The Institution of Structural Engineers

Possible solution to past AM examination question

Question 1 - April 2013

Multi-storey Car Park

by Dr Peter Gardner

Question 1. Multi-storey car park

Client's requirements

1. A new multi-storey car park situated in a town centre. See Figure Q1.
2. Parking is to be provided on 6 levels and there are to be at least 600 car parking spaces. Each car parking space is to be at least 2.4m x 4.8m in plan.
3. All external columns and any columns proposed within the car parking areas are to be at a minimum spacing of 6.0m centre-to-centre.
4. The internal clear height from each floor to the underside of the horizontal floor support structure above is to be at least 2.3m. There is no overall height restriction to the building.
5. The external cladding to the building is to be of cavity wall construction comprising 102mm brickwork and 100mm blockwork constructed to 1.2m above and 0.6m below each floor level. The external columns are to be clad in 100mm blockwork. Internal proprietary crash barriers are to be provided around the perimeter of each floor.

Imposed loading

6. Each floor 2.50kN/m^2

Site conditions

7. The site is level and located in a town centre.
8. Basic wind speed is 40m/s based on a 3-second gust: the mean hourly wind speed is 20m/s.
9. Ground Conditions:

Ground - 2.0m	Made ground
2.0 -7.0m	Sand and gravel N=20
Below 7.0m	Firm to stiff clay C=250kN/m^2

Ground water was encountered at 4.0m below ground level.

Omit from consideration

10. Detail design of the stair and lift shafts, which are external to the building and do not contribute to its overall stability. Design of the crash barriers.

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 construction, that an additional floor could be added above Level 6. Explain the effect this will have on the design of the building. (10 marks)

SECTION 2 (70 marks)

For the solution recommended in Section 1(a):

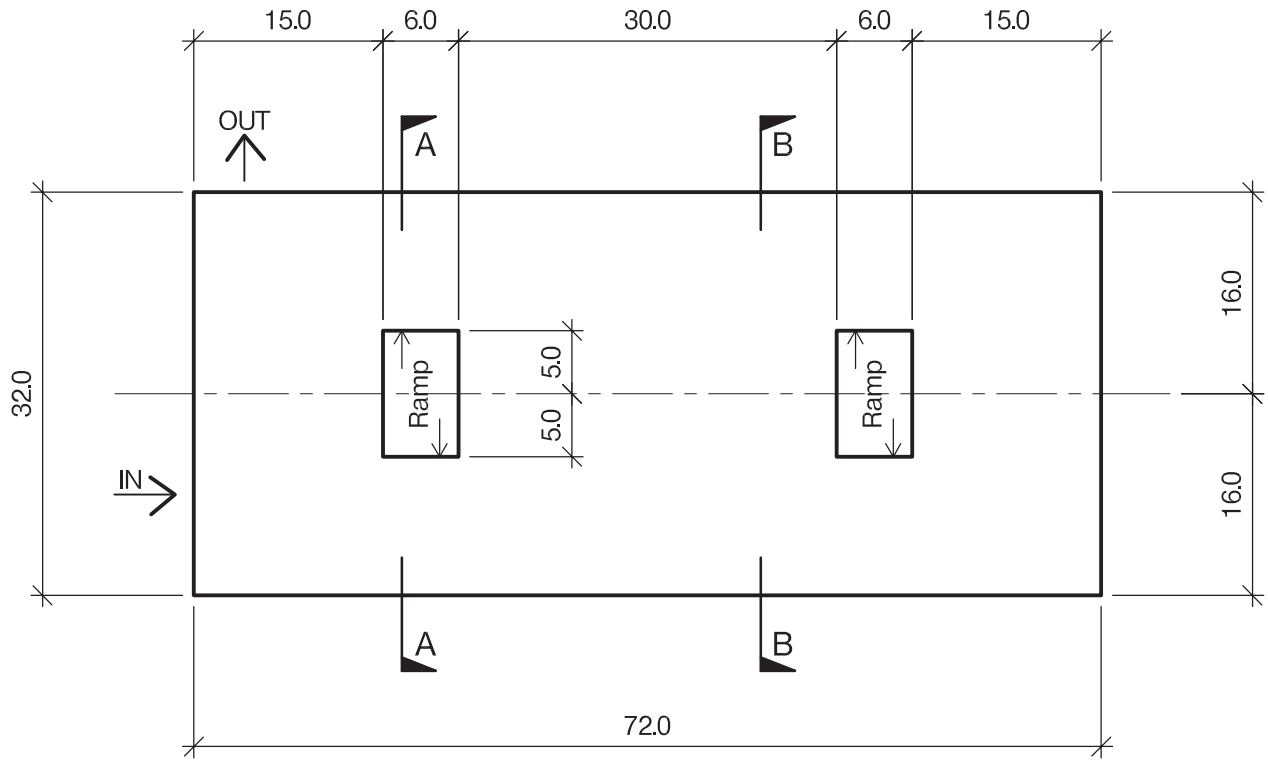
c. Prepare sufficient design calculations to establish the form and size of the principal structural elements including the foundations. (30 marks)

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:

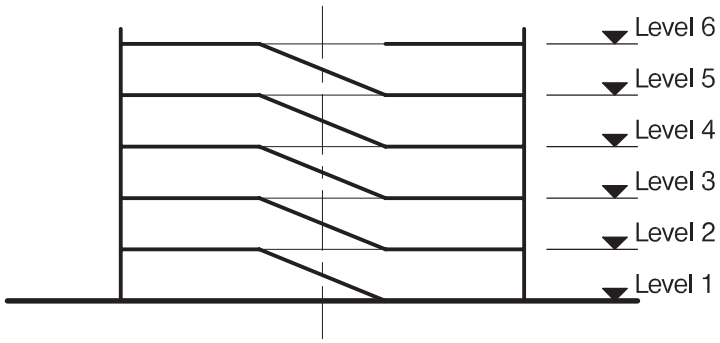
   (i) The top floor perimeter parapet cladding detail.

   (ii) A perimeter column at ground floor level. (30 marks)

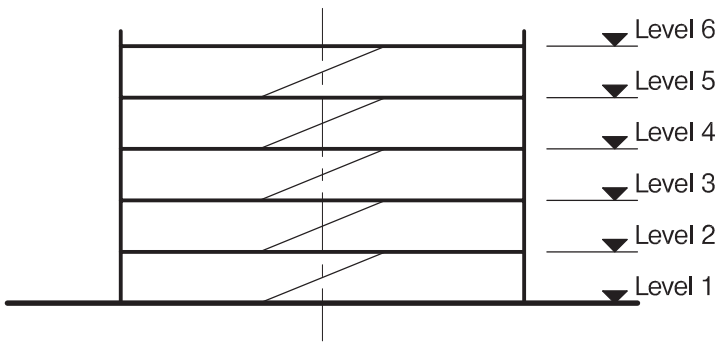
e. Prepare a detailed method statement for the safe construction of the building. (10 marks)



PLAN



SECTION A-A



SECTION B-B

NOTE: All dimensions are in metres

FIGURE Q1

Multi-storey car park

Introduction

This question relates to a six-storey car park situated in a town centre. It has a simple rectangular footprint with two internal ramps. This provides a relatively straightforward question which necessitates some dimensional analysis and layout and then the design of columns, floor plates, a stability system and the foundations.

The brief

- Parking is to be provided on all six levels and the brief stipulates that each car parking space is to be at least 2.4m x 4.8m in plan and there are to be a total of at least 600 spaces.
- All columns, whether external or internal are to have a minimum spacing of 6m centre to centre.
- The internal clear height (floor to underside of structure) is to be a least 2.3m but there is no overall height restriction on the building.
- The external cladding is to be cavity wall construction comprising standard single skin brickwork and 100mm of block work, constructed 1.2m above and 0.6m below each floor level.
- The external columns are clad in block work. No mention is made of the internal columns which therefore presumably can be left exposed.
- The imposed load for each floor is given, as is the wind speed.
- The ground consists of three layers: made ground, sand and gravel, and firm to stiff clay, with groundwater encountered 4m below ground level.

The layout (car parking bays and structural elements)

Although this is an engineering rather than architectural examination, often some geometrical analysis is required, and in this question it is necessary to set-out the parking bays and make some assessment of access between levels. It would be reasonable to assume that the requirement for 600 spaces can be achieved without too much difficulty, and a few minutes with a calculator and a couple of sketches suggests this is the case (see figure 1). The question states that each car parking space is to be at least 2.4 x 4.8 and does not say this needs to be a clear dimension between the columns. Nevertheless it seems sensible to keep internal columns to a minimum, so that they don't unduly limit the access space to the bays.

The plan shows two access ramps implying that there is an up and down ramp in each of the two locations. Therefore the layout provides a circular route for vehicles ascending or descending. To avoid vehicles having to travel all the way to level 6 in

order to exit the car park it seems sensible to provide a cut-through at each level (see figure 1). Although this may seem unnecessarily complicated for a structural engineering examination, a satisfactory solution drops out fairly quickly, and leads to a sensible column layout (bearing in mind the requirement for a minimum spacing of 6m). One must ensure your solution complies with the brief, but these issues can consume time if you dwell too long on them!

As with all column arrangements there is a balance between the building's functionality (reducing the number of columns) and increased structural depths, but in this case, as the columns can be accommodated on the edge of parking bays they would not have a detrimental effect on the overall performance of the car park, which has resulted in the column layout shown in figure 2.

The Structure

It would seem sensible to provide concrete floors, supported on concrete or steel beams with the vertical supports provided by concrete or steel columns. This gives candidates an opportunity to select the material with which they are most familiar. Although there is no overall height restriction and therefore the structural zone is not limited, it would be desirable to aim for an efficient structural arrangement but avoiding overly complex design options remembering that you have to design whatever you propose in section 1.

Stability

It is essential that stability is provided in both directions. The brief does not limit you to any specific type of stability systems, so moment resisting frames would be an option, but have no structural advantage in this case as there is no limitation in the brief that prevents a braced proposal. It therefore seems sensible to propose steel diagonal cross bracing at appropriate locations in all four elevations, or bracing East-West and shear walls North-South, with concrete slabs acting as diaphragms, transferring lateral loads to the bracing/sear walls (see figure 2).

If the building is constructed entirely of reinforced concrete, it would be possible to consider shear walls rather than bracing, but although they are not explicitly excluded by the brief, the description of the cladding suggests an open aspect between the cavity wall construction at each level. The North-South walls of the ramps could be used as shear walls, but an alternative arrangement would be needed to provide stability East-West.

Foundations

The soil profile provides a number of possibilities for the foundations, all of which should be assessed before one is recommended. Whatever foundation are proposed they must be below the made ground. The three levels that need to be considered are: the sand and gravel at 2m (i.e. the sand and gravel above the water table), at 4m where groundwater is encountered (which will reduce the bearing capacity), and at 7m in the clay. This would potentially result in pads at 2m, pads or piles at 4m, or piles into the clay at 7m.

The Design

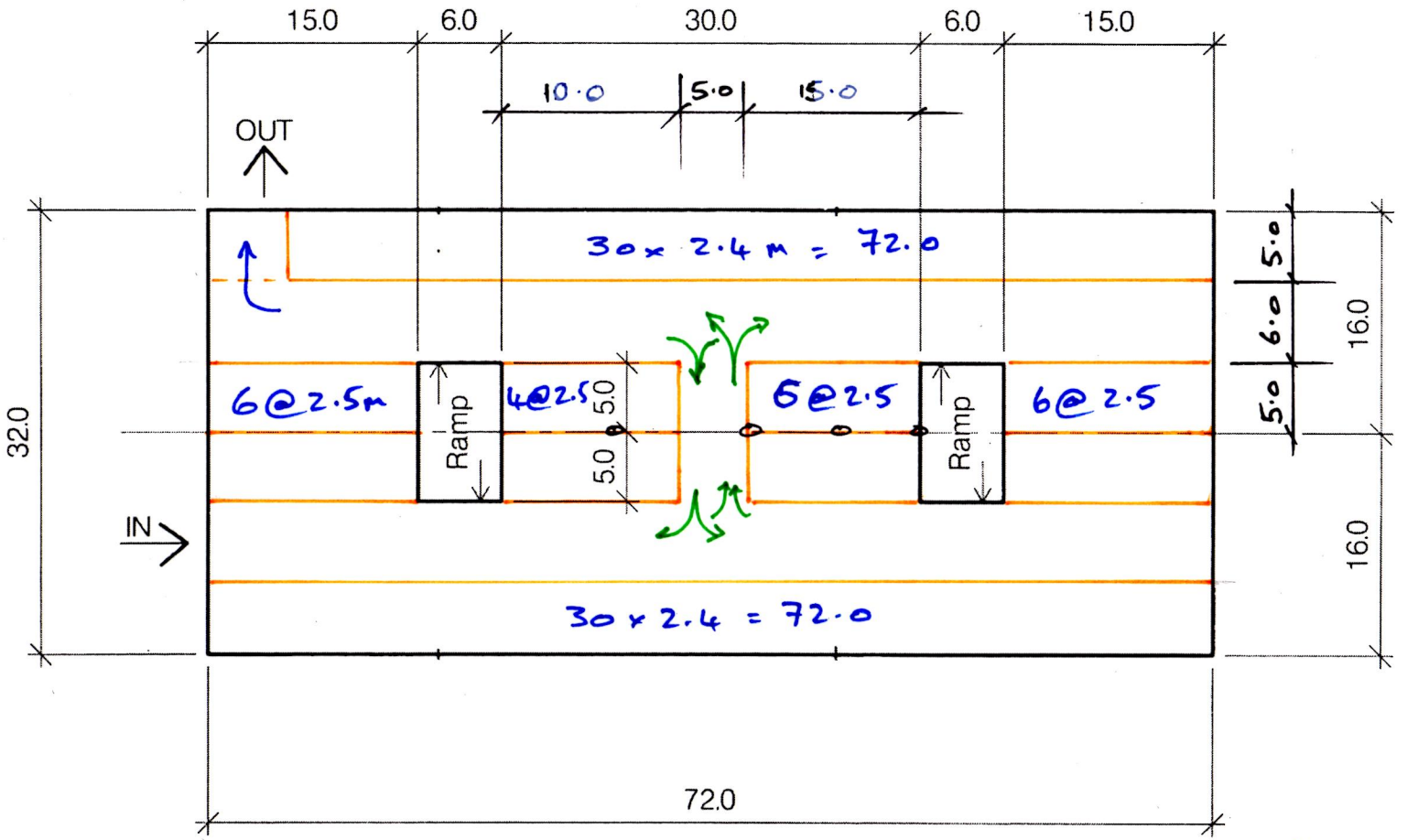
Section 2 of the question clearly asks for calculations to establish the form and size of the principal structural elements which would comprise the floor slab, floor beams, columns, stability system, the external cladding and the foundations.

Section 1(b) – Client change

Section 1(b) asks for an explanation of the implications of adding an additional level after completion of the construction. Adding an extra level would merely increase the vertical and lateral loads on the columns, foundations and stability system but because the construction is complete it is possible (even likely) that these elements would not have sufficient spare capacity. If, after a design check these elements were judged to be adequate, an additional level could be added without major design implications but if not, there would be significant design and construction implications (depending on what elements were undersized). Additional there would be planning implications and issues of disproportionate collapse to consider.

Summary

This is a relatively straightforward and fair question. It contains an element of geometrical layout, and the design of a number of structural elements, but it does not contain any undue difficulty or complexity, and thus should provide a good vehicle for candidates to demonstrate their experience in reinforced concrete and/or steel work design.

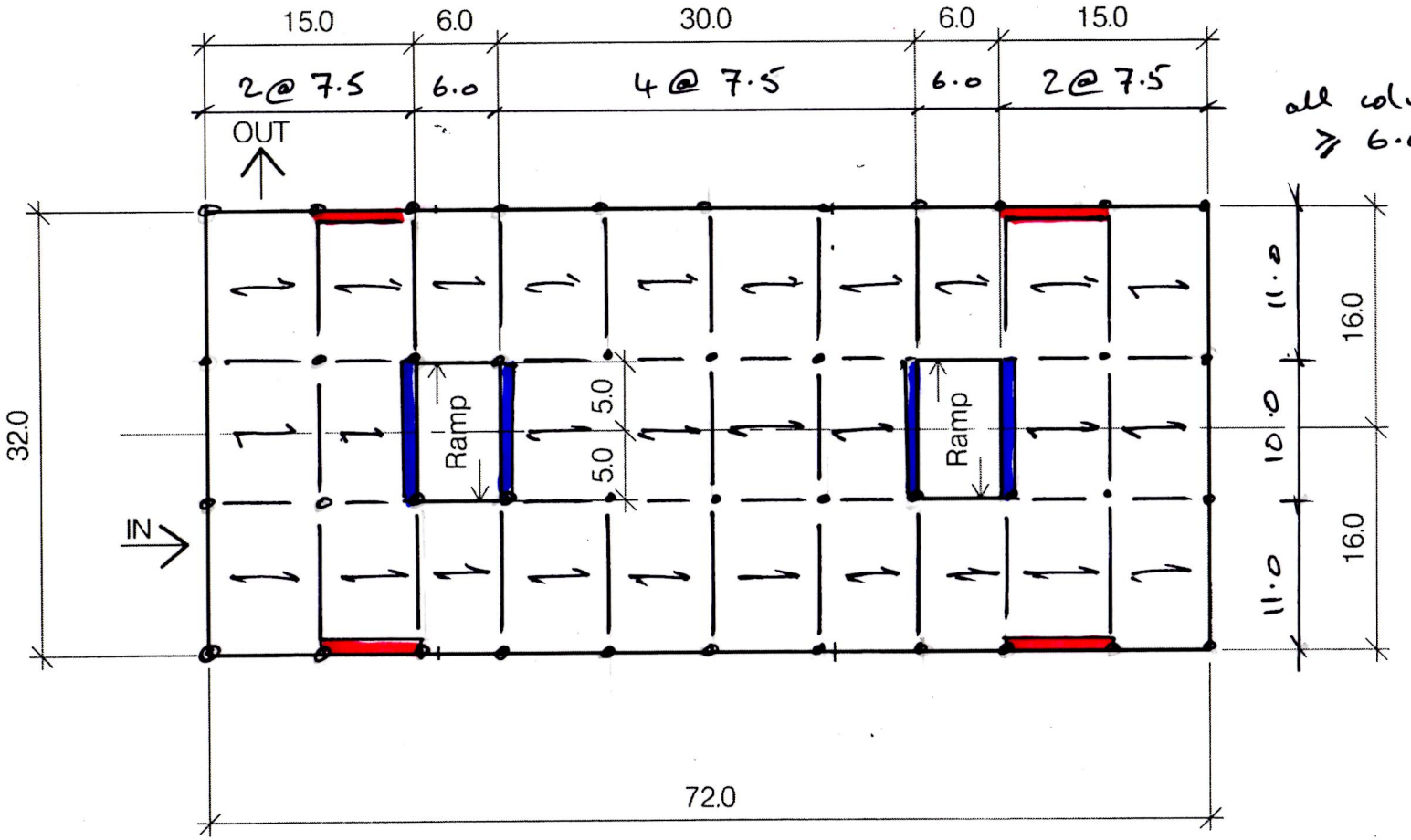


PARKING BAY LAYOUT

PLAN

Q1 2013 figure 1.

Number of bays: [30 + 22] x 2
= 104 per level
less 2 for ground floor exit
∴ TOTAL = 6 x 104 - 2 = 622 > 600 ∴ OK.



all column spacings ≥ 6.0m.

PLAN

STRUCTURAL LAYOUT

shear wall

vertical bracing

Q1 2013 figure 2.