

# *The Institution of Structural Engineers*

Possible solution to past AM examination question

**Question 1 - July 2016**

**Showroom and office development**

by Dr Peter Gardner

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 the 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 1. Showroom and office development

## Client's requirements

1. A new four storey triangular shaped ground floor showroom and office development above located on a corner plot adjacent to existing buildings. See Figure Q1.
2. No foundations are to be installed within 2.0m of the existing buildings.
3. No columns are permitted within the 2.0m building setback between Level 1 and Level 2.
4. The centres of the perimeter columns are to be at a minimum spacing of 6.0m and the internal columns are to be at a minimum spacing of 4.5m.
5. The showroom and offices are to have an internal floor to ceiling height of 3.0m. The overall floor depths at Level 2 and above are to include a 150mm raised floor and 450mm deep service zone between the ceiling and the underside of the floor construction.
6. The external cladding is to be glass curtain walling and the roof is to be flat.

## Imposed loading

7. Roof            1.50kN/m<sup>2</sup>  
    Floors        4.00kN/m<sup>2</sup>  
    Imposed loadings include allowances for finishes, services and partitions.

## Site conditions

8. The site is level and located in the centre of a town.
9. Basic wind speed is 42m/s based on a 3 second gust; the equivalent mean hourly wind speed is 21m/s.
10. Ground conditions:
 

Ground level – 1.5m	Made ground
1.5m – 3.5m	Loose sand, N = 5
3.5m – 8.0m	Sand, N = 10
Below 8.0m	Sandstone, allowable bearing capacity 1500kN/m <sup>2</sup>

 Ground water was encountered at 3.0m below ground level.

## Omit from consideration

11. Detail design of the stair and lift shafts, although their contribution (if any) to the overall stability and load transfer must be stated in Section 1(a).

## SECTION 1

**(30 marks)**

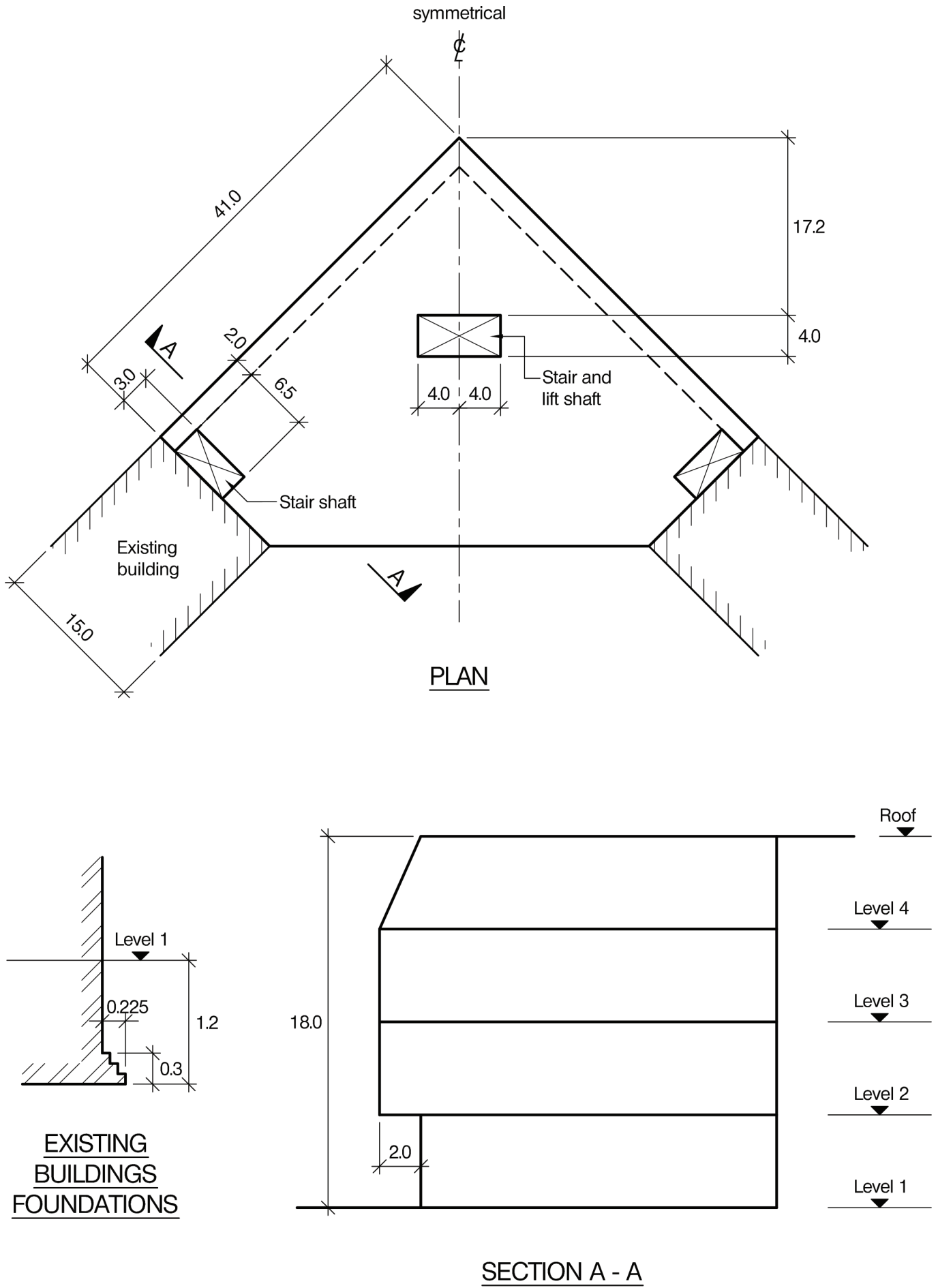
- a. Prepare a design appraisal with appropriate sketches indicating a viable structural solution for the proposed scheme. Indicate clearly the functional framing, load transfer and stability aspects of the scheme. Justify the reasons for the solution. (20 marks)
- b. The client proposes after completion of the design and before construction that only one row of columns is permitted in the showroom at Level 1. Explain the effect this will have on the design and outline any resulting changes to your original proposal. (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) The perimeter columns and floor construction at Level 2 at the setback.
  - (ii) A perimeter column at Level 1. (30 marks)
- e. Prepare a detailed method statement for the safe construction of the building. (10 marks)



NOTE: All dimensions are in metres

FIGURE Q1

## **Introduction**

This is an interesting mainstream question that provides an ideal vehicle for competent candidates to demonstrate their structural engineering knowledge. The building has an unusual geometry with some specific constraints, none of which should cause any particular difficulties.

The project consists of an essentially triangular building sitting between two existing buildings as shown on figure Q1 of the question paper. The building itself has four stories with the upper level having a sloping facade on two elevations. There are constraints on foundation locations in the area of the existing buildings and the ground floor is set back 2m on two elevations.

## **The brief**

- Provide a new four-storey triangular shaped building consisting of a ground floor showroom and offices above.
- Two of the ground floor (level 1) elevations are set back two metres (see figure Q1 of the question paper).
- The building is located on a corner plot and abuts two existing buildings, the consequences of which need to be taken into account in the proposals for the new structure.
- No foundations for the new buildings are permitted within 2m of the existing buildings.
- The perimeter columns are to have a minimum spacing of 6m and the internal columns are to have a minimum spacing of 4.5m
- Each of the four levels is to have an internal floor-to-ceiling height of 3m. Each of the upper floors (level 2, 3 and 4) is to have a 150mm raised floor and a 450mm deep service zone between the ceiling and the underside of the floor above. This means that a raised floor is not required on the ground floor (level 1) (as it's a showroom) and that each level (2, 3, 4 and roof) has a 450mm deep service zone between the ceiling and the underside of the structure. One could get into a debate about whether the ground floor needs a raised floor and whether the words strictly require a service zone between the ceiling under the roof construction but as there is no overall height constraint any sensible interpretation would be acceptable.
- Two elevations of the upper storey have a sloping facade.
- The external cladding is to be glass curtain walling. The roof is flat.
- The site is located in the centre of a town. The soil consists of 1.5m of made ground, a further 6.5m of sand with firm sandstone 8m below ground level. Groundwater is encountered 3m below ground level.
- There are three rectangular shafts shown on the plan (see figure Q1): two stair shafts and one lift/stair shaft. The question makes it clear these can be used to provide overall stability if required.

## **Design appraisal**

It seems to me that each constraint/requirement is clear and relatively easy to deal with in its own right but that they all interrelate and thus cannot be dealt with in isolation. For example, the requirement to offset the foundations to avoid surcharging the existing foundations will have an impact on column locations and foundation selection. Equally the stability system will be significantly impacted by the column locations and the foundation arrangement. It's therefore important that the proposal for each element is fully explained and an understanding of how each element interrelates with the rest of the structure is clearly demonstrated.

As with most questions the starting point is the layout of the columns. As summarised above there are minimum spacings for both the perimeter and internal columns, in addition to the setback of the ground floor columns on two elevations. Additionally, the foundations need to be setback on the elevations where the new building abuts the existing buildings but this doesn't directly affect column positions as the foundations (ground beams) can cantilever to support a column abutting the existing buildings. The minimum spacing of 6m for the perimeter columns would seem a sensible place to start bearing in mind that this minimum applies to the setback columns as well as the columns on the upper stories. If the ground floor columns are setback 2m this would give a convenient column spacing of 6.5m in both directions on the ground floor forming a neat symmetrical grid, with each of the columns run through to the upper levels apart from the columns in the area of the setback. In this area, to avoid any compromise of the minimum internal column spacing it would be safest to move the columns area out by 2m necessitating a cantilever at level 2 and 8.5m floor spans in the perimeter bays. See figures 2 and 3.

The next issue to deal with is the storey heights and the requirements for raised floors and service zones in the ceiling. As mentioned above each of the three intermediate levels (floors at level 2, 3, 4) need to incorporate a 600mm allowance for these two elements. The ground floor doesn't need a raised floor. As there is no overall height constraint nor does the building appear to need to match the level of the existing buildings, the dimensions are not critical. An allowance for a structural depth of 900mm (based on span/depth ratios) should be ample. See figure3.

## **Proposed solution**

Structural frame and floors. The frame could be steel or reinforced concrete (but see section below on stability). The floors could be any form of traditional office flooring including composite slabs, a two-way or one-way spanning slab or precast floors on beams.

Foundations. Before the foundations can be proposed an assessment needs to be made of the ground conditions. The ground consists of weak fill over relatively weak sand but with sandstone at 8m. It would therefore seem sensible to propose bored piles bearing directly on the sandstone. The edge of the pile would need to be a minimum of 2m from the existing buildings with ground beams cantilevered out to pick up the perimeter columns. See figures 1 and 3.

Stability. The building has two stair shafts and one lift shaft which can be used to provide stability. The question makes it clear that these can be used to "contribute" to stability but any

use must be fully described in section 1a (although the design can be omitted from 2c). Utilizing the shafts would provide the simplest and most effective stability system, although alternatives could involve bracing (but consider the glazed facades) or moment resisting frames. As the shafts are symmetrically positioned, as long as all three are used they would provide a satisfactory stability system, although their orientation would provide an additional complication. The two stair shafts are in the area where there can be no perimeter piles and thus there would be a complicated transfer of loads from the shafts into the foundations system, although the whole ground floor plate would act as a single diaphragm transmitting horizontal loads into the piles.

If a braced system was proposed, the bracing would potentially be seen through the glazed curtain walling and its visual impact would need to be considered.

The third option would be moment resisting frames. Structurally this would be perfectly possible, with significant stiffness, and thus lateral resistance being developed through the rigid frames. However, in this situation, where there are better alternatives, this would be the least preferred option.

### **Section 1b (change of client requirement)**

The scenario presented in section 1b involves the proposal to remove a significant proportion of the ground floor columns (after the design has been completed but before construction). It is proposed that a single row of columns will still be permitted and that there would be no change to the column locations in the upper levels (in the office area). Although it is not specified where the row of columns is positioned, the structural consequences of the removal of a significant proportion of the columns would be similar wherever the remaining columns were located.

The principal significance is that much larger beams would be required for the level 2 floor which would in turn increase the construction depth at level 2. This would also significantly increase the load on the remaining ground floor columns and thus the foundations. It would be sensible to keep the existing pile locations, using lower capacity piles to support the ground floor slab in areas where there is no column above (ie to maintain the existing spans) and obviously larger piles (or probably groups) above the now more heavily loaded columns. All these issues should be discussed as part of your answer.

### **Summary**

Although at first glance this looks a relatively straightforward question, as mentioned in the introduction, all the elements interrelate and it's particularly important in this question to make sure that the proposed elements are consistent with the constraints and the overall design philosophy, thus providing a coherent structural scheme. However, the question should provide an ideal vehicle to demonstrate your structural knowledge and experience, having sufficient complexity to enable you to discuss the pros and cons of the various options but nothing that becomes problematic or overcomplicates the solution.



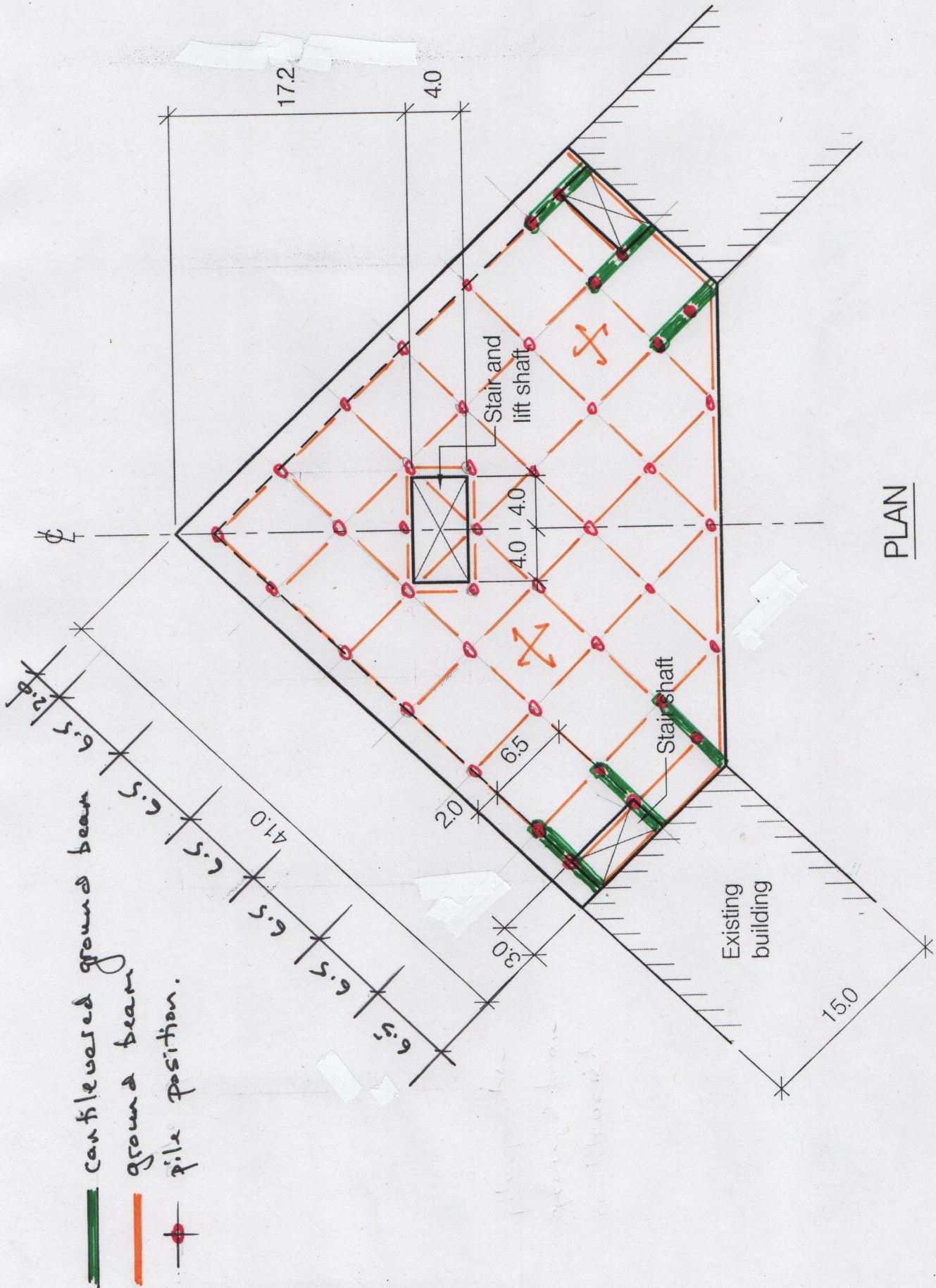
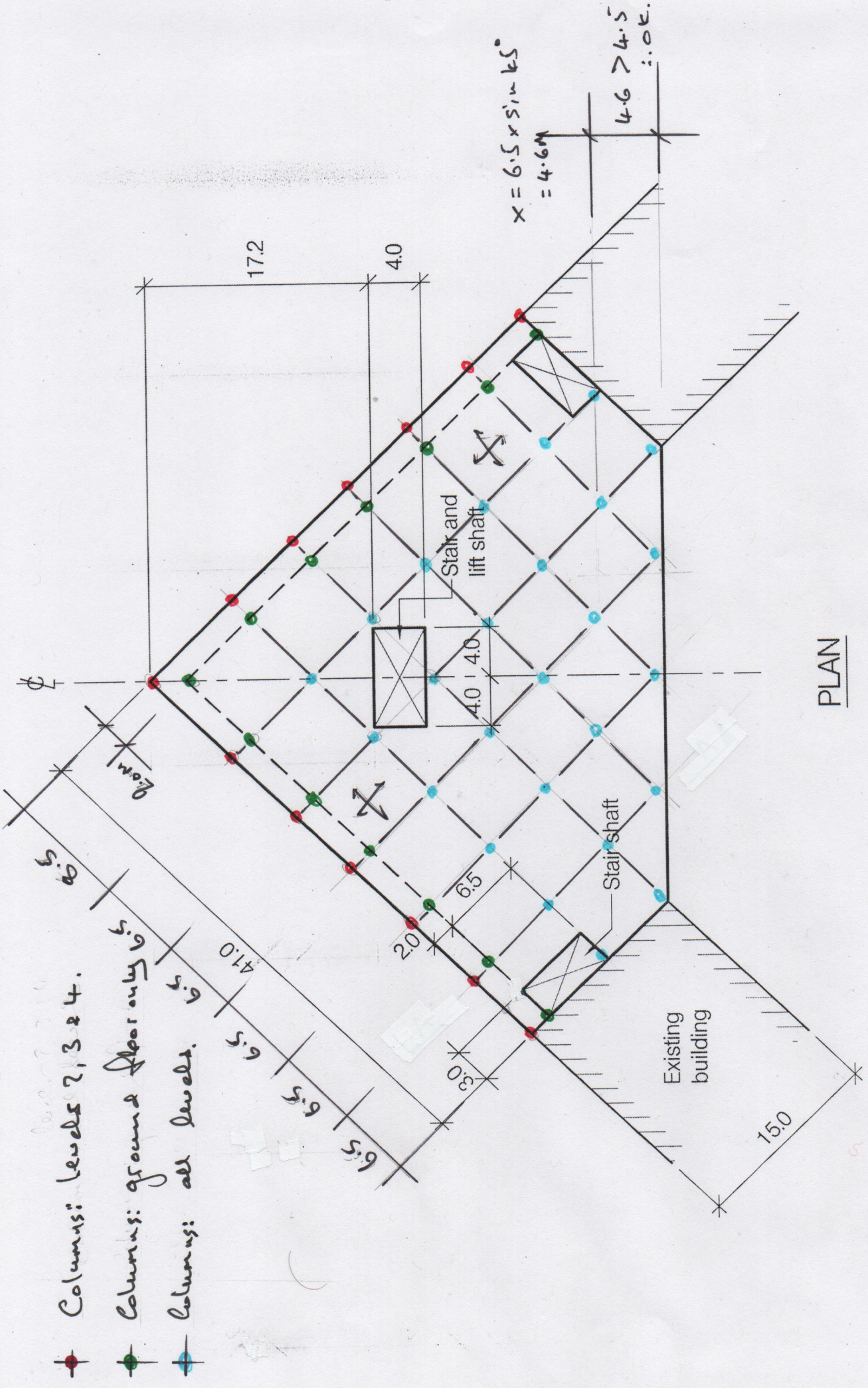


Figure 1. Ground Floor Plan: Slabs, piles and ground beams





PLAN

Figure 2. Column Positions.



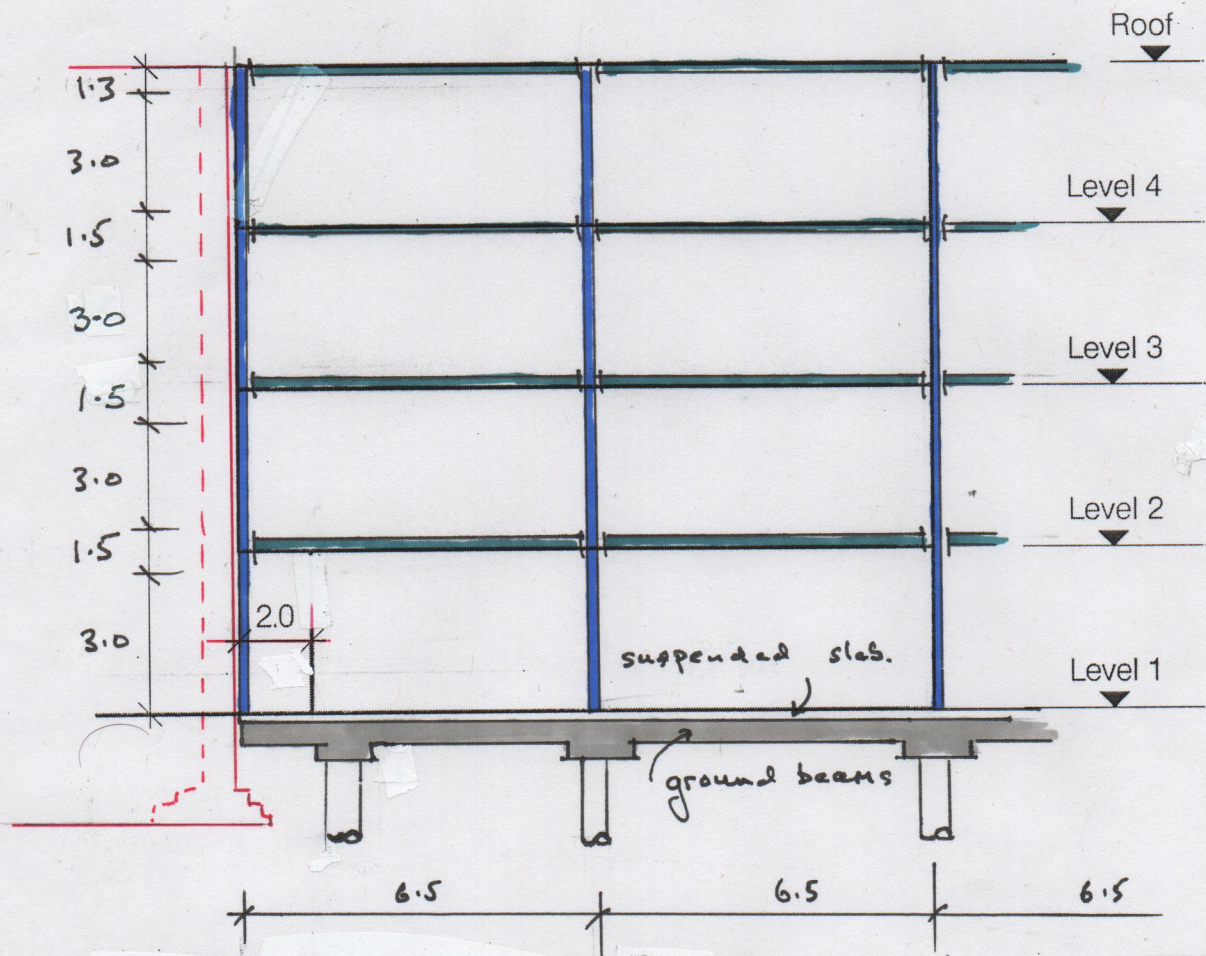
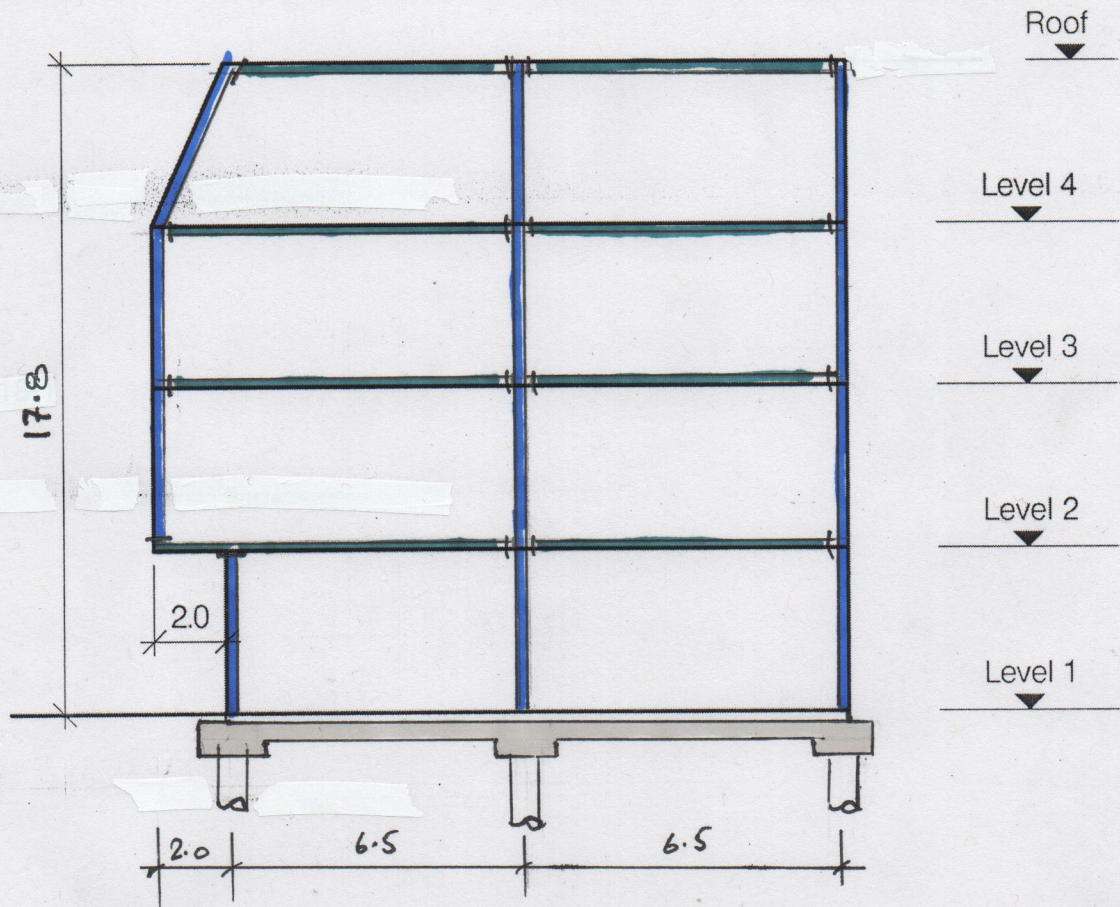


Figure 3. SECTIONS.