Possible solution to past CM examination question

Question 1 - April 2009

Office building incorporating an existing stone tower

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Question 1. Office Building Incorporating An Existing Stone Tower

Client's requirements

1. An existing stone tower is to be used in a new office development; see Figure Q1.
2. The tower is made from stone set in mortar and cannot be used to support the new office structure in any form. The new building is to be set partially into the interior of the tower as shown on Figure Q1.
3. The Architect wishes to retain the smallest floor depth possible and to have the building clad entirely in glass. The Architect has also stipulated that there is to be no visible structure around the glazed perimeter other than columns and the floor plate. Columns are to be spaced at least 8.0m apart.
4. The building is to have a 3.1m clear height between each floor and ceiling and is to be 4 storeys high. The height of the tower is 16.5m. The Architect has requested that the maximum level of the roof line of the building matches the height of the tower.
5. The existing stone tower is founded at a constant depth of 1.0m below ground level. The foundation of the tower does not extend beyond its plan area.

Imposed loading

6. Roof 2.5kN/m^2
   Floor loading 6.0kN/m^2
   Loadings include an allowance for partitions, finishes, services and ceilings.

Site conditions

7. The site is level and located in a park in the centre of a town.
   Basic wind speed is 40m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20m/s.
8. Ground conditions – Assumed to vary linearly between boreholes

Borehole 1	Ground – 1.0m	Made ground
	Below 1.0m	Rock. Allowable bearing pressure = 1000kN/m^2
Borehole 2	Ground – 5.0m	Made ground
	5.0m - 8.0m	Stiff clay C = 80kN/m^2
	Below 10.0m	Rock. Allowable bearing pressure = 1000kN/m^2

Omit from consideration

9. Detailed design of staircases

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 design has been completed, the Client advises you that he wishes to include an atrium opening of the full width of the building at the south end with the floors set back by 5.0m from the south wall. Write a letter to the Client explaining how this might be achieved. **(10 marks)**

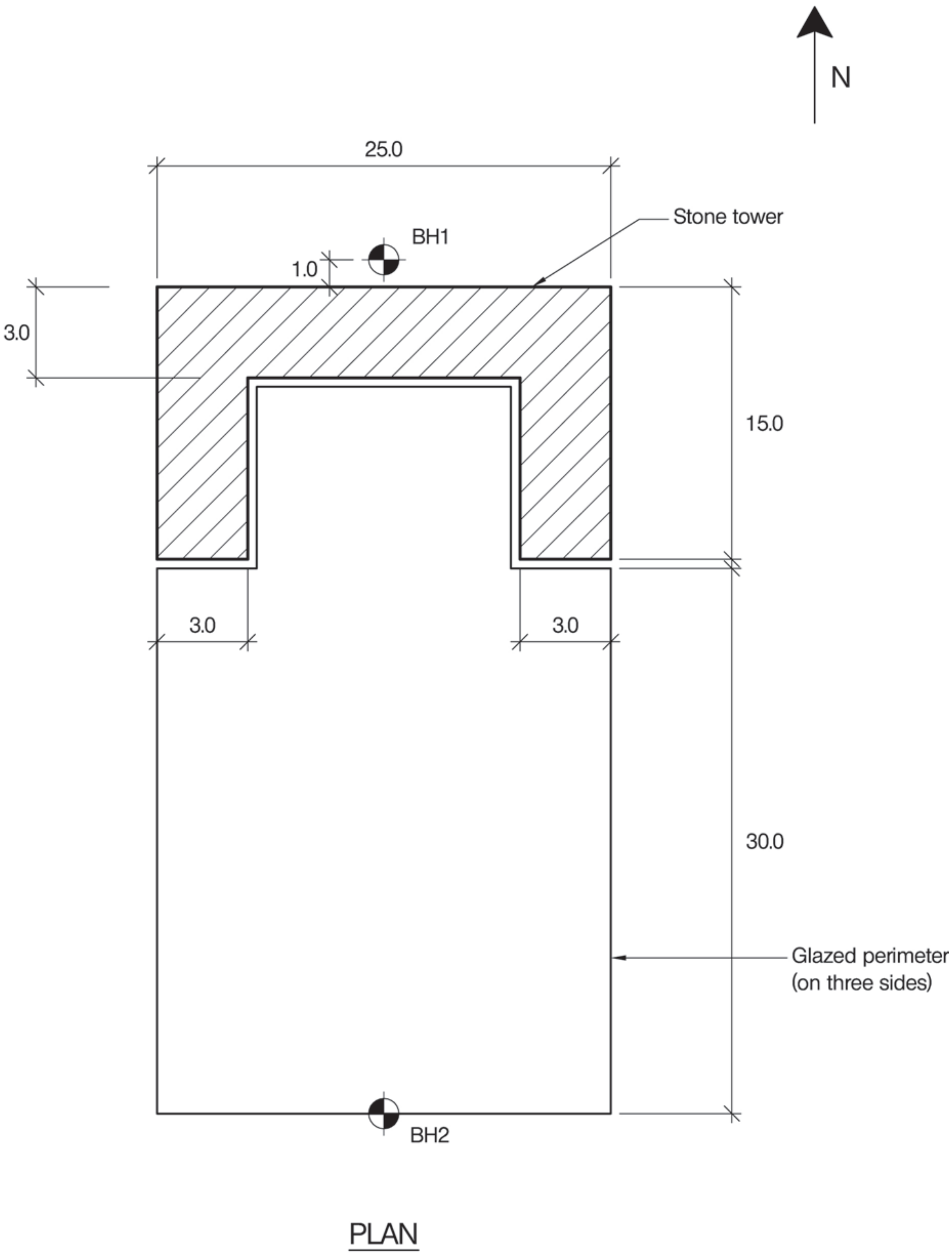
SECTION 2 (50 marks)

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 office building and an outline construction programme. **(10 marks)**



NOTE: All dimensions are in metres

FIGURE Q1

Introduction

This question relates to a new office development wrapped around an existing stone tower. The new office building is structurally independent from the tower, but is clearly intended to be architecturally linked. There are structural implications to consider.

The brief is relatively straightforward with clear constraints. The building is of comparatively modest scale, so first impressions are of an understandable question without any insurmountable difficulties.

The issues

- The brief states that the tower cannot be used to support the new office and that the foundations of the tower do not extend beyond its plan area. Any attempt to use the tower for structural support would result in automatic failure.

- There is a client requirement for slender floors and for the building to be clad entirely in glass. There is a stipulation of no visible structure around the glazed perimeter other than the columns and floor. This means there can be no diagonals, or any other form of additional structure around the perimeter. The key requirement is for "no visible [additional] structure around the glazed perimeter" so strictly speaking additional structural elements could be added anywhere as long as they are not actually on the perimeter, but the spirit of this requirement is surely to provide clean uncluttered lines when viewed from the outside. However, in a fully glazed building any internal structural elements would be visible, wherever placed!

- Columns are to be spaced at least 8 metres apart. There is no specific reference to external or internal columns, so this should be read to be all columns. The examiners are rightly hard on any candidate who infringes any of the stipulated client requirements.

- The building is to have a 3.1 metre clear height between each floor and ceiling, and the overall height of the building must not exceed that of the tower. So effectively this constraint sets the maximum floor depth. Even at this stage, without the benefit of any calculation, you should be preparing yourself to design/specify relatively slender floors spanning at least eight metres.

- The ground conditions are clear, with two borehole logs showing varying depths of made ground, stiff clay and rock. The question says that you may assume the ground conditions vary linearly between boreholes, and the existing stone tower foundations are one metre below ground level, so actually the stone tower sits on the made ground or stiff clay on all but its northern edge. This is somewhat curious and is unlikely to be the case in practice, however the question is about a new office building and not about the stone tower, so there is no reason for us to concern ourselves about the foundations of the stone tower, other than to make sure the new building doesn't interfere with them. Despite the borehole profiles, it might be reasonable to assume that the tower is founded on rock, in which case the new building will not influence the foundations at all, however as discussed above, a literal interpretation of the data suggests that the tower is on rock on its north face and on softer ground on the southern end. By ensuring that the foundations of the new building are kept away from the tower, the more onerous of the two interpretations relating to the tower's foundations can be easily dealt with.

In summary, the critical elements that will impact on the overall design appraisal and resulting schemes are: the floor depths, the column spacings, requirement for structural independence from the tower (superstructure and foundations), the stipulation of no visible structure other than the columns and floor around the perimeter, the stability system and dealing with the variable soil conditions.

Proposed solution

Bearing in mind that all the way through any of these questions you need to have firmly planted in your mind the need to provide two distinct and viable solutions, the obvious starting point would be to quantify the constraints: initially the available construction depths and then the column layouts.

Floor depths

The brief says “the architect wishes to retain the smallest floor depth possible”. A simple calculation (see figure one) shows that there is in fact ample floor depth. This leaves a choice, either to have a building overall height less than the tower (the question says “maximum level of the top of the tower”, not that it must be the same height) or have a floor depth greater than the absolute minimum. Because the question specifically states “smallest possible floor depth”, my advice would be to demonstrate your ability to design slender floors. One way of squaring this circle would be to design a minimum depth floor and use the resulting available space for services (raised floors and/or ceiling voids) with a commentary saying that the overall height could be reduced by allowing less service space.

Column layout

The next step is probably to lay out the columns, providing as much variation as possible within the absolute constraint of a minimum centre to centre spacing of 8 metres. There is no reason why columns shouldn't be adjacent to the stone tower, but we must bear in mind that the foundations to these columns may need to be set back to avoid surcharging or disturbing the material under the stone tower. Figure 3 provides four possible layouts.

A more radical column layout (longer spans and cantilevered floors) would provide greater variation between the schemes but this would immediately conflict with the minimum floor depth requirement.

Stability system

The next area to consider is probably the stability system which often provides opportunities for variation for the two required schemes. In this case we are prohibited from having any form of additional stability system in the glass clad elevations. It is less clear whether bracing is allowed on the new building/stone tower interface. We therefore need to think about the constraints in relation to the interface between the stone tower and the new building. The brief says "the building is clad <u>entirely</u> in glass" but the diagram clearly says the glazed perimeter is on three sides. This leaves the detail of the interface between the stone tower and the new building open to interpretation, which in turn has implications for the stability system. There are three possible interpretations/assumptions, the first is that the glazed perimeter continues around the stone tower, the second is that solid cladding (eg brickwork) is used, and a third is that the elevations are open, allowing the face of the stone tower to form the internal walls, with a weatherproof (but not structural) joint between the two. Each of these assumptions provides different constraints on the stability system: the assumption of a solid wall enables the use of shear walls, whereas the visually open assumption would limit the use of these elevations to aid stability (see figure 4).

The building must clearly have some form of vertical access in the form of stairs (and possibly a lift) which would be enclosed in a fireproof shaft. It would seem reasonable that these somehow could be used to contribute to the building's stability, either as a shear core or to locate diagonal bracing. At this point we need to consider how shear cores would fit in with the requirement for columns to be spaced eight metres apart: are they to be fitted around the columns, are they allowed in addition to the columns and how close to the perimeter can they go? Whatever you decide, the cores must be kept away from the perimeter (at least on the three exposed sides).

Whatever is proposed, the arrangement must be symmetrical so as not to induce torsion in the overall structure. Some candidates (possibly as a consequence of their interpretation of the brief) offered stability systems (cores and/or bracing) concentrated at the north end adjacent to the stone tower. This would induce significant torsion, which was ignored (this was a significant error!). A symmetrical system at the north and south ends completely overcomes this problem.

The above discussion is leading us to provide a stability system comprising internal shear walls and/or vertical bracing and an alternative with no additional internal structural components, relying on the frame to provide lateral resistance.

The option of a full moment-frame in both directions would provide a visually uncluttered building and crucially a distinct and viable alternative to a braced frame. The main discussion point with this option is the increased flexibility of the frame which will result in increased lateral movement, which is especially important adjacent to the stone tower (this was not appreciated by many candidates who attempted this question).

Ground conditions and foundations

As far as the ground conditions are concerned, we have rock relatively close to the surface at the northern end and a deep seam of made ground, with a further three metres of stiff clay on top of rock at the southern end (see figure 2). Although it would be theoretically possible to found the building on the stiff clay, there is a very significant issue of differential settlement. Also, from a practical point view the stiff clay starts five metres down, at the southern end, which would be deep (but feasible) for the construction of traditional foundations. By going down an extra three metres the whole building can be founded on the rock, which seems the only practical solution.

By founding the new building on the rock, its foundations cannot surcharge any soft ground under the stone tower. To avoid any disturbance to the existing structure the new foundations should be positioned away from the tower's footings (this may necessitate cantilevered foundations or ground beams if the columns are located on the perimeter). However, even though this isn't strictly in accordance with the data given, it would seem reasonable to assume that the tower is on the rock. In these situations a discussion of the various options/interpretations resulting in an argued assumption (as I have done here), seems a reasonable approach.

A combination of different column layouts, different stability systems, possibly combined with variations in the foundation system, would therefore form the basis of our "two distinct and viable schemes".

Letter

In this particular question the letter gives tremendous opportunity for discussing the structural implications of various options that can be proposed to meet clients revisions.

The client wishes to introduce an atrium at the south end the building with all the floors set back five metres from the south elevation. This will have a fairly dramatic effect on the whole structure and gives a perfect vehicle for discussion in the letter.

The inclusion of an atrium is likely to interfere with the framing arrangements and the stability system. Because the building has been based on a minimum clear column spacing of 8 metres, the atrium will compromise the symmetry of the overall grid layout. The "obvious" grid layout is a line of internal columns 5m from the south elevation with the remaining columns evenly spaced (on a 9.25m grid) but this clearly infringes the original brief. Adherence to the existing 8m minimum spacing will necessitate a 3m cantilever with all the inherent disadvantages (deflection/vibration). The letter can therefore discuss the possibilities afforded by a modification of the eight metre requirement, and the alternatives if the constraint stays. Figure 5 shows one possible layout based on a 9.25 c/c grid running North – South.

The other major issue is the structure and stability of the south elevation, which was previously afforded natural support from the floor plates and the overall stability system. The overall stability arrangement will need to be modified and the south elevation itself will now create additional issues.

The south elevation's columns will now span the full building height without intermediate support from the floors and the whole elevation will link to the main structure at roof level (potentially with roof bracing depending on whether we assume a solid or glass roof).

It's completely inadequate to just provide a few bland statements about checking structural sections for new loads (which is what many candidates did).

Summary

This question is relatively straightforward, with some clear constraints on column spacings, storey heights and perimeter limitations, which should have provided an ideal question to demonstrate an understanding of structure behaviour, particularly in relation to alternative stability systems. There are however areas where the brief needs to be interpreted, with different structural implications depending on what is assumed/decided. This can be turned to your advantage by discussing the issues and the options afforded by each choice/assumption.

Because of its relative simplicity, it's even more important with this question to fully develop clear "distinct and viable" alternatives utilising all possible attributes (column layouts, stability systems etc), a full analysis of the merits of each option and a clear understanding of the structure's behaviour. Many candidates offered no more than slight variation between schemes based only on alternative column layouts, even though there are clearly alternatives available (stability systems and possibly foundation arrangements). This was an ideal vehicle to demonstrate an understanding of structure behaviour and to propose different structural arrangements.

All-in-all this is a fundamentally straightforward question that should have been ideal for a competent, experienced candidate, who could have concentrated on demonstrating an understanding of structure behaviour and an ability to conceptualise different arrangements.

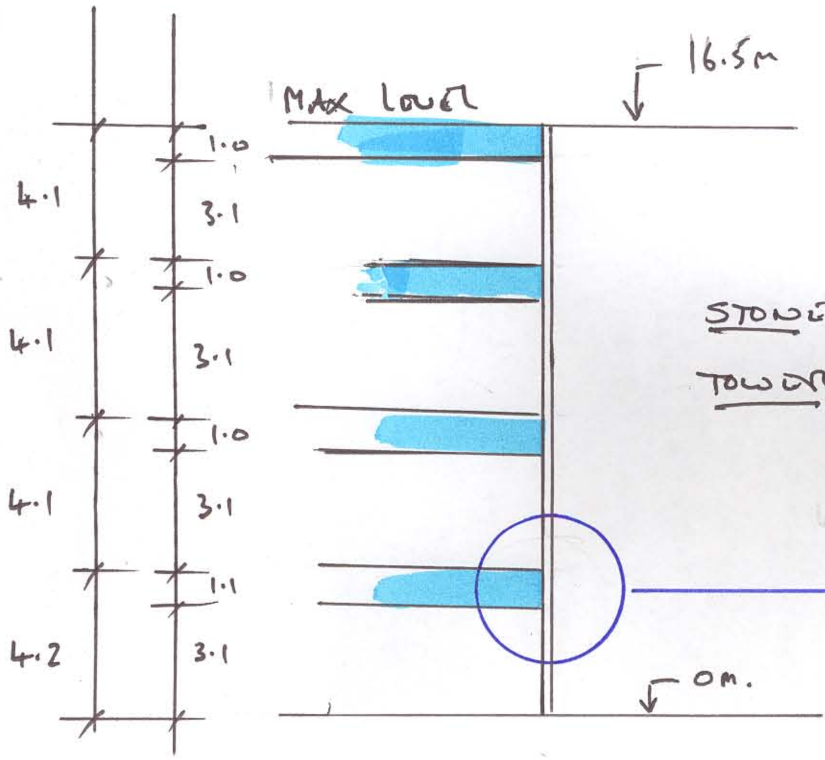


FIG 1. FLOOR HEIGHTS.

SLENDER FLOOR REQUIRED

$\therefore \frac{\text{SPAN}}{\text{DEPTH}} \approx 15-20.$

say $\frac{8000}{15} = 530$ mm.

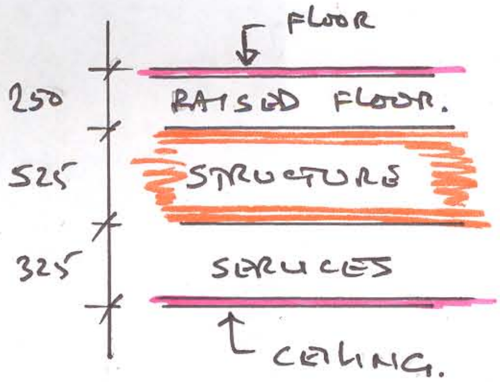


Fig 1(a) FLOOR ZONE.

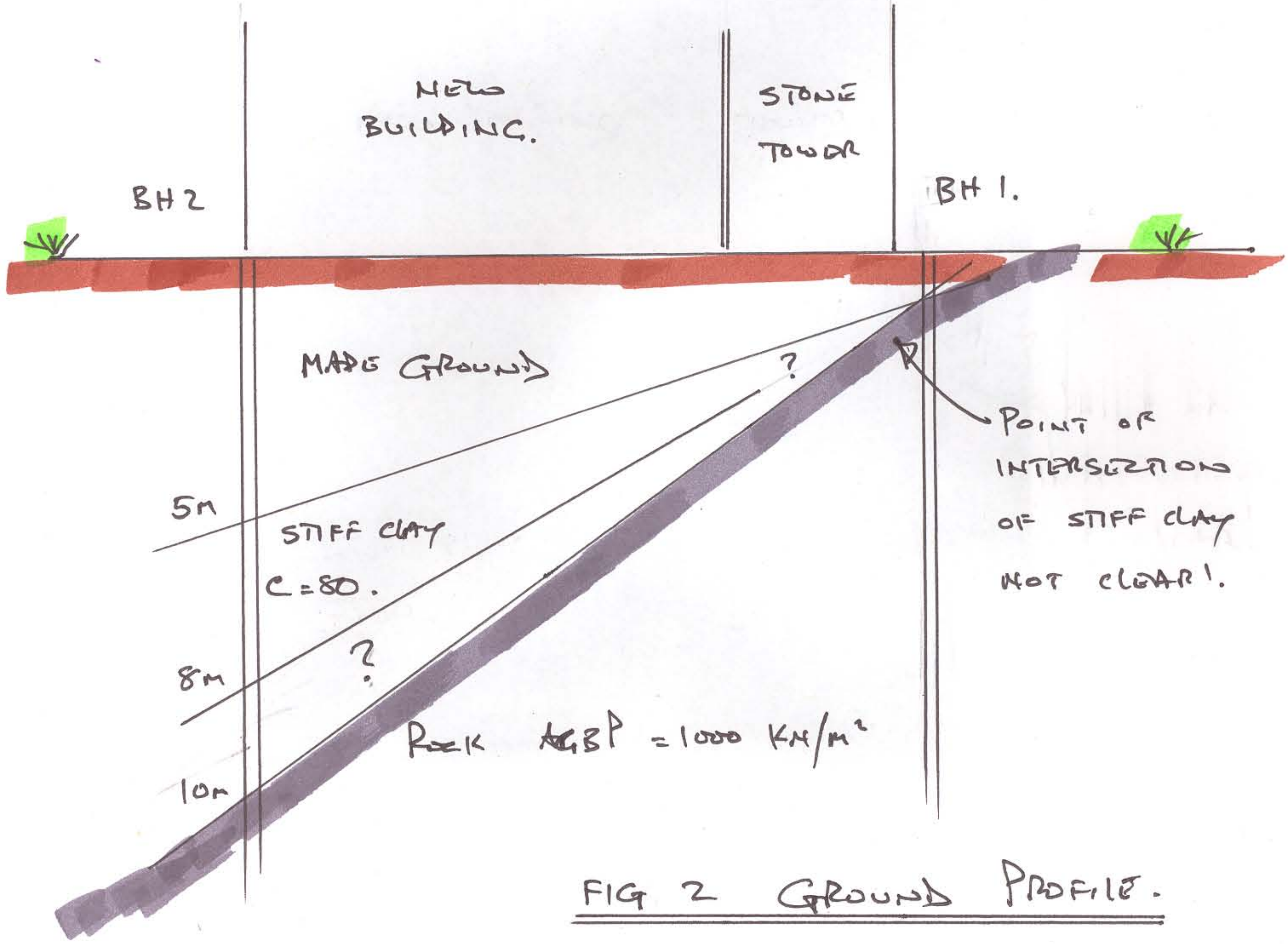
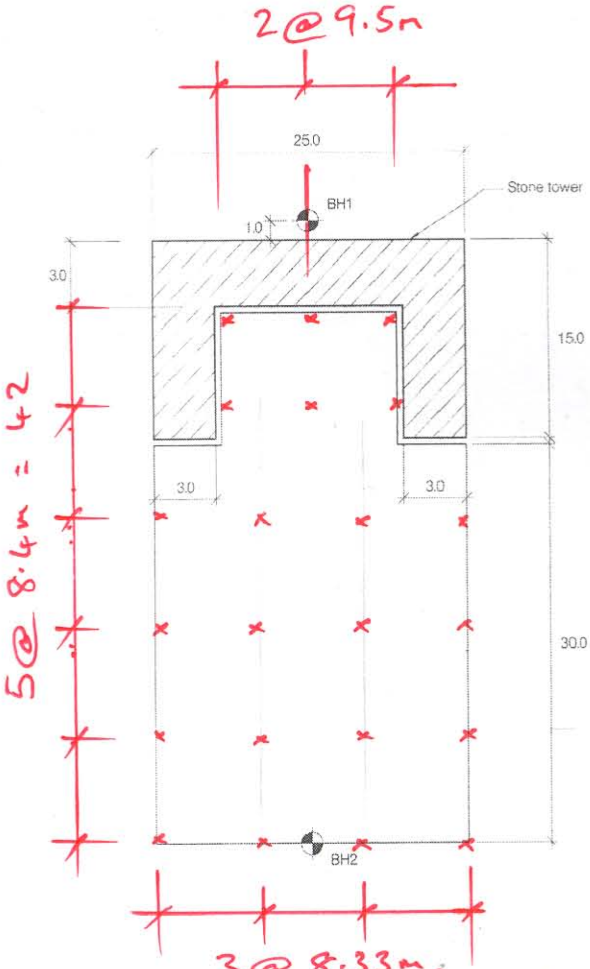
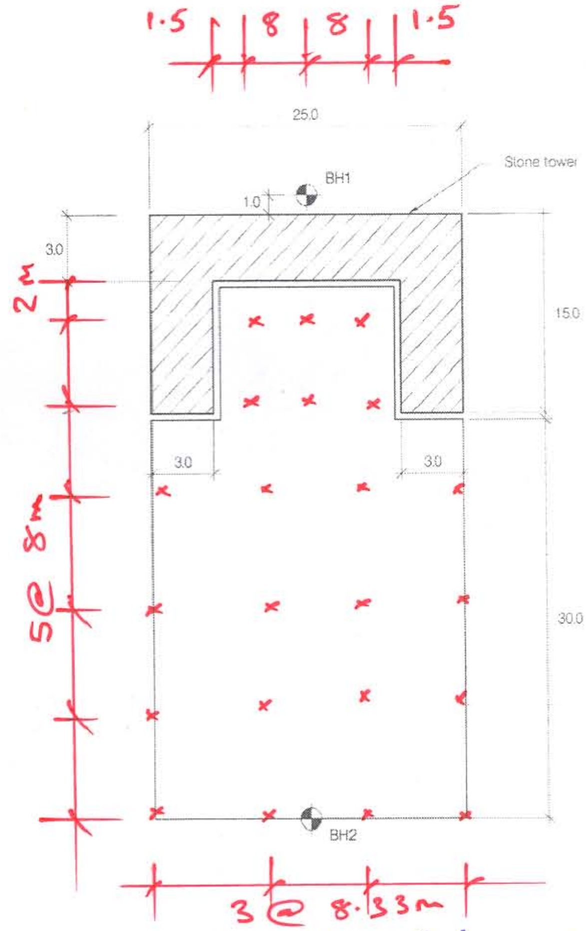


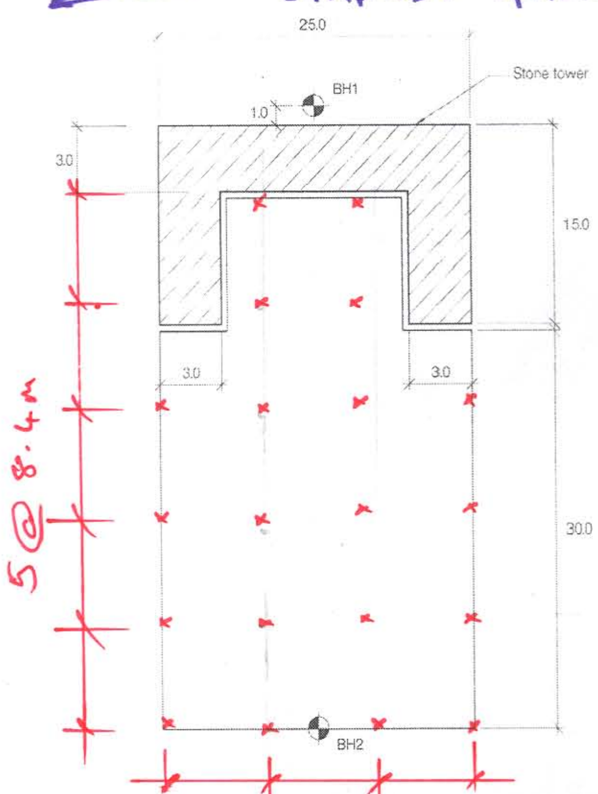
FIG 2 GROUND PROFILE.



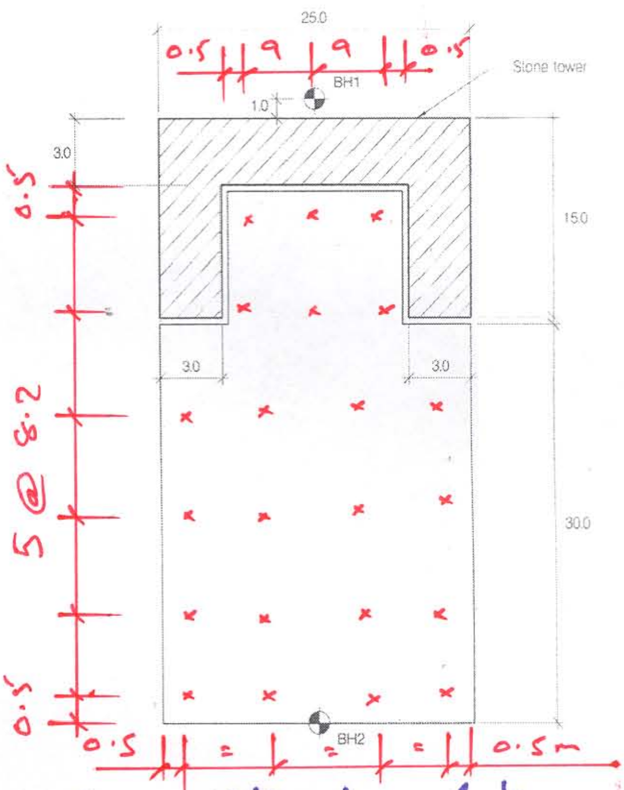
Option 1. Columns evenly spaced
Simplest option



Option 2. Columns kept away from tower



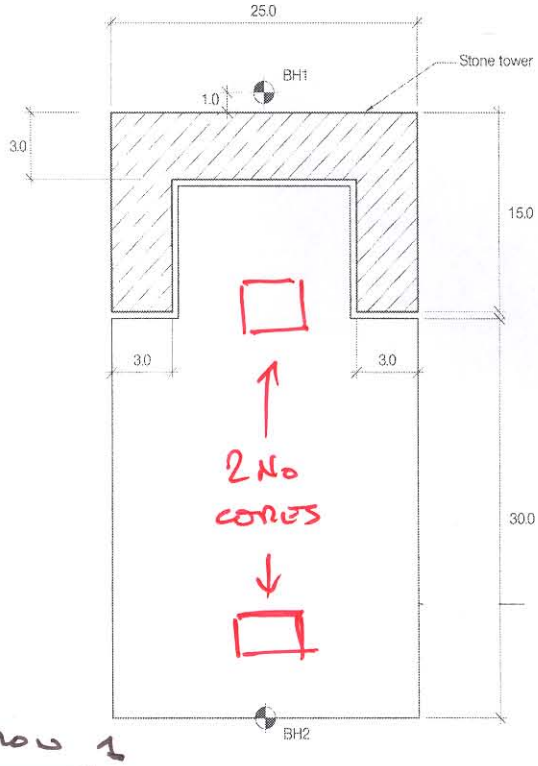
Option 3. Columns evenly spaced to minimise ~~floor~~ spans BUT cantilevers by tower.



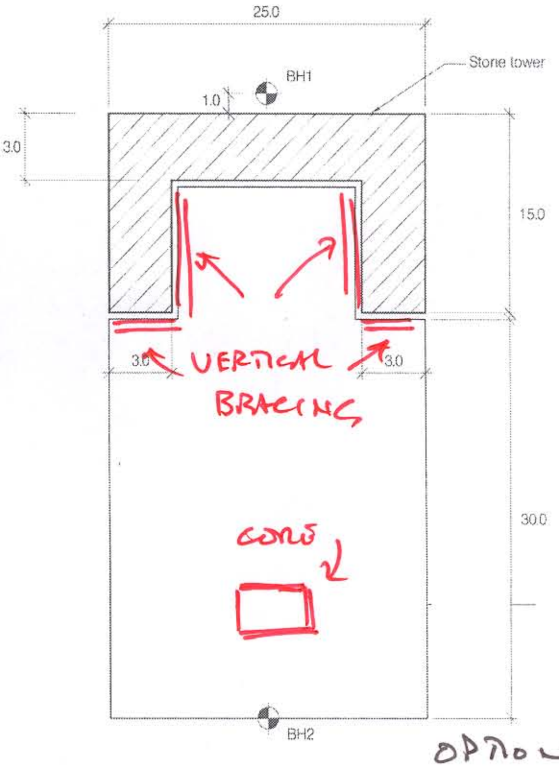
Option 4. Columns inset by 0.5m for architectural effect.

FIG 3: Four possible column layouts.

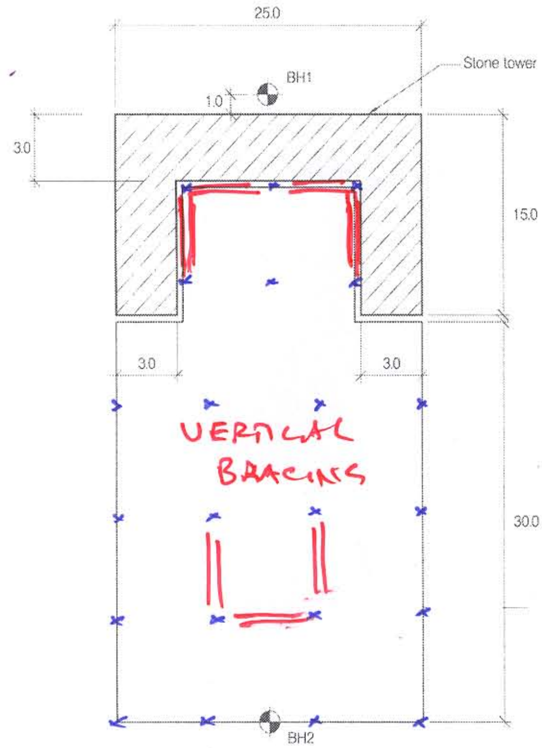
FIG. 4. FOUR POSSIBLE STABILITY LAYOUTS.



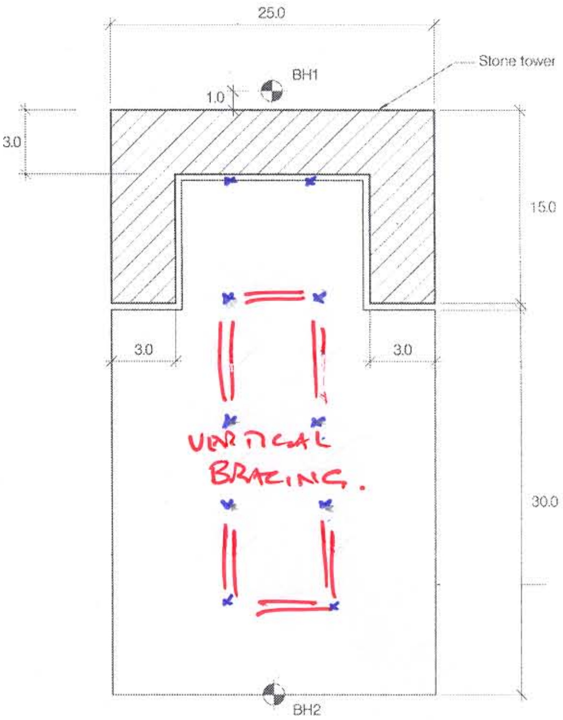
OPTION 1



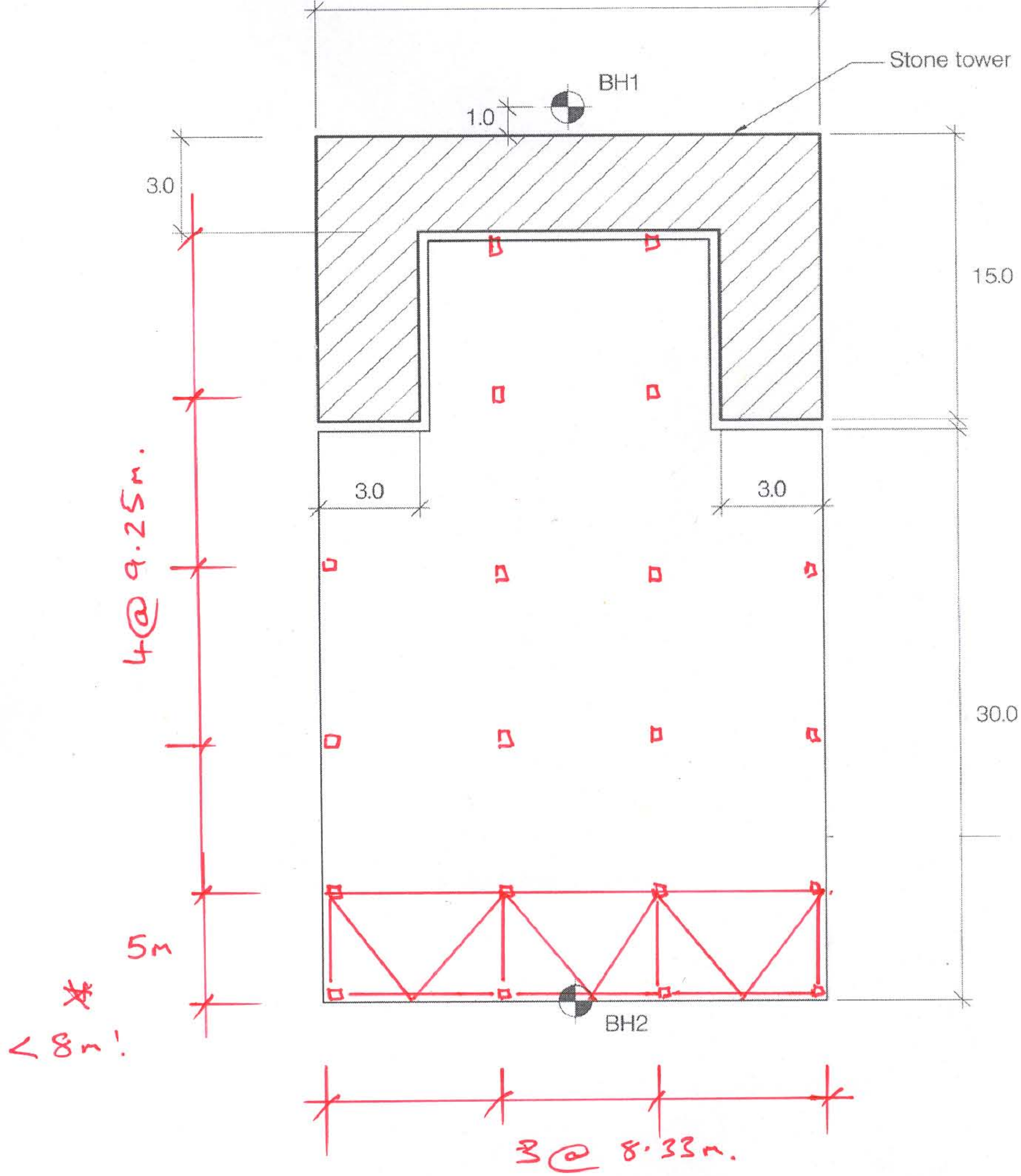
OPTION 2



OPTION 3.



OPTION 4



- Grid layout in response to client change (letter).
- option assumes column spacing criteria relaxed.
- Full height columns on southern elevation.
- Roof bracing supports & stabilizes column heads

FIG 5: REVISED LAYOUT IN RESPONSE TO CLIENT CHANGE