Possible solution to past CM examination question

Question 1 April/September 2007

Library and Exhibition Centre

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. Library and Exhibition Centre

Client's requirements

1. A library and exhibition centre to be constructed in a city centre; see Figure Q1.
2. The north and south elevations are to be glazed. The east and west walls are to be clad in masonry.
3. A fully glazed structurally independent staircase and lift/elevator shaft is to be located outside each corner of the building, but they shall not be used to stabilise the building.
4. Columns are permitted in the external elevations. Internal columns are to be located at a minimum of 8.0m centres and at least 8.0m from an external wall. A maximum of three lines of internal columns are permitted along the east to west direction on the two display levels. Four internal columns only are permitted at atrium floor level.
5. The roof over the atrium is to be glazed.
6. The client has stipulated that diagonal bracing is not permitted in the interior of the building. Unobtrusive diagonal bracing is permitted in the external elevations if necessary.
7. Clear floor heights of 3.8 m are required for all gallery levels and 4.0 m for all display levels. The minimum clear height at the Atrium level under the Gallery Floors is 5.2 m.
8. No part of the structure shall encroach onto the vacant sites as defined on the site plan.

Imposed Loading

9.

Roof	1.0 kN/m^2
Gallery, Display Floors	5.0 kN/m^2
Atrium Floor Loading	5.0 kN/m^2

Loadings include an allowance for partitions, finishes, services and ceilings where appropriate.

Site Conditions

10. The site is level and located in a city centre. Roads are located to the north and south faces of the building. Vacant sites are present on the east and west.

    Basic wind speed is 40 m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20 m/s.

11. Ground conditions:

Borehole 1	
Ground level – 1.5m	made ground
1.5 m – 5.0 m	Firm to stiff fissured clay C = 100 kN/m^2
Below 5.0 m	Rock – allowable safe bearing pressure 1000 kN/m^2
Borehole 2	
Ground level – 1.0m	made ground
1.0 m – 4.0 m	Firm to stiff fissured clay C = 100 kN/m^2
4.0 m – 6.0 m	Stiff to very stiff clay C = 150 kN/m^2
Below 6.0 m	Rock – allowable safe bearing pressure 1000 kN/m^2

Omit from consideration

12. Detailed design of stairs and independent lift/elevator shafts.

continued overleaf

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 completion of the design, the client wishes to have the atrium floor level as a column free space. Write a letter to your client advising him of the implications of this change and how his requirements might be accommodated. (10 marks)

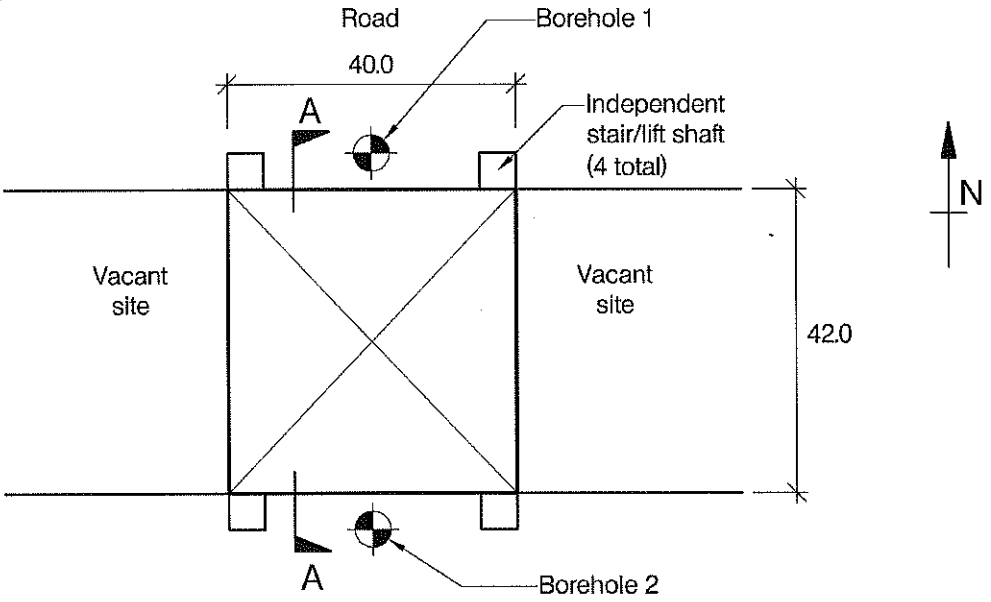
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

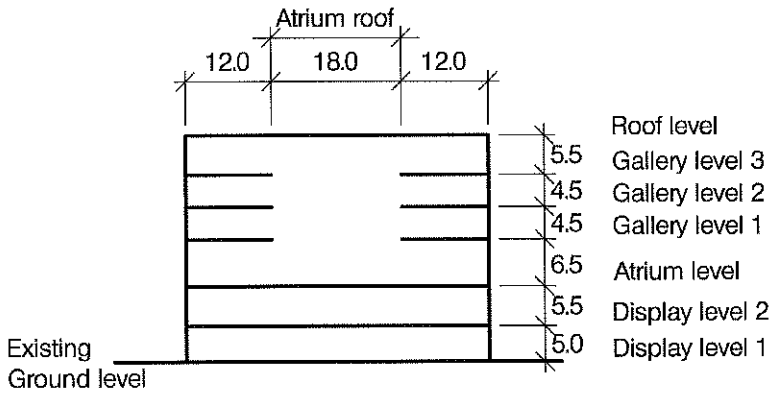
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare sufficient 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)

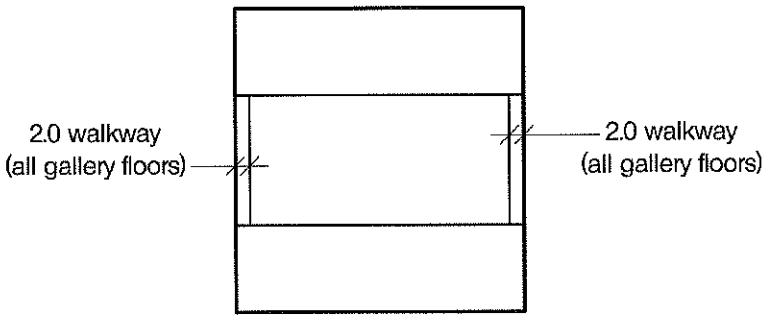
e. Prepare a detailed method statement for the safe construction of the structure and an outline construction programme. (10 marks)



SITE PLAN



SECTION A-A



FLOOR PLAN AT GALLERY LEVEL 1

NOTE: All dimensions are in metres

FIGURE Q1

Introduction.

The question relates to a multi-storey building, effectively with three zones: a display level, an atrium and a gallery level. There are constraints on the number and positioning of the columns, but this provides opportunities for variation. There are fixed storey heights and related structural zones. Stability needs to be addressed without utilising the stairwells (again an advantage as it provides the opportunity for variation). The cantilevered walkways must have an influence on the construction. There are issues that need addressing in the ground without any undue complexity and the proximity of the adjacent sites must be taken into account.

The issues:

- north and south elevations glazed – movement / deflection
- east and west elevations clad in masonry - stiff / heavy

- minimum spacing of internal columns 8m c/c
- maximum of three lines of columns on display levels (direction?)
- only four columns in the Atrium
- no restriction at gallery levels or on external columns

- stability independent of lift shafts (but access between lift shaft and building)
- no internal bracing
- bracing is permitted in external elevations (unobtrusive!)

- fixed floor heights - limits beam depths - s/d ratios

- structure not to encroach onto adjacent site (including foundations - automatic failure)

- 1/1.5m of made ground, thus suspended ground floor slab
- fissured firm/stiff clay!!
- rock 5/6m down - perfect foundation material (GBP=1000kN/m^2)

The structural zones, columns spacings and transfer structure.

The structural zones are clearly defined in the question and a diagram summarising this information is probably useful both in terms of clarifying the brief and clearly indicating to the examiner said this constraint has been understood. It would be very risky to breach this constraint as this would constitute infringement of the brief, but also this surely gives clues to the expectations of the chief examiner, in that there is a greater structural depth allowed in areas where deeper beams may be required to deal with the consequences of reduced numbers of columns.

The issue of the columns spacings coupled with structural zones and any related transfers structure is probably an obvious place to start. The question states that no internal columns are to be closer than eight metres centre to centre and that only three rows of columns are permitted in the east/west direction. This constraint could it be read two ways: three rows East/West or three rows North/South (along the East/West direction [elevation])!

It seems sensible to propose the maximum number of columns allowed (which automatically keeps the beam sizes to a minimum, and makes it more likely that they will fit within the structural zones). In the N/S direction there is the option of dividing the 42m into an equal number of spaces or to align with the balcony geometry. This suggests a grid of 12/9/9/12 or 4@10.5m (see figure 2).

The atrium level requires the number of columns to be reduced to four. This again gives a variety of options, as the spacing of these columns can divide the 40 metres equally; alternatively the columns can be positioned directly over those below. The former will produce the most economic spans, but the latter provides the most straightforward transfer of loads to the foundations.

One option would be to use four columns throughout the building. Although this would meet the brief, it would result in beams that were larger than necessary in some areas but negate the need for a transfer structure. Assuming it is feasible (in relation to beam depths) this layout would be suitable for one of the two schemes.

As a consequence of the reduced number of columns in the atrium, and assuming that the proposal use more columns in the gallery levels, there is now opportunity to create variety in the way the loads are transferred between levels. There are various possibilities for transfer structures including plate girders, Vierendeel trusses and supporting the gallery levels from the roof. Beams at the atrium level create potential issues of structural depth and deflection. Any moment resisting frame/Vierendeel option should discuss deflection, and construction complexity. The roof truss option is probably the most appropriate (greatest structural depth and limits deflection).

The stability system

The stability system offers a range of options. The brief specifically excludes using the four stairwells, which are therefore virtually irrelevant to the proposal. The brief allows for cross bracing in the external elevations. The North and South facades are glazed and the East and West elevations are masonry (where the stability system has no visual impact whatsoever). The "obvious" solution therefore is to provide rigid cross bracing (or possibly a diaphragm wall) in the East West direction and perhaps one option of a moment resisting frame with the second option of aesthetically pleasing cross bracing in the north and south faces.

The question suggests an unobtrusive stability system would be advantageous and clearly a moment resisting frame provide this, but the downside is deflection, particularly in relation

to the glazed facade. There seems little point in providing a moment resisting stability systems N/S.

The stair/lift shafts cannot provide stability but surely create a constraint in relation to the location of bracing (access between the stairs and the building). No dimension is given for the lift shaft but it does not appear to align with proposed columns spacings.

Tension bracing in the east and west elevations with perhaps bracing across the whole of the north and south elevations making an architectural feature seems the best solution, with an alternative of the same solution in the east and west elevations and moment resisting frame providing stability in the other direction with an articulation of the possibility of moment resisting frames in both directions, dismissed because of the greater deflection for no architectural or engineering benefit.

Soil profile, foundations and ground floor slab

The soil profile is relatively straightforward with sloping layers of stiff clay (with the softer, upper level containing fissures), and underlying rock. It therefore seems an obvious solution to pile down to the rock. There is a possible alternative of a raft spreading the whole building load, and this certainly would provide an automatic solution to the adjacent site issue, but has disadvantages in terms of depth, additional construction costs and principally the fissures in the clay. This probably leads one back to piles. Other variations could include pads constructed on the rock (which are really just an alternative construction method to piles).

The ground floor slab could be a founded on the clay (but definitely not on the made ground) or suspended from the building frame/piled foundations. The side walls could be supported on ground beams or strips taken down to the rock. This safest proposal (and certainly the one I would recommend) would be the ground floor and walls supported from the foundation system taken down to the rock (whether this is driven piles or mass concrete pads/strips).

Both the stability system and the foundation system illustrate an interesting point in relation to discussing and selecting "two distinct and viable solutions". In both cases it seems to me that there is an obvious single solution, and in the case of this particular question it would certainly be reasonable to conclude that as long as two distinct and viable solutions to the main structural frame (as discussed above) have been proposed, it may be that a single stability system and a single foundation system should be proposed. It is not the case that every element of the solution needs to offer two possibilities. In the case of stability and the foundations it is arguable whether there are two distinct and viable alternatives or whether there is really one sensible option and some other possibilities. This is a matter of judgment but one way of squaring-the-circle is to discuss a range of options (so that the examiners are aware that you can see various alternatives and can articulate the pros and cons of each). If you feel there is really only one realistic option, these alternatives can be dismissed, whereas if you think there are two options, each can be

presented as viable proposals. Irrespective of which option you select, it would surely be common-sense to package the options that represent your best engineering judgment into the scheme you eventually recommend.

The letter.

The letter provides a scenario where the client wishes to make the atrium level completely column-free. As the original scheme proposes a reduced number of columns in this area, the response is likely to be an extension of the existing proposals. The problems will be exacerbated due to the significantly increased spans and loads. Deflection and/or construction depths are likely to be constraining factors, particularly for the deep beam and Vierendeel options. Probably the most appropriate solution would be to construct trusses at roof level and hang the whole gallery construction from the roof. These trusses are likely to be deeper than permitted by the current structural zone, which would marginally raise the overall height of the building (may have planning considerations). An indication of the increased building height (based on simple span depth ratios) would be helpful. There may be additional stability issues, but they should be easily catered for.

Summary.

This question provides an opportunity to propose a full solution without too much difficulty and thus gain enough mark for a comfortable pass. This is because it contains sufficient complexity to offer a challenge, but not so much difficulty that you run the risk of getting bogged-down, and critically there is sufficient variation to enable candidates to easily identify the crucial "two distinct and viable solutions". It should offer a suitably experienced candidate an ideal vehicle to demonstrate their competence (and thus achieve a pass mark).

p.s. Many of the candidates who attempted this question did not take advantage of the obvious variation in columns spacings, for instance some adopted four columns running throughout the building for both schemes, depriving themselves of the obvious variation. To make matters worse some of these candidates did not pay any particular attention to the structural zones. A number of moment resisting stability systems were proposed (when a braced system was probably the most appropriate) but did not discuss the inherent disadvantage of this system (lateral movement particularly in relation to the glazed facade). Some candidates proposed transfer structures that would not fit in the structural zones. Some candidates ignored the implications of the vacant site, when all they needed to do was offset the piles/caps. Some founded the whole building on the clay without recognising the issues connected with the fissures or the good bearing provided by the rock only 5/6 metres down. Few took account of access from the stairwells (ie placed bracing in this area).

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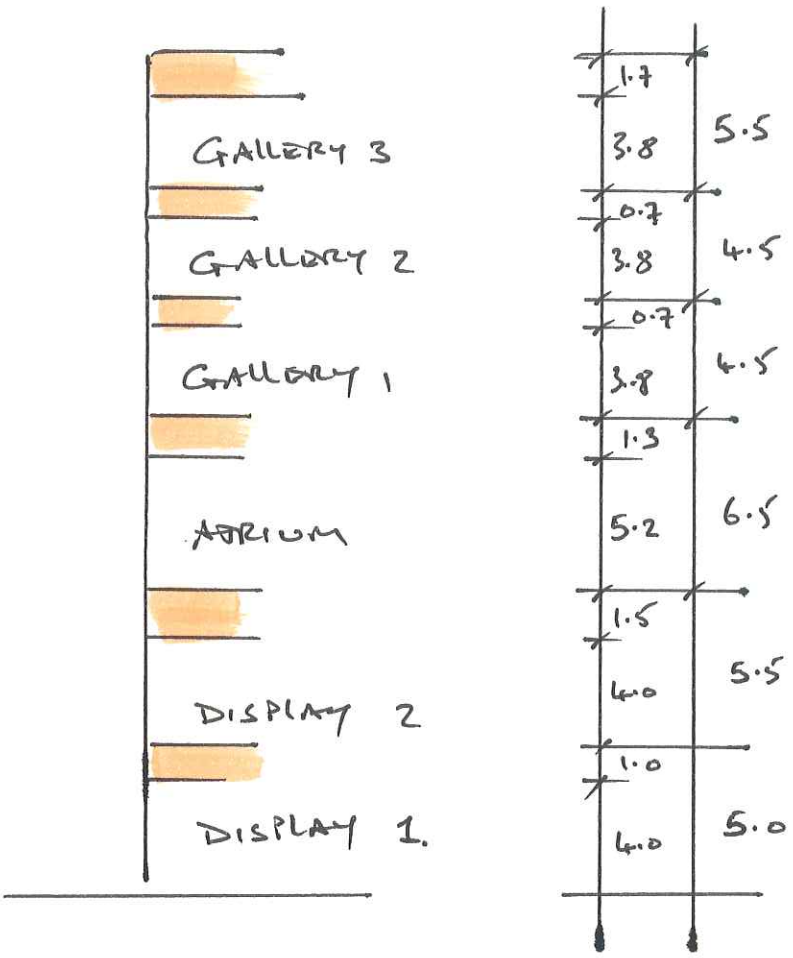
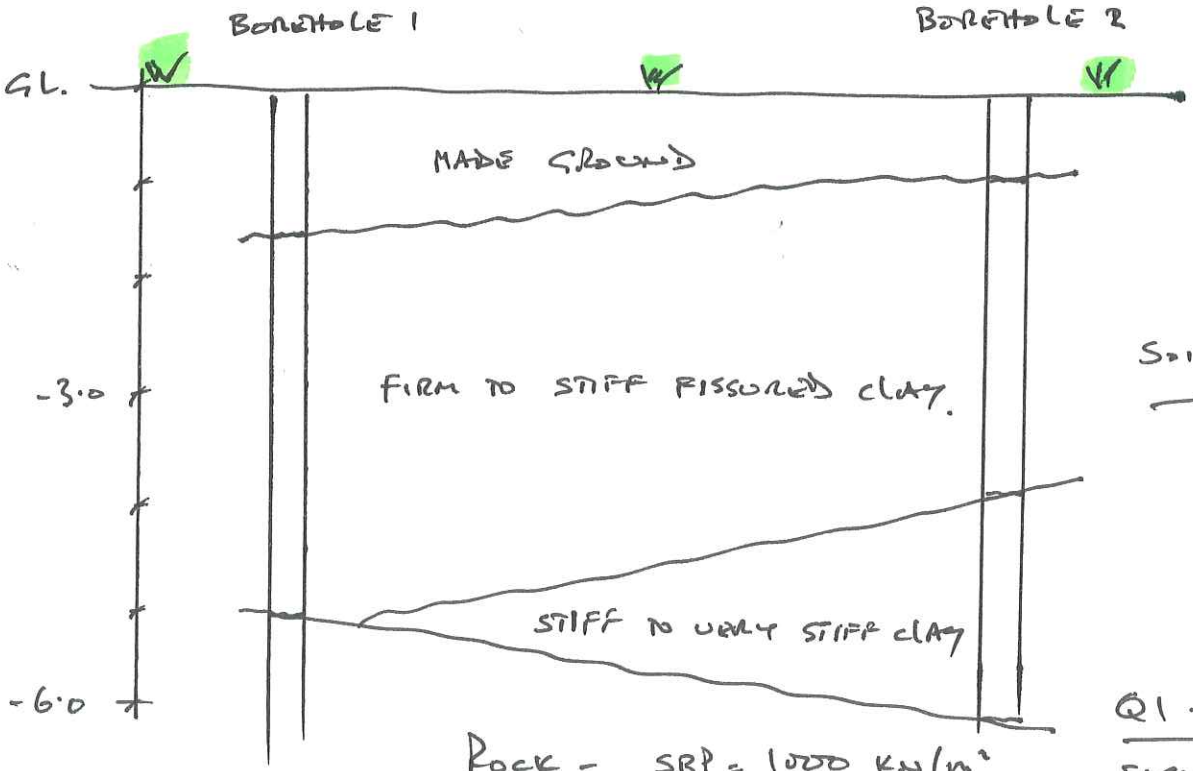


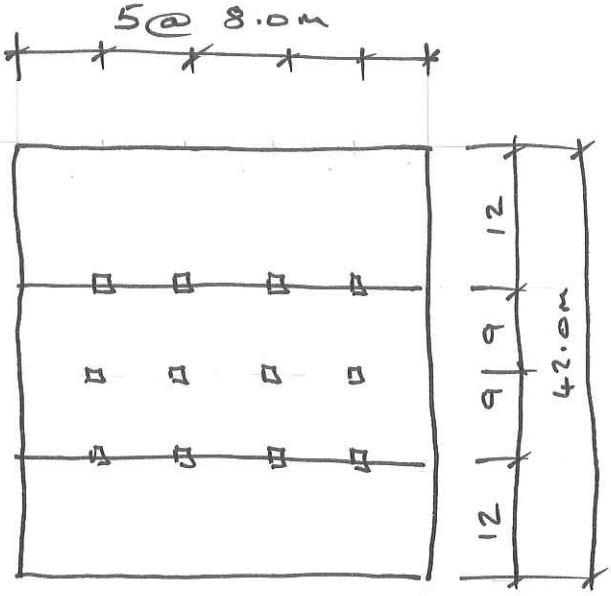
FLOOR HEIGHTS



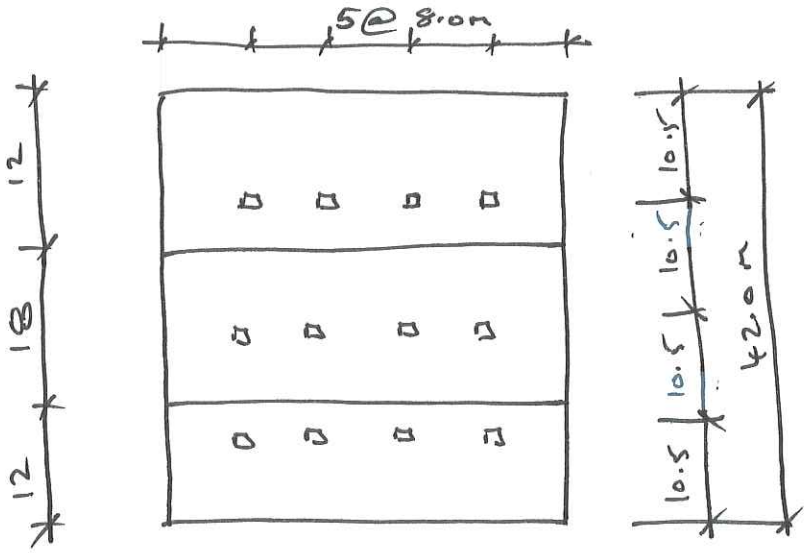
SOIL PROFILE

Q1 - 2007

FIGURE 1 of 6



OPTION 1

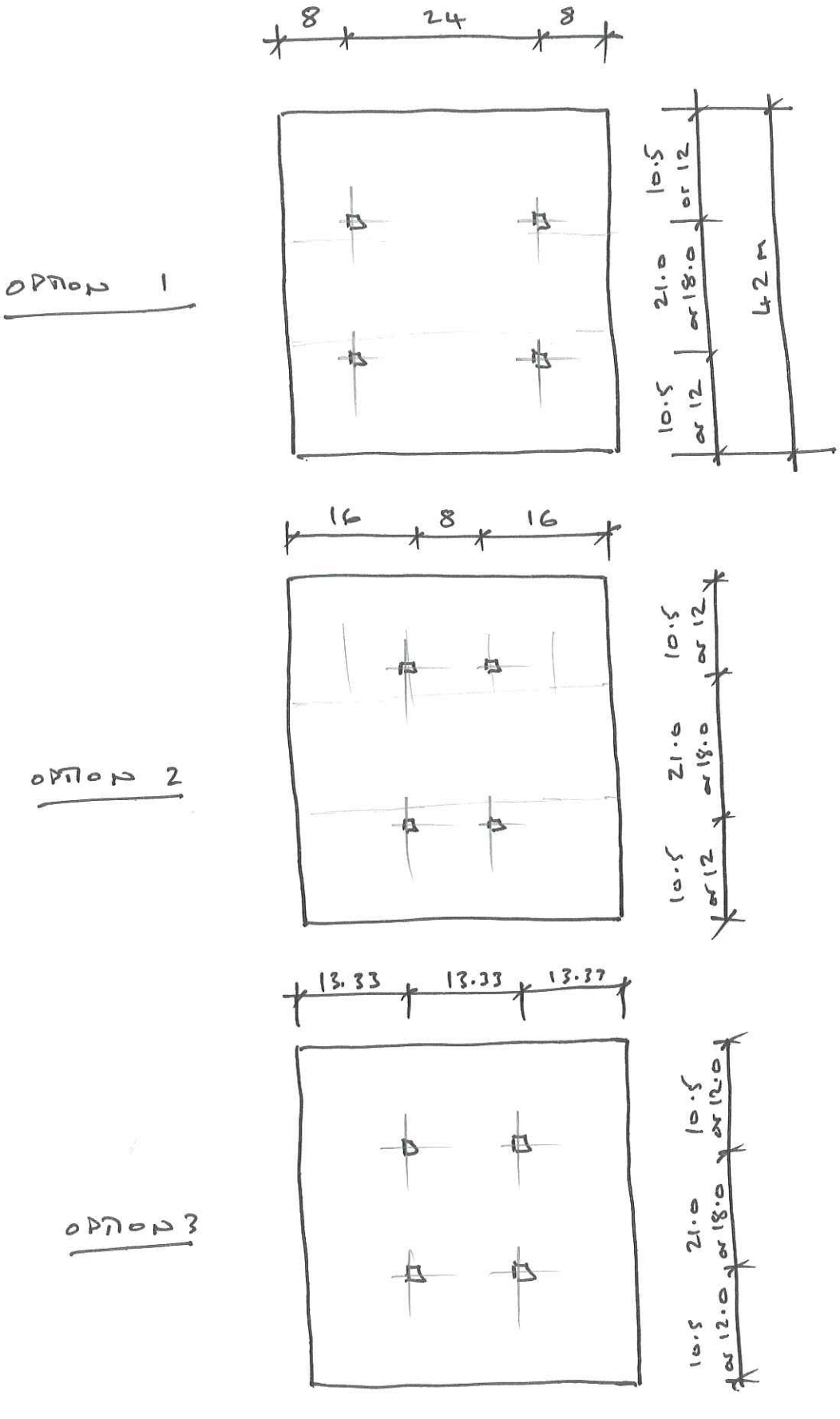


OPTION 2

COLUMN LAYOUT - DISPLAY LEVEL.

PLAN.

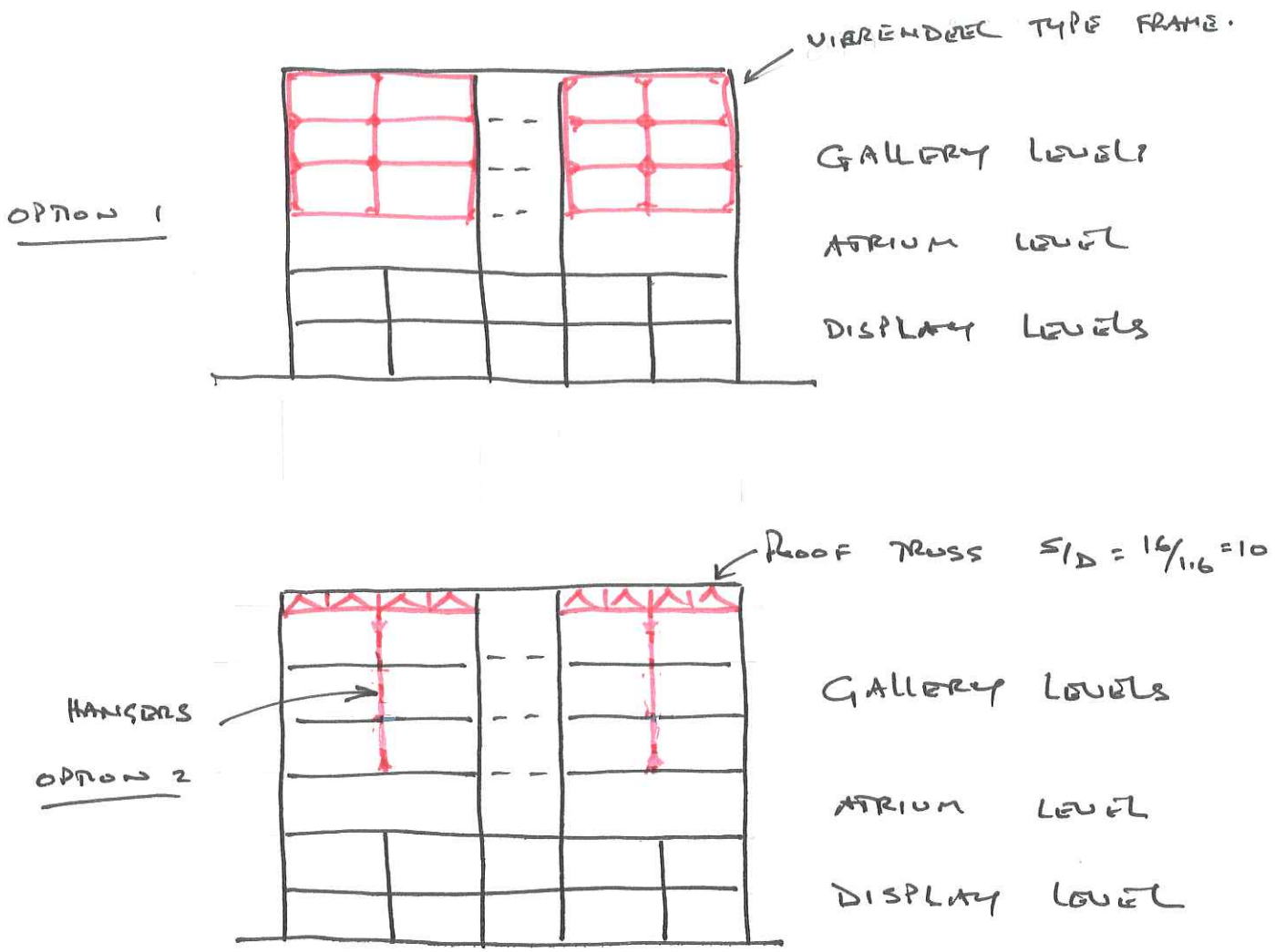
FIGURE 2



COLUMN LAYOUT - ATRIUM LEVEL

PLAN.

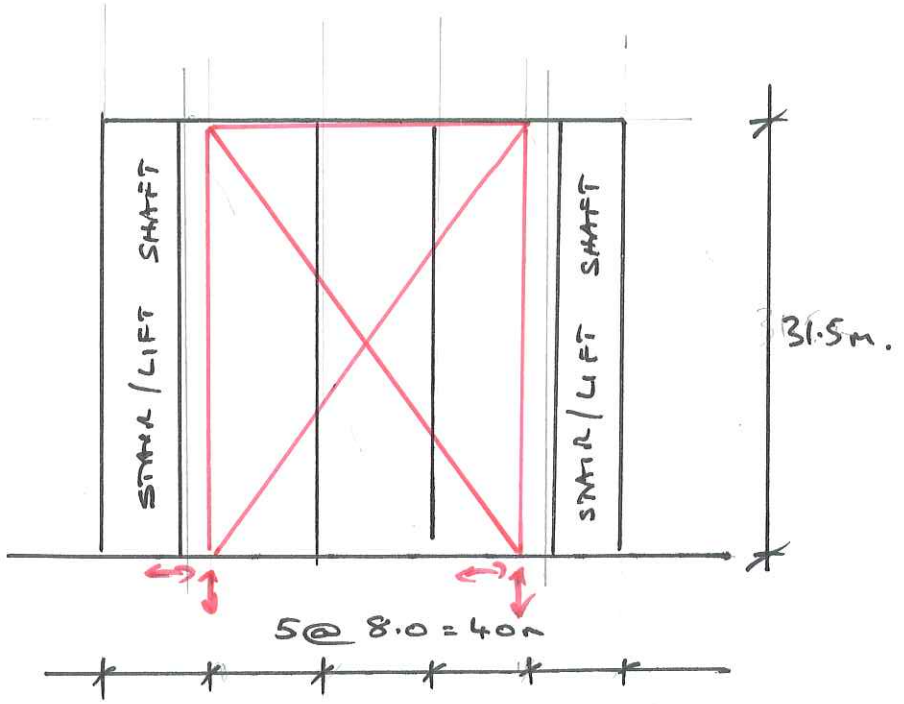
FIGURE 3



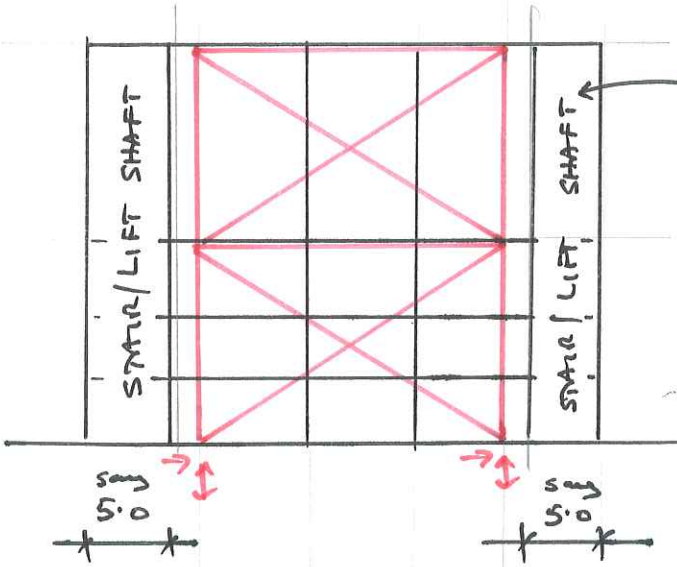
TRANSFER OPTIONS TO SUPPORT GALLERY FLOORS

FIGURE 4

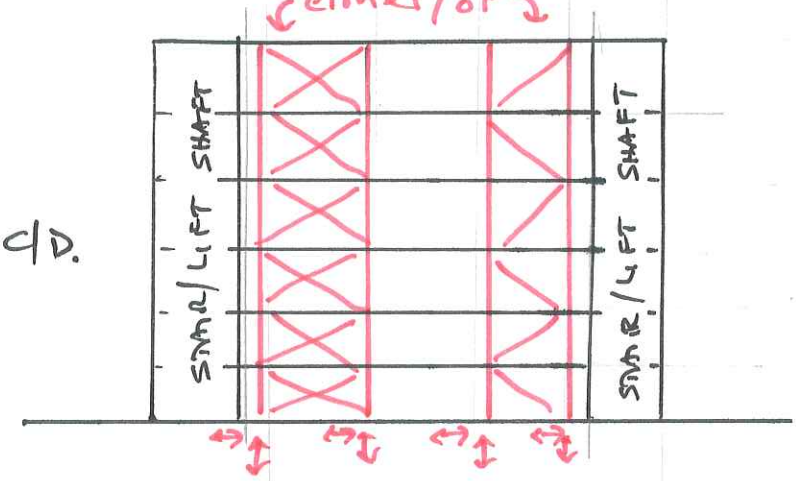
OPTION A



OPTION B

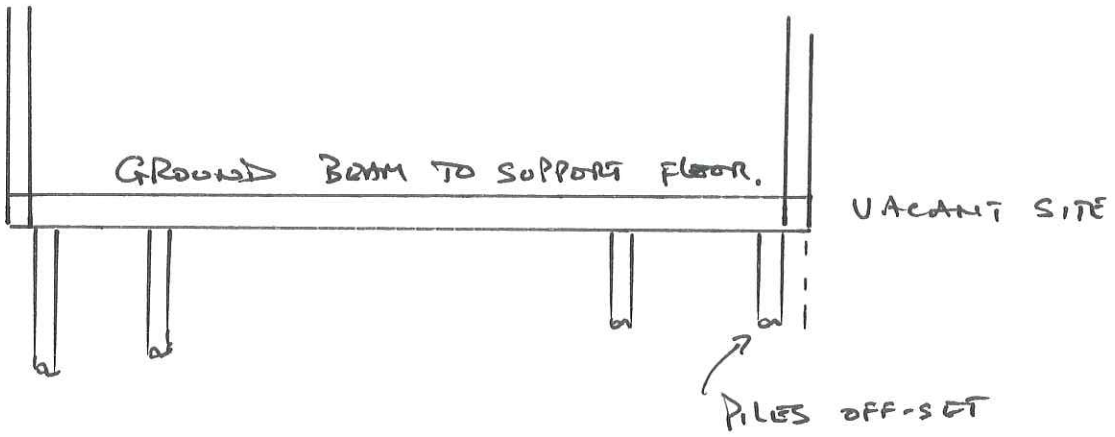


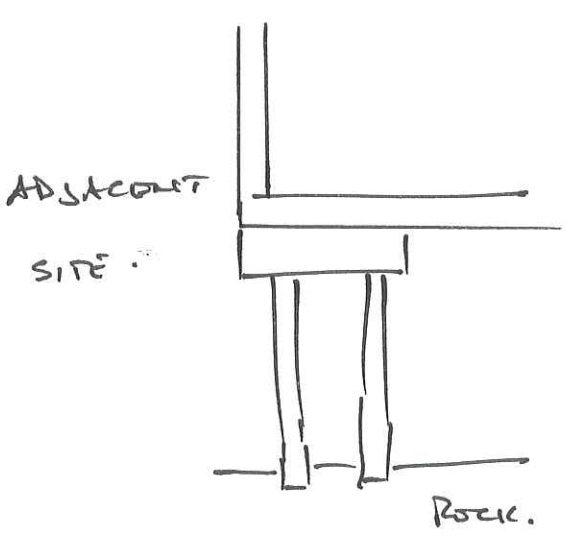
OPTION C/D.



LATERAL STABILITY NORTH & SOUTH ELEVATIONS.

FIGURE 5


GROUND BEAM TO SUPPORT FLOOR.
VACANT SITE
PILES OFF-SET


ADJACENT SITE.
ROCK.

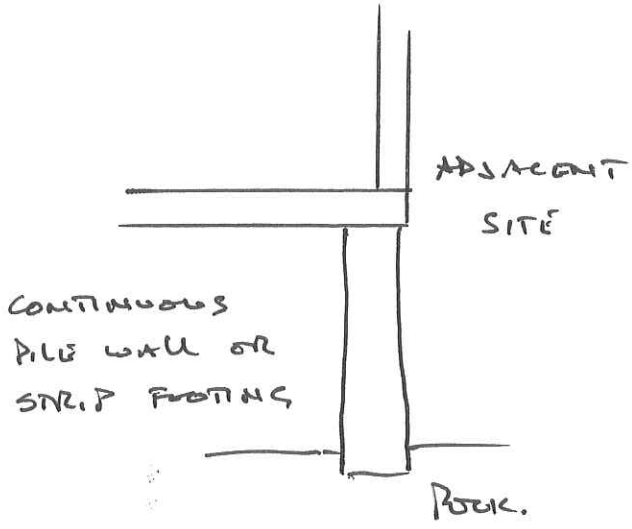

ADJACENT SITE
CONTINUOUS PILE WALL OR STRIP FOOTING
ROCK.

FIGURE 6.16