frame**
NTS

**Note: Secondary steel not shown**




**Section Y-Y**
NTS

## Selection of scheme

The following salient features could appropriately be considered in recommending the preferred scheme considering the pros and cons of each scheme.

| | | | | |
|---|---|---|---|---|
| Economy | Buildability | Safety | Robustness | Durability |
| Site constraints | Speed of construction | Aesthetic | Acoustics | Thermal mass |
| Sustainability | Vibration | Fire resistance | | |

# Letter

The objective of letter writing is to test the competency of candidates in dealing with a design change situation after the completion of the detailed design as usually faced in real professional practice. The presence of non-technical personnel in the client's team is not uncommon. Therefore, the letter should be written effectively and adequately to depict the structural implications to a non-technical reader.

The design change situation in this question requires inclusion of a basement plant room below the generator room with a 2.5m clear headroom.

The following points depict the consequences of constructing a basement below the generator room.

- The ground floor general arrangement layout requires alteration to support the cable trenches and generator.
- The difference in foundation levels between generator room and electrical plant rooms needs careful consideration to prevent the differential settlement.
- The clear headroom requirement and depth of cable trench at ground floor pushes the basement foundation level below water table level. Hence, the base and retaining walls of the basement need to be provided with approved waterproofing protection.
- The design should cater for the hydrostatic uplift pressure on the base and horizontal hydrostatic pressure on the retaining walls of the basement created by the shallow water table.
- The implications of earth retaining during excavation and dewatering on the construction sequence need to be highlighted in the letter.
- The incorporation of basement below generator room would escalate the project cost and increase the time frame for construction.

It is worth noting the following,

- Candidate may include sketches to illustrate the structural and geotechnical implications of the inclusion of basement.
- If the structural implications of the design change requirement seem trivial to the candidate, then it implies that he/she has disregarded or overlooked an essential part of the question.
- The letter rather should focus on explaining the structural aspects of the design change requirement and not over-emphasise the aspect relating to additional fees.

## Summary

This question is a relatively straightforward for those candidates who possess good experience in the design and construction of concrete and steel structures with different types of foundation systems and earth retaining and stabilising systems.

Arriving at two distinct and viable solution becomes possible when the inherent characteristics of these systems are suitably utilised and combined in the appraisal to deal with different materials, load paths and construction methods.

Structural steel was adopted in both schemes for the superstructure though a timber roof is viable. However, if candidates opt for timber roof, it is vital to consider appropriate flue supporting arrangement and fire proofing of the timber works. Concrete structures for the superstructure were not opted considering the small footprint of the building and to minimise site work by maximising off site fabrication of steelworks.

It is also important to demonstrate in the answer that the stability of the structure at both the temporary and permanent condition is maintained. Stability checks on over turning and sliding must be provided based on the elements sizes obtained for the building and retaining walls.