The Institution of Structural Engineers

Possible solution to past AM examination question

Question 1 - July 2015

Warehouse, office and showroom

by Dr Peter Gardner

Question 1. Warehouse, office and showroom development

Client's requirements

1. A new warehouse, office and showroom development. See Figure Q1.
2. No columns are permitted within the warehouse. The roof is to be of clear span construction.
3. Only 3 columns in a single row are permitted within the office and showroom area.
4. All external columns are to be at not less than 6.0m centres.
5. Two delivery doors 6.0m high by 10.0m wide are required in the east end of the warehouse.
6. The external cladding to the warehouse is to be of insulated composite steel cladding with a single skin of 140mm concrete blockwork to a height of 3.0m above ground floor level to the inside face.
7. The external cladding to the offices is to be of glazed curtain walling with no obstructions permitted behind the glazing.
8. The roofs to the development are to be of insulated composite steel cladding.

Imposed loading

9. Roof 0.75kN/m^2
   Office and Showroom 5.00kN/m^2
   Warehouse 15.00kN/m^2

   Imposed loading includes allowances for finishes, services and partitions.

Site conditions

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

Borehole 2	
Ground - 2.0m	Top soil and fill
2.0m - 4.5m	Sand and gravel N = 15
Below 4.5m	Very stiff clay C = 250kN/m^2

Borehole 1	
Ground - 0.5m	Top soil and fill
0.5m – 3.0m	Sand and gravel N = 15
Below 3.0m	Very stiff clay C = 250kN/m^2

Ground conditions can be assumed to vary linearly between boreholes.
Ground water was encountered at 2.5m below ground level in Borehole 2.

Omit from consideration

13. Detail design of stair and lift shaft core.

SECTION 1 (30 marks)

a. Prepare a design appraisal with appropriate sketches indicating a viable structural solution for the proposed scheme. Indicate clearly the functional framing, load transfer and stability aspects of the scheme. Justify the reasons for the solution. (20 marks)

b. On completion of the design the client asks if it is feasible to add two addition floors of residential accommodation above the offices. Explain the implications this will have on the design. (10 marks)

SECTION 2 (70 marks)

For the solution recommended in Section 1(a):

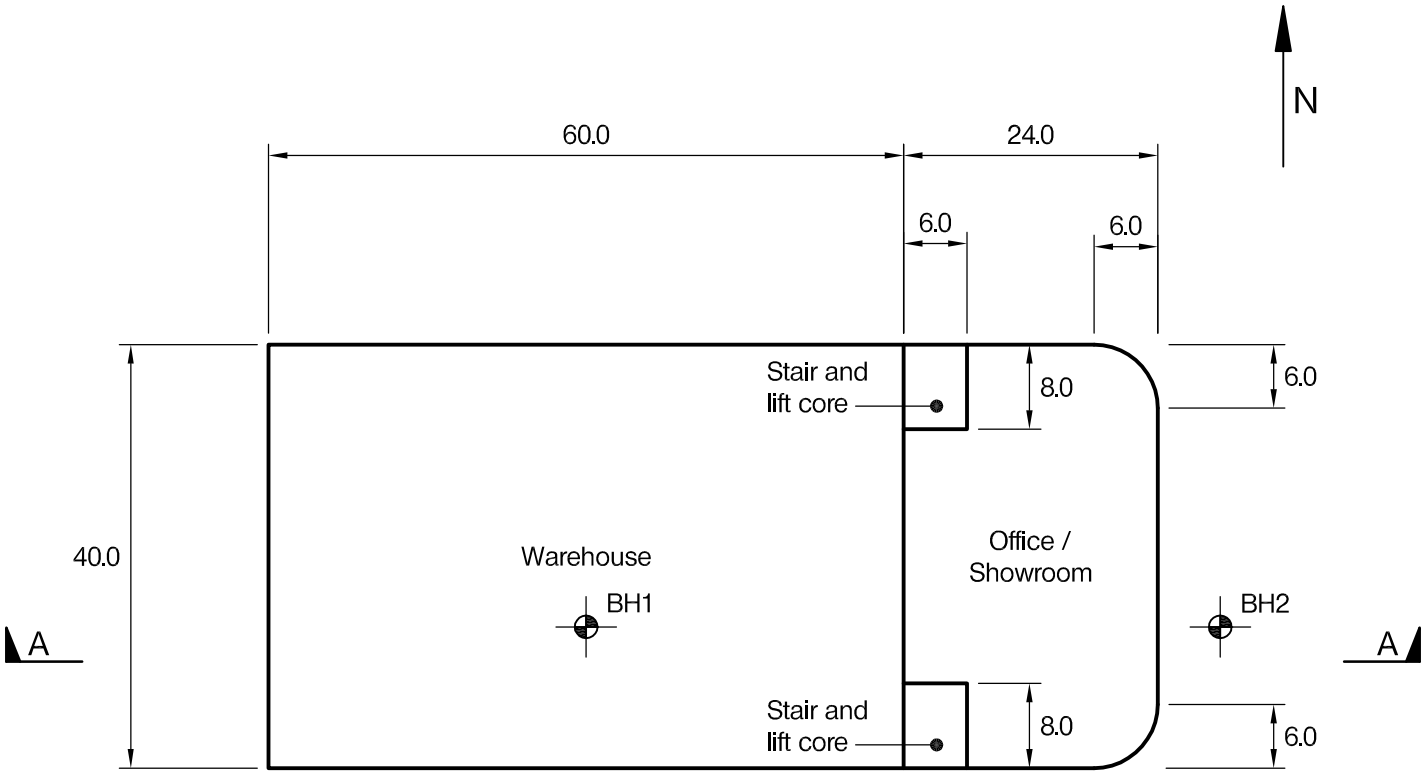
c. Prepare sufficient design calculations to establish the form and size of the principal structural elements including the foundations. (30 marks)

d. Prepare general arrangement 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:

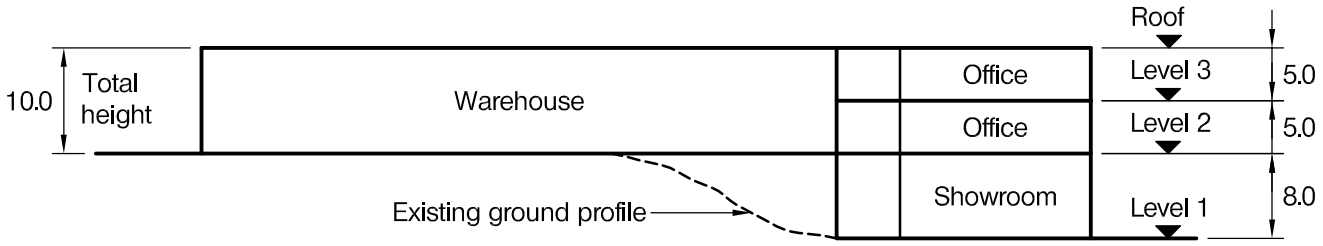
   (i) Perimeter column to the showroom at Level 1.

   (ii) Floor / retaining wall junction between the warehouse and the office at Level 2. (30 marks)

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



PLAN



SECTION A - A

NOTE: All dimensions are in metres

FIGURE Q1

Introduction

This question relates to a single-storey warehouse with attached offices and showroom over three stories, constructed on two distinct levels, on a site located on the outskirts of a large city. The warehouse is to be constructed to provide a clear open space. The office and showrooms have structural limitations as might be expected in a building/question of this type. The overall construction is 84m x 40m representing a relatively straightforward but fairly large building.

The brief

Overall structure

- 84m x 40m building consisting of a single-storey warehouse and three-storey office/showroom area.
- All external columns to be a minimum of 6m c/c.
- The roof is to be insulated composite steel cladding.
- Two stair and lift cores are symmetrically positioned in two corners of the office/showroom area.

Warehouse

- No internal columns are permitted in the warehouse necessitating a fairly large span roof.
- Two delivery doors, 6m high and 10m wide are required in the East elevation of the warehouse (see commentary below).
- External cladding to the warehouse is to be insulated composite steel cladding (same as roof) with a single skin of 140mm concrete blockwork to a height of 3m above internal ground level.

Offices and showroom

- Only three columns in a single row are permitted within the office and showroom area.
- The external cladding to the offices is to be glazed curtain walling with "no obstructions permitted behind the glazing" (see commentary below).

Site and ground conditions

- The site is located on the outskirts of a large city with a normal wind speed.
- The site has a significant change of level between the location of the warehouse and the showroom.
- The ground conditions consist of a level of topsoil and fill overlying weak sand and gravel all over very stiff clay.
- Ground conditions vary linearly between boreholes.
- Groundwater was encountered in the granular material in one of the boreholes.

Design appraisal

Height restrictions

The overall height of the warehouse and the office/showroom block are shown on the diagram but no clear internal heights are given for either area. The warehouse has a large span which will necessitate a significant roof structure. A portal frame would generally have sloping rafters whereas a trussed roof would be fairly deep but have parallel chords, both of which would therefore use a significant amount of the overall height. The ultimate limiting factor is the doors which are required to be 6m high, therefore this would set a minimum internal clear height of 6.0m. However either a portal frame or trussed roof should be readily accommodated within 4m.

Implications of the curtain walling

The brief states that the external cladding to the offices is to be glazed curtain walling, "with no obstructions permitted behind the glazing". The brief says “offices” (not office/showroom area), so one interpretation is that the curtain walling starts at office level, the other that it is full height in the office/showroom area. It seems most likely that the whole of the office/showroom block is clad with curtain walling, which is the assumption I am making. It is also important how the requirement for "no obstructions permitted behind the glazing" is interpreted. One assumes this means no visual intrusion but of course columns and floors would be visible. The most likely meaning is that no bracing is to be visible behind glazing but this is open to interpretation. This issue should be discussed and the assumption you make should be clearly stated, as this will have a significant impact on the stability system proposed for the office/showroom area.

Warehouse

The warehouse represents a relatively straightforward open space with no internal columns permitted which will necessitate a roof spanning 40m. This would suggest either a portal frame or a lattice trussed roof. As this is a relatively large span for a portal frame and as there are no restrictions on bracing in the warehouse elevations, steel trusses in the roof supported on steel columns would probably be the best option. The implications of the two doors need to be considered but they can be easily accommodated.

It should be immediately apparent that the doors are relatively large and with two located in the same elevation they will form a significant proportion of that elevation; however it is curious that they are specified in the East elevation which is the junction between the offices and the warehouse. This presents a dilemma as the suspicion must be that this is a misprint and in fact the delivery doors are in the West elevation. They would serve no practical or logical purpose in the East elevation (large doors connecting the warehouse and offices). In a situation such as this any sensible interpretation would be acceptable, the one thing I wouldn't recommend is to just ignore something that is a specific client requirement but that doesn't quite seem correct. You cannot be marked down for any sensible interpretation of the brief if it’s not clear. However, what you must do is recognise that doors of this size will have an impact on the structural layout in terms of: location, supporting the roof above the doors, supporting the doors themselves and the implications on wind loading (dominant opening - assuming they are positioned in the West (external) elevation!).

Offices and showroom

The offices and showroom are constructed over three levels with a plan area of 24m x 40m.
They have the same limitation on external columns spacing as the warehouse and the same roof construction.

Three internal columns are permitted in a single row. This would suggest three columns equally spaced running North-South providing a maximum beam span of 12m.

The North-East and South-East corners are curved and the external cladding around the whole office/showroom area is to be glazed curtain walling with "no obstructions permitted behind the glazing". This is assumed to mean no visible bracing (see above).

Site and ground conditions

The site is located on the outskirts of a large city with a basic wind speed of 40 m/s. This provides a standard wind loading but the implications of the large doors must be taken into account.

The site has a significant change of level halfway across, falling by 8m. There are two boreholes with the same soil identified in both (see figure 4). The brief guides us to assume linear variation between the boreholes. Groundwater was encountered in the sand and gravel layer in borehole two. The sand and gravel is not particularly strong especially as groundwater has been encountered in one of the boreholes

but there is good bearing capacity in the clay. Pad foundations are a possiblity but are complicated by the water and the sloping strata. This leads to my preference for a piled solution utilising the clay.

There is a significant amount of topsoil and fill which would have no usable bearing capacity even for the ground floor slab and its depth makes it impractical to remove and replace, suggesting that a suspended ground floor slab supported on piles and ground beams is required throughout (particularly in the warehouse area where the loads are higher and the fill is thicker). There will be a void in the space between the warehouse floor at the Eastern end where the ground dips away. It is unclear how this gap is dealt with. If the void is filled it will necessitate a retaining wall but the void could be left with a concrete wall filling the gap, allowing visual continuity of the side elevation, with the external cladding finishing at the warehouse floor level. Careful consideration will also be needed regarding the warehouse columns/piles in the area where the existing ground falls away. Similar consideration will be needed for the Western showroom wall.

Design solution

Warehouse

Because the warehouse requires a relatively large span and there are no restrictions on bracing in any of the perimeter walls (of the warehouse), my preference is for simply supported steel lattice roof trusses rather than a portal frame (see figure 3). Using a span depth ratio of say 15 this would suggest a depth of 2.5/3.0. This fits comfortably in the overall height and the specified height of the doors giving a maximum construction depth of 4m [10.0 (overall height) - 6.0 (height of the doors)].

Office/showroom

The office/showroom area is a relatively straightforward office block but the row three of columns permitted by the brief should be utilised to reduce the floor spans as much as possible. I propose a centrally located row of columns North/South as shown in figure 1 & 2, with a braced steel frame supporting composite or pre-stressed concrete floors. A concrete frame would be an alternative, but as steel would be preferable for the warehouse structure, it seems logical to use steel throughout.

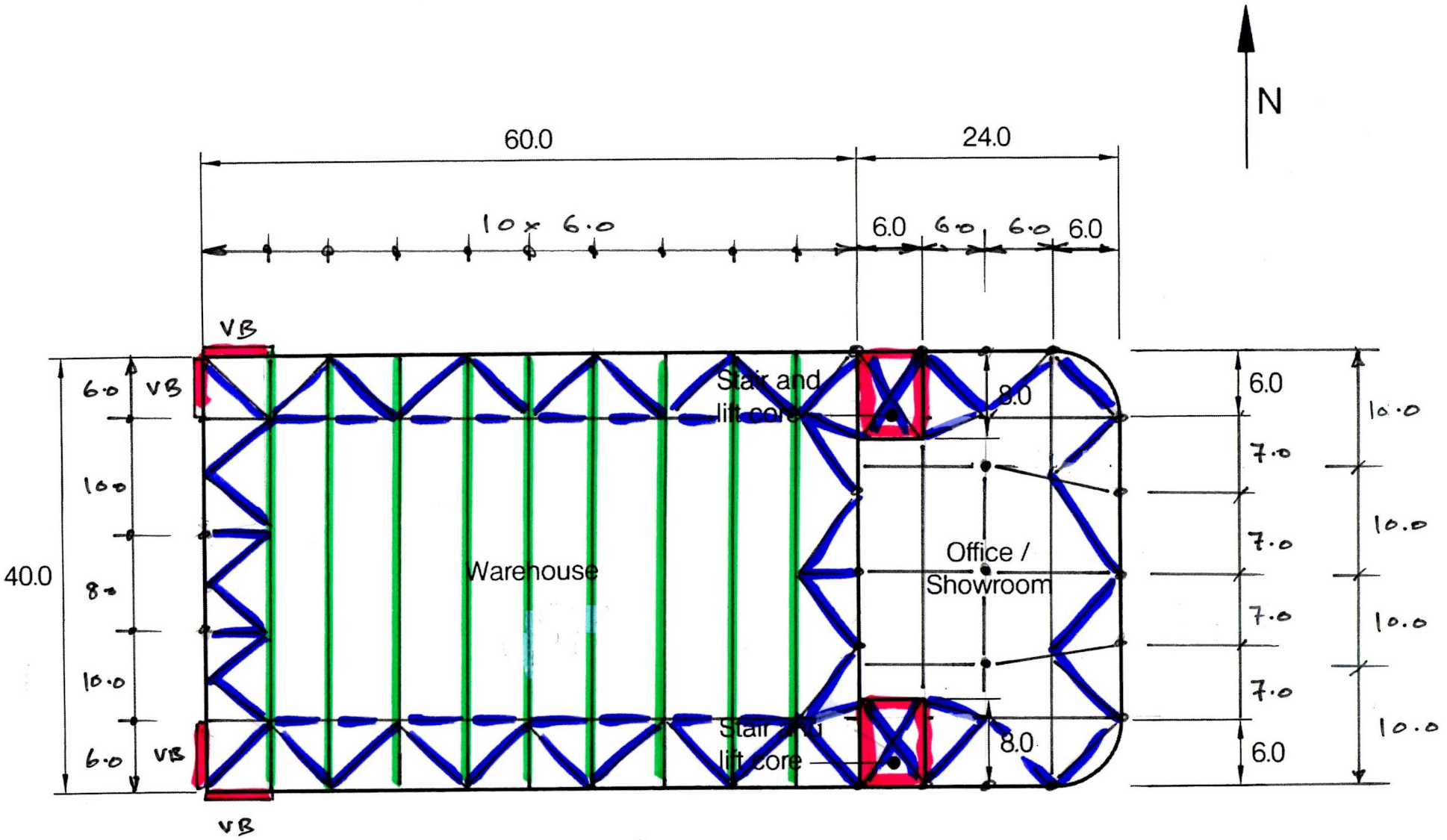
Stability

There are two stair/lift cores which can be used for stability but they would be insufficient on their own to brace the whole structure. Working on the assumption that the requirement for "no obstructions permitted behind the glazing" means no bracing, then we have a slightly more complex situation for stabilising the office block. Traditional vertical bracing can be provided in the Western corners of the warehouse which together with the two stair cores will provide lateral stability for the whole building. Roof bracing will transfer the lateral forces from the office/showroom area to the bracing and cores. The lateral forces from the office/showroom block will transfer to the vertical cores and vertical bracing via the roof bracing and diaphragm action of the concrete floors (see figure 1).

An alternative solution would be to provide traditional bracing in the warehouse and to construct the offices as moment resisting frames, but this would create a stiff warehouse and a flexible office block and is unnecessarily complicated compared with the scheme suggested above.

Summary

This is a straightforward question but there are issues to think about: particularly in relation to the doors (location and size), the implications of the significant change in ground level in relation to the warehouse structure (floor, columns and foundations) and the stability system. The brief provides sufficient scope to enable candidates to demonstrate their ability to interpret issues and to propose an appropriate structure that works within the parameters set in the question.



VB - VERTICAL BRACING

STAIR & LIFT CORE

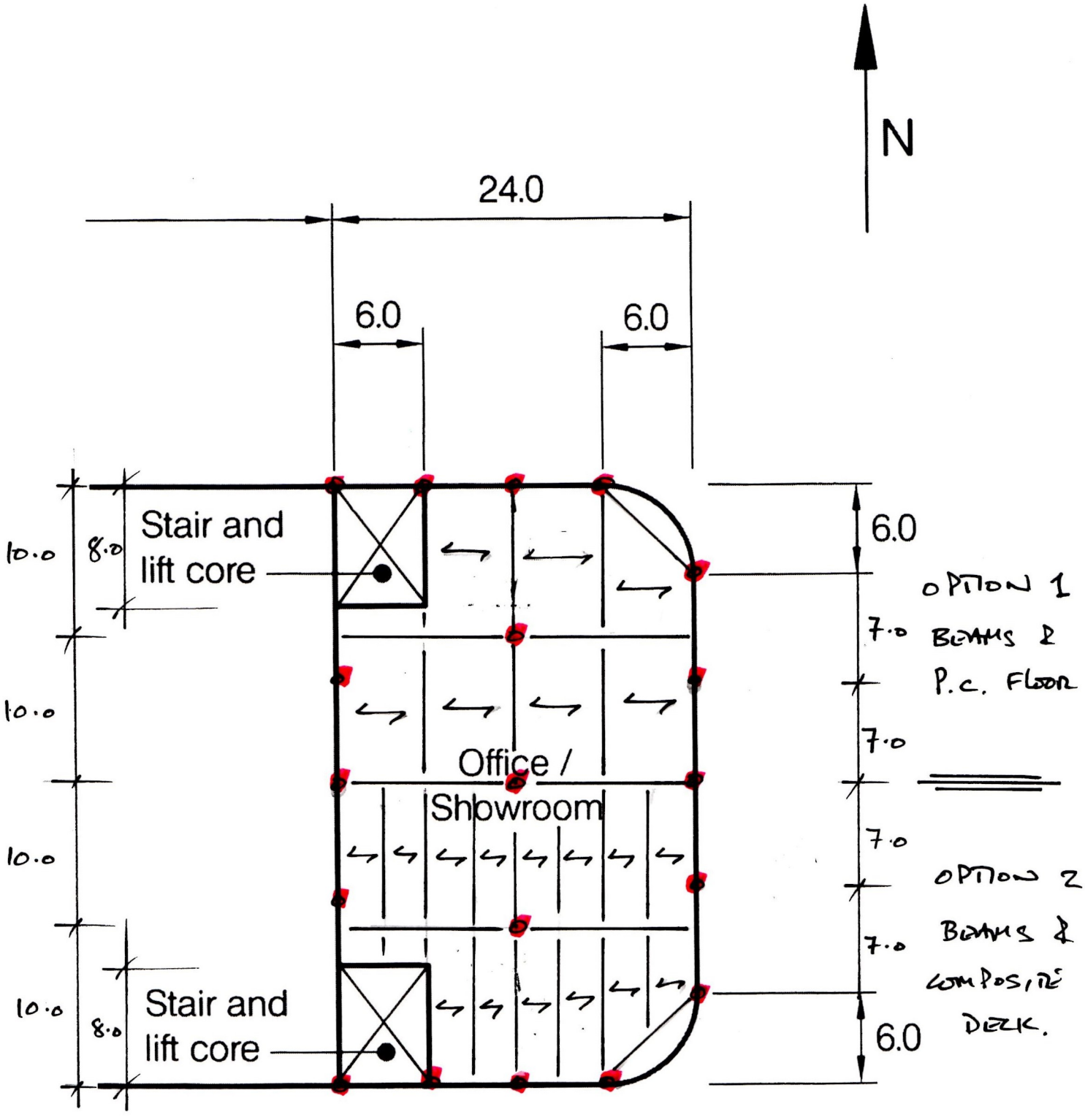
40m SPAN ROOF TRUSS

HORIZONTAL BRACING.

OFFICE ROOF STEEL

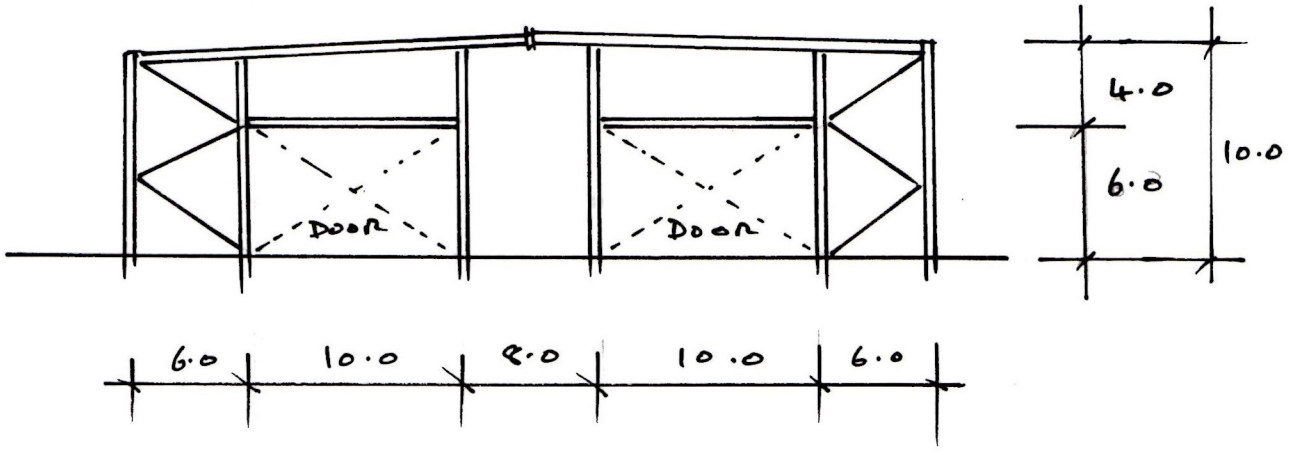
PLAN - ROOF STEELWORK & BRACING

FIGURE 1.

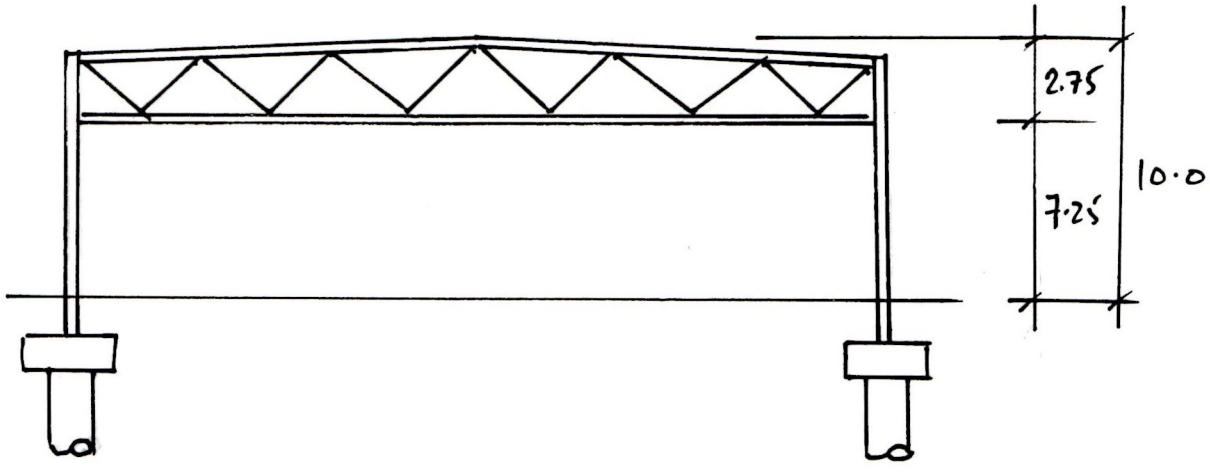


PLAN. - OFFICE FLOOR STEELWORK.

FIGURE 2.



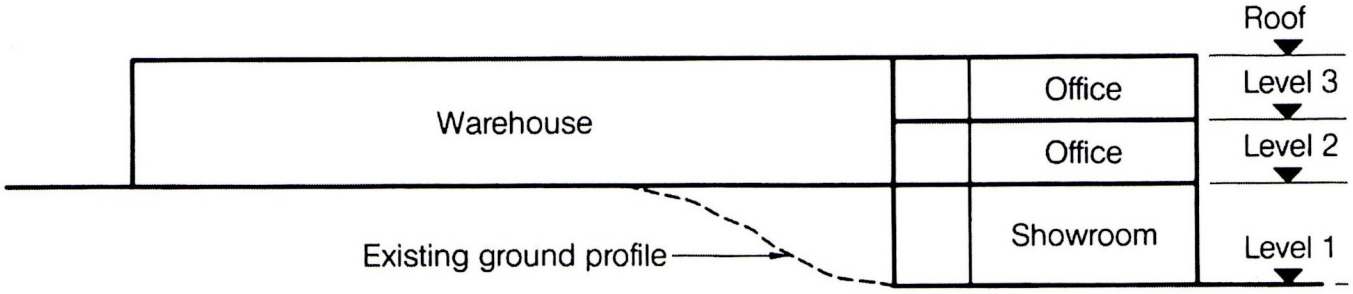
GABLE ELEVATION.



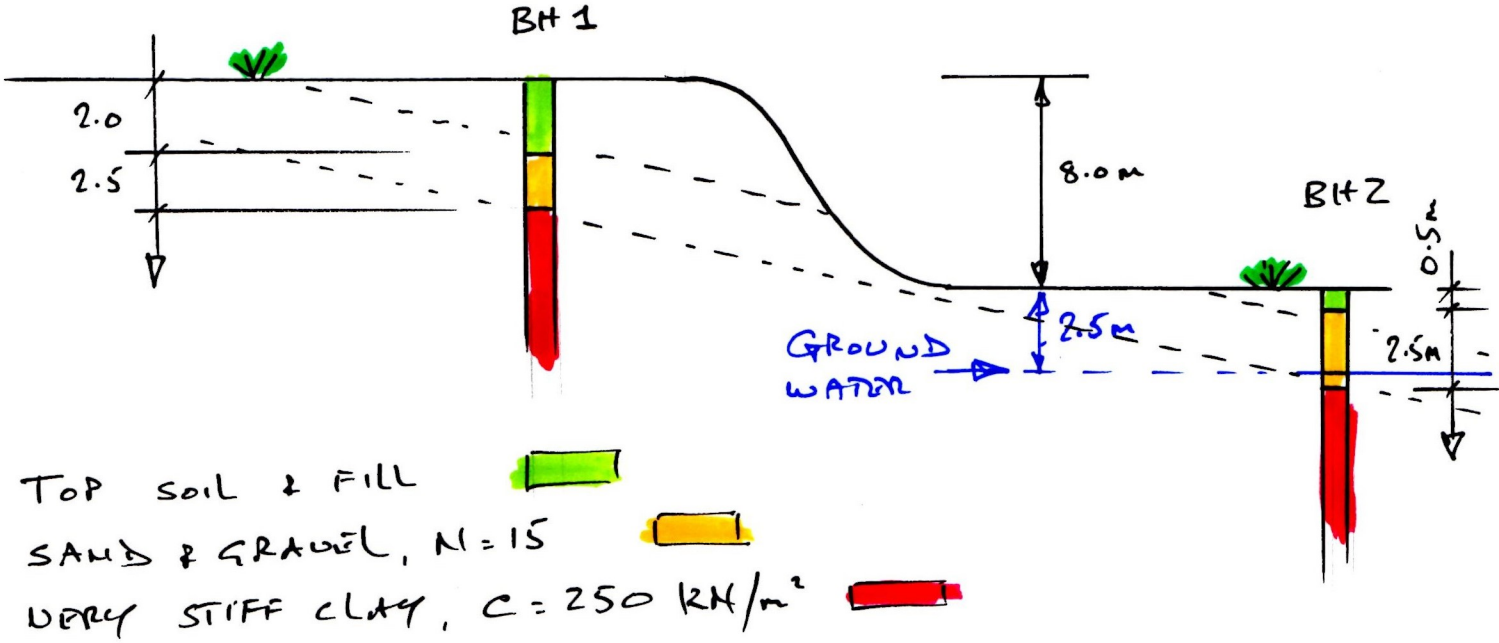
SECTION.

WAREHOUSE SECTIONS & ELEVATIONS

FIGURE 3.



SECTION A - A



SOIL PROFILE

FIGURE 4.

N.B. exaggerated vertical scale.