Possible solution to past CM examination question

Question 4 - April 2009

Commercial Building

by Bob Wilson

Question 4. Commercial Building

Client's requirements

1. A seven-storey commercial building on a square site 45.0m x 45.0m: see Fig. Q4.
2. The facade at the south-east corner is to be inclined between level 2 and the roof. All other facades are to be vertical. All facades are required to be fully-glazed between level 2 and the roof.
3. To provide flexibility for building entry points, the clear distance between external columns on level 1 must be a minimum of 8.0m. External columns on level 2 and above, if required, must be evenly-spaced. No column is permitted on any level at the north-west corner of the building.
4. Neither external nor internal structural walls are permitted. A clear distance of at least 7.0m is required between an internal column and any other column or external enclosure. The service cores are to be structurally independent of the main building.
5. No foundations may extend beyond the site boundary.
6. Allowable structural floor zones are:
   Level 2: 1.7m
   Other levels and roof: 1.2m
7. A minimum fire resistance of 2 hours is required for all structural elements.

Imposed loading

8. Roof 2.5kN/m²
   All floors 5.0 kN/m²

Site conditions

9. The site is level and is located in the suburban area of a town 200km from the sea. Basic wind speed is 40m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20m/s.
10. Ground Conditions

Ground level – 2.0m	Loose fill
2.0m – 5.0m	Sandy gravel. N varies from 10 to 20
5.0m – 8.0m	Weathered rock. Allowable bearing pressure 500kN/m²
Below 8.0m	Rock. Allowable bearing pressure 1500kN/m²

Ground water was encountered at 2.5m below ground level.

Omit from consideration

11. Detailed design of the service cores.

SECTION 1 (50 marks)

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. 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. Before construction begins, a group of piles forming the foundations of a previous building on the site are discovered. The group comprises 49 concrete piles each 600mm diameter in a 7 x 7 grid spaced at 3.0m centres in both directions and the centre of the group is located at the north-west corner of the site. The client wishes to know whether the piles can be re-used. Write a letter to the client advising him of the implications of the discovery and the practicality of re-using the piles. **(10 marks)**

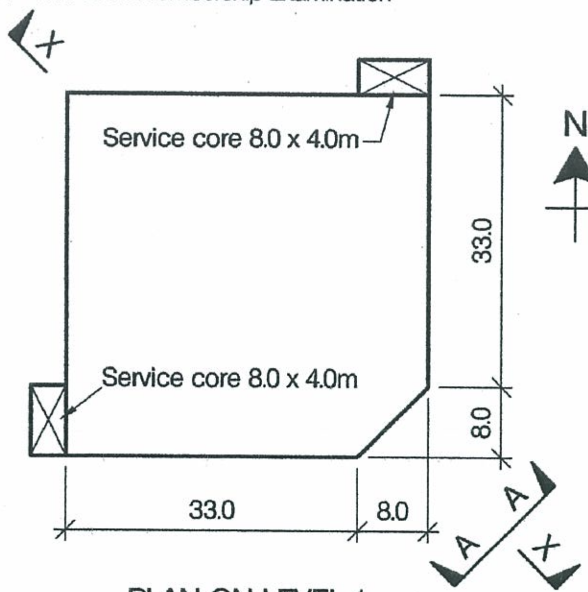
SECTION 2 (50 marks)

For the solution recommended in Section 1(a):

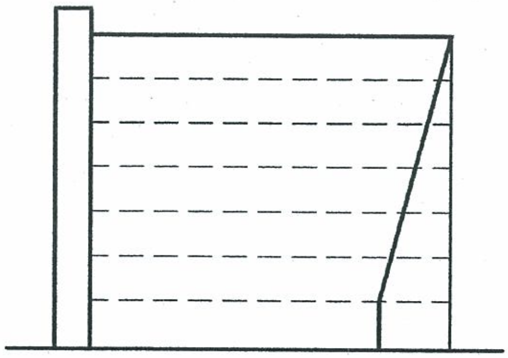
c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. **(20 marks)**

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)**

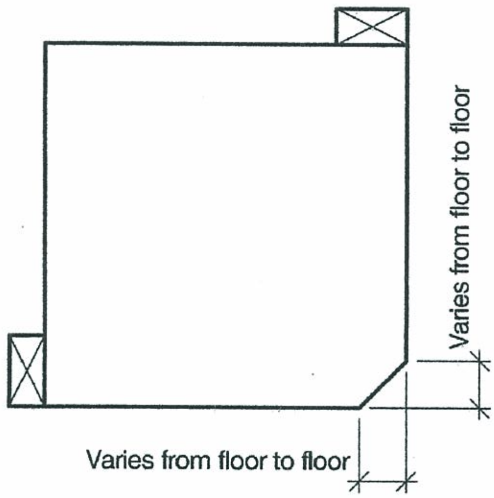
e. Prepare a detailed method statement for the safe construction of the building and an outline construction programme. **(10 marks)**



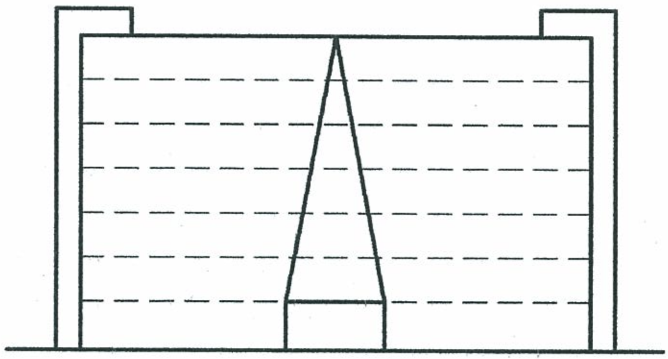
PLAN ON LEVEL 1
(PLAN ON LEVEL 2 SIMILAR)



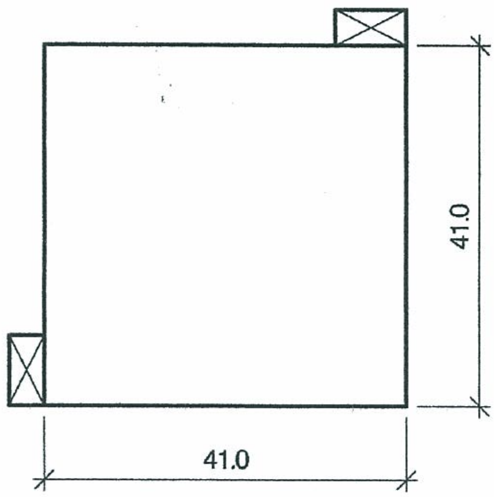
ELEVATION FACING SOUTH



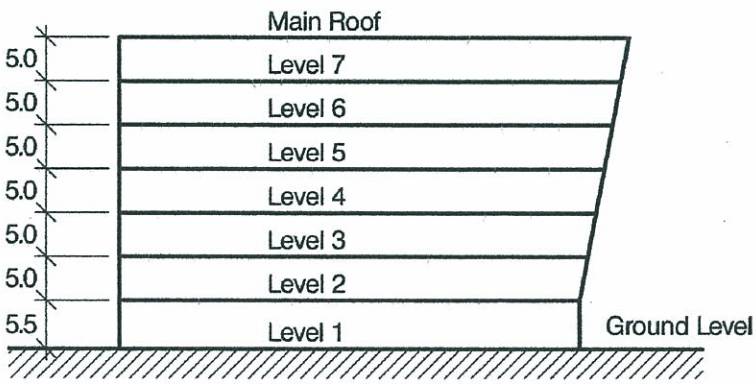
PLAN ON LEVELS 3 TO 7



VIEW LOOKING FROM A-A



PLAN ON MAIN ROOF



SECTION X-X

NOTE: All dimensions are in metres

FIGURE Q4

Fig. 01

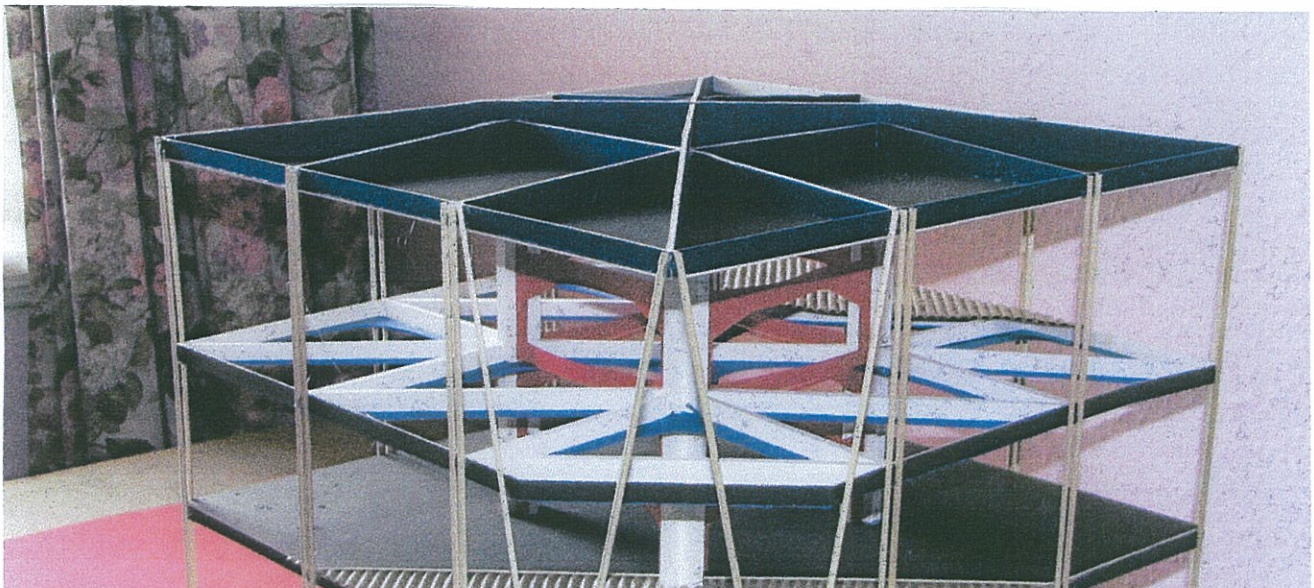


Fig. 02

RAW

Question 4 - Commercial Building: 2009 relates to a Seven-storey building on a square site. Figures 01 and 02 show two distinct and viable solutions, as required by Section 1a.

Figure 01 shows the basis of Option 'A', though it should be noted that several of the floor slabs have been left out of the model for simplicity. The basis of the option is the use of square, flat slab panels supported on columns. It is essentially a reinforced concrete solution.

Because the south-eastern corner façade is inclined and the floor slabs cut back progressively from the top floor [Level 7] to Level 2 there cannot be a corner column.

Client's requirement number 3 does not allow a column at the north-western corner of the building.

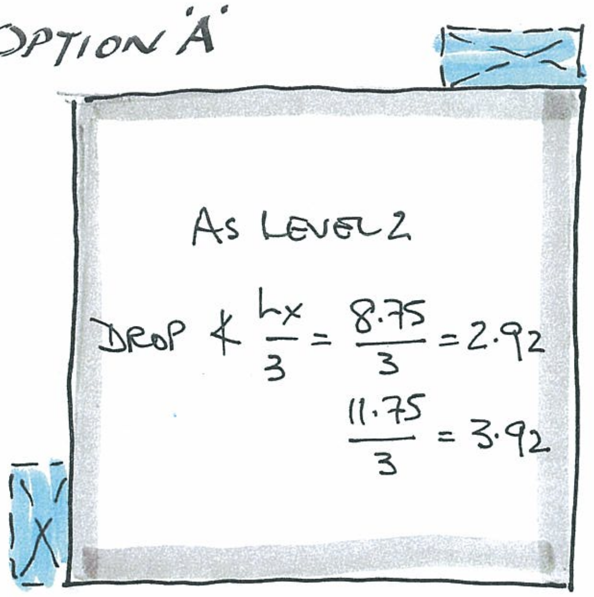
Consequently, this design has no column at any of the corners. Instead, the floor edges are supported by a tension tie, itself supported at roof level by an upstand edge beam. This beam cantilevers over the supporting column, and the structural framing has been featured (see Figure 01).

Figure 02 illustrates Option 'B' where a group of four columns forms a stifly-braced "core" up the middle of this building. A grid of steel girders at roof level supports hangers around the perimeter that, in turn, support the free ends of the local floor beam grid. Note that alternate floors have been omitted on the model for simplicity.

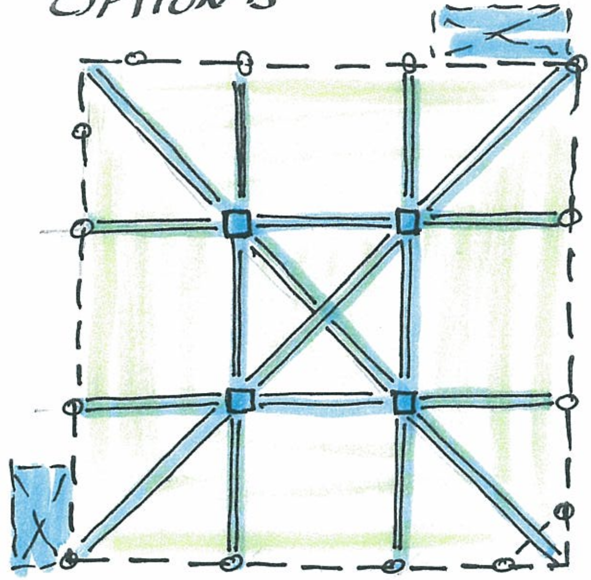
RAW

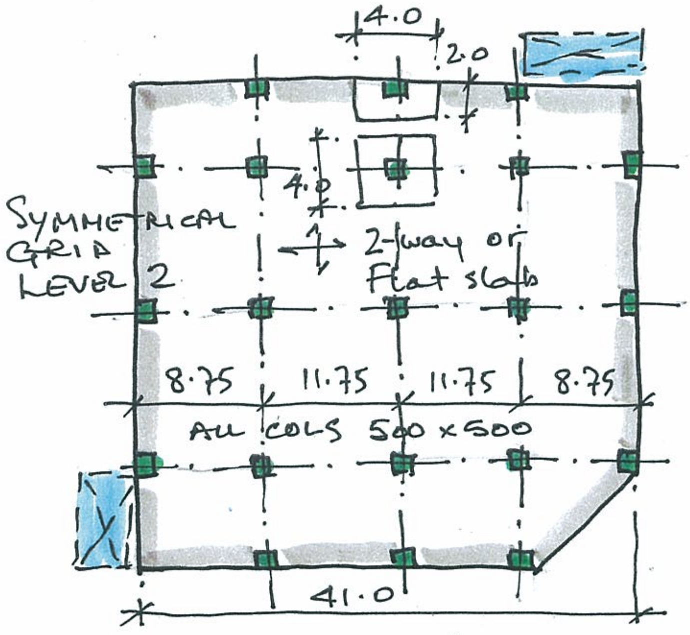
The Client's requirements numbers 3 and 4 dictate the grids:

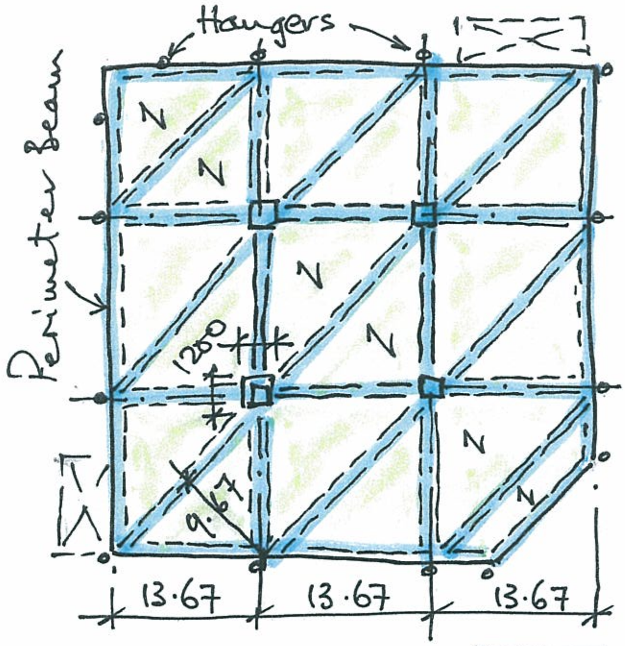
OPTION 'A'

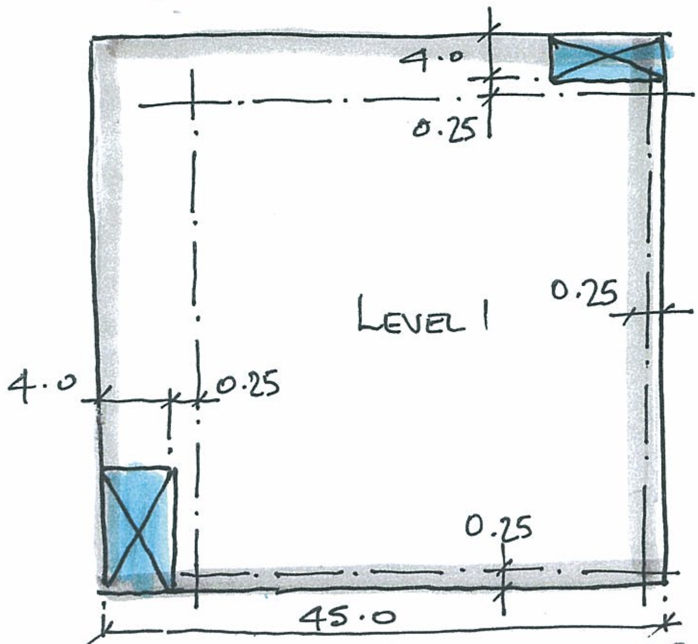


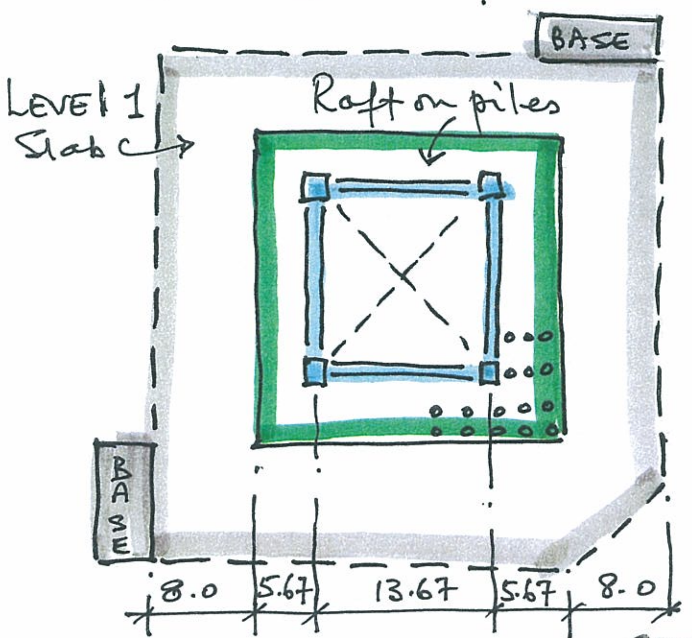
OPTION 'B'











RAW

One element of the "distinctness" emerges immediately — the slab spans are different. After that one thing leads to another...

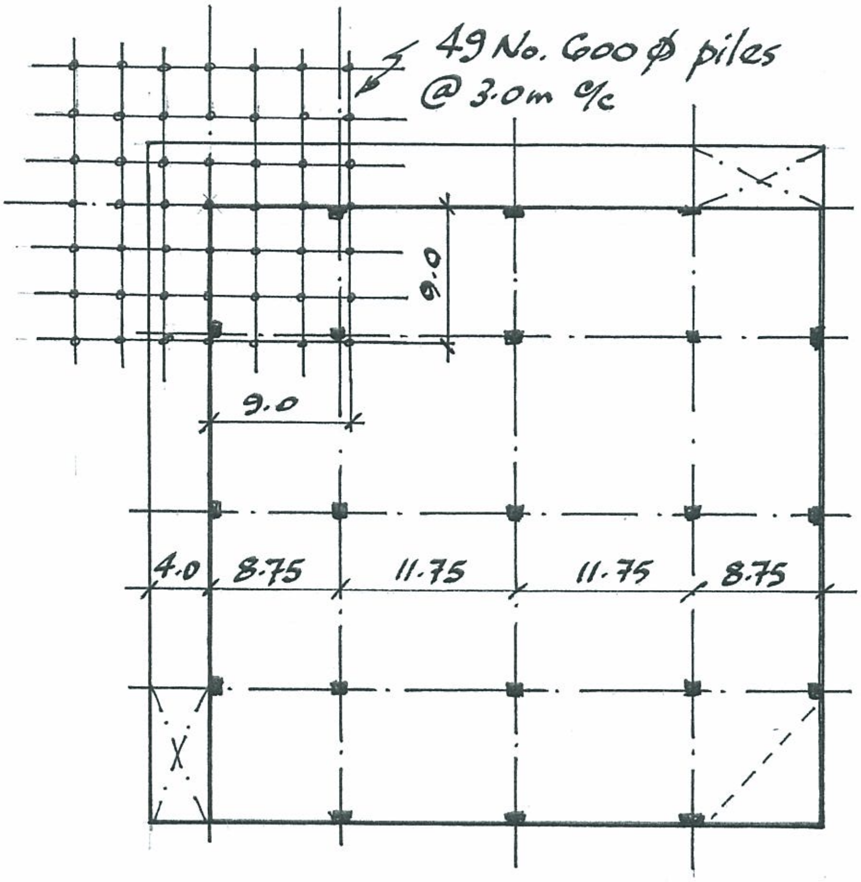
Option A can use 2-way or flat slab principles. The flat-slab choice would probably have drop panels to take the punching shear. These are indicated in Figure 01 at all seven floors and look strange when isolated! The columns are sized 500 x 500 so that the grid can be calculated. This size seems to be credible though no loads are known yet. The capacity can be adjusted using a suitable grade of concrete and varying amounts of rebar. Although redistribution of moments may be permitted the candidate probably won't have time to do the calculations and it is doubtful that there will be marks available for this sophistication. The "simple" method of calculation allowed in BS 8110 is appropriate because there are more than three bays in each direction.

Clearly this is a "moment frame" and stability is achieved by the stiff joints at each level. Consequently the columns need additional strength, above the axial capacity, to take moments. If the candidate decides to prepare calculations using "column charts" a reference needs to be given.

Section 2c - calculations should include reinforcement for a "typical" panel, an internal column and its foundation. It seems likely that individual pads on mass-concrete piers founded in the sandy gravel would carry the load. If possible the candidate should "reserve" piling for Option "B". The Level 1 slab would be "ground bearing" on compacted granular fill. The service cores might be able to stand on this slab without deeper foundations.

RAW

It is worth looking at Section 1b at this point:



"Before construction begins, a group of piles... are discovered. The centre of the group is located at the north-west corner of the site."

It is absolutely necessary for the Engineer to plot the pile positions relative to the proposed building - in this case Option 'A'. Although I tried to draw this plan "freehand in good proportion", in the end it was quicker to draw the plan to scale [above]. The group of piles only affects 3 columns because no column is allowed at this corner [Client's requirement number 3].

One must assume that the piles go down 8.0m to rock and that none of the piles are compromised in any way ["necking", "void at the base", "lack of compaction", etc.]

RAW

With this assumption it should be possible to substitute piles for two or even all three mass concrete piers under these column positions.

However, the relevant piles would need to be investigated in order to confirm that they are suitable, and the three column bases would need to be tied together with ground beams to eliminate the effects of eccentricity – the loads do not coincide with the axes of the piles. Whether there would be any cost benefit is doubtful. The programme might be affected – lengthened – too.

The contractor may prefer to excavate and "clear" the affected areas under the columns and proceed with the planned foundations.

In any event the 25 piles located under the ground floor [Level 1] slab would all need to be cut down into, say, the sandy gravel and backfilled with the rest of the site [removal of the existing loose fill, or its compaction] with selected granular material compacted in layers. The quality of the "Loose Fill" is unknown and may be contaminated with plaster [gypsum attacks concrete] and/or timber, etc.

All things considered, it is unlikely that the pile group can be beneficially used. However, it is a warning because if previous foundations needed piling perhaps the use of piling should be considered for the new works.

GROUND PROFILE

RAW

Section 1a always includes "the foundations" in the text specifically to remind the candidate of the need to spend time on them. The foundations for Option 'A' can be expected to be different from those for Option 'B'! It can be a bad mistake to "save time" by making them the same.

The ground profile shown on page 06 has a ground water level at -2.5m, only 0.5m below the nominal top of the sandy gravel. The average 'N' value is 15 – indicating a possible bearing capacity of 150 kN/m², but the high GWL will halve this value to 75 kN/m². It will be more efficient to found on the weathered rock at 500 kN/m² or even the rock at 1500 kN/m² – the problem will be to excavate through the waterlogged sandy gravel.

An approximate column load will indicate the pad area that will be necessary - but do not expect many marks for this work since Section 2c is where these are available for calculations. If you feel unsure about specifying foundations without an estimate of load the following might be done:

Imposed load per floor — 5.0 kN/m²
Permanent load per floor (say) — 12.0 kN/m²
$(11.75/_{24} \times 24)$

$$17.0 \text{ kN/m}^2 \times 12 \times 12$$
$$= 2448 \times 7 \text{ levels incl. roof}$$
$$= 17136 \text{ kN [unfactored]}$$

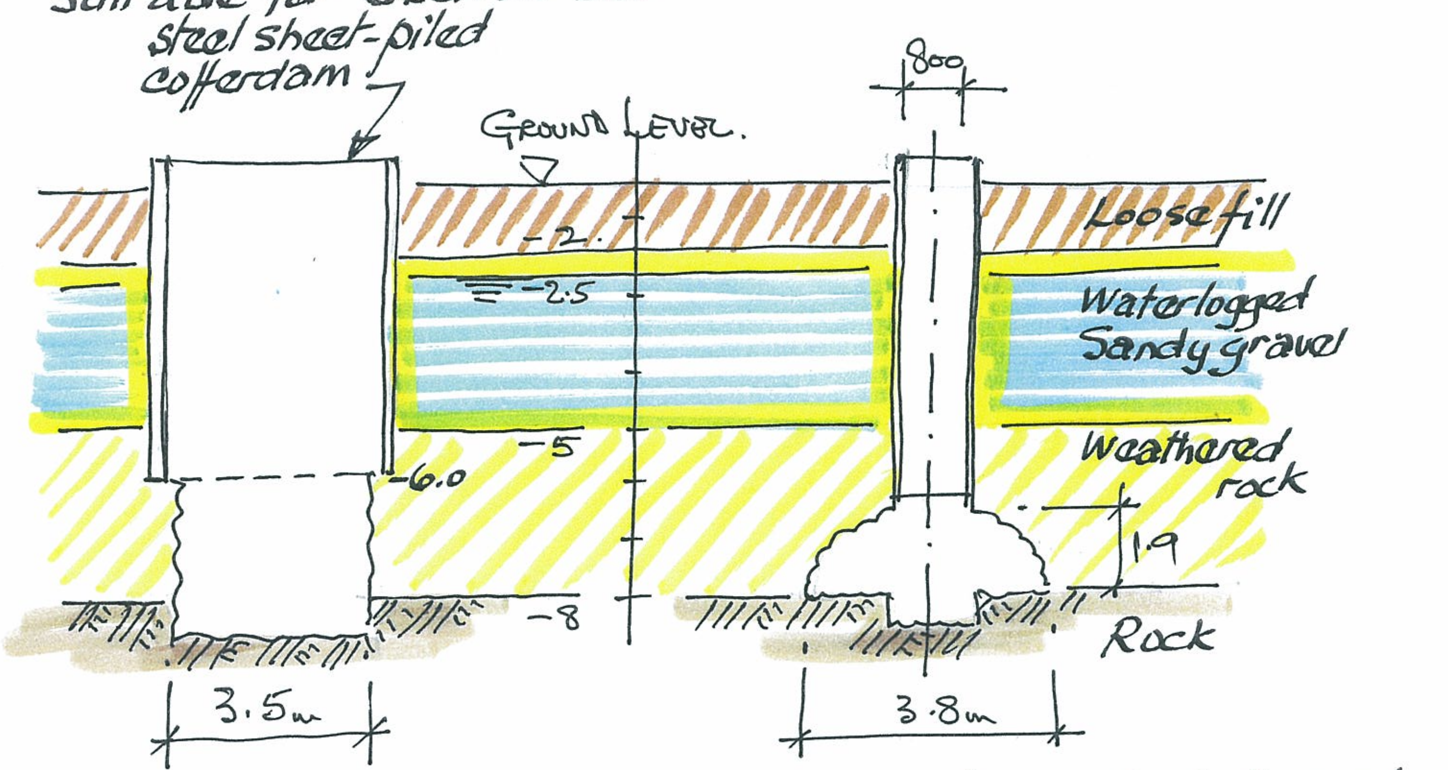
$$\text{Area} \simeq \frac{17136}{500} = 34\text{m}^2$$

$$\text{or } \frac{17136}{1500} = 11.5\text{m}^2$$

"Site conditions" number 10 quotes "allowable" bearing pressure

RAW

A square pad 6m × 6m provides 36m² but the pads would touch [column spacing only 11.75m].
A square pad 3.5 × 3.5m provides 12.25m² and is credible.
A 3.8m diameter "base" provides 11.34m² but is too big for a single caisson pile [realistic diameters range between 600mm dia and 2400mm dia, although the largest machines can dig pile shafts up to 4.57m diameter – ref. Tomlinson "Foundation design and construction", 7th Edition, I.S.B.N-13: 978-0-13-031180-1; probably one of the books you will consider taking into the examination with you!]
"Belling buckets normally cut base diameters up to 3700mm, although diameters of as much as 7300m are possible..."
so the 3.8m diameter is credible using an 800mm diameter shaft under-reamed or belled out in the weathered rock which is 3.0m nominal thickness. Water would be controlled by using casing and/or bentonite. The following would be suitable for Section 2e.

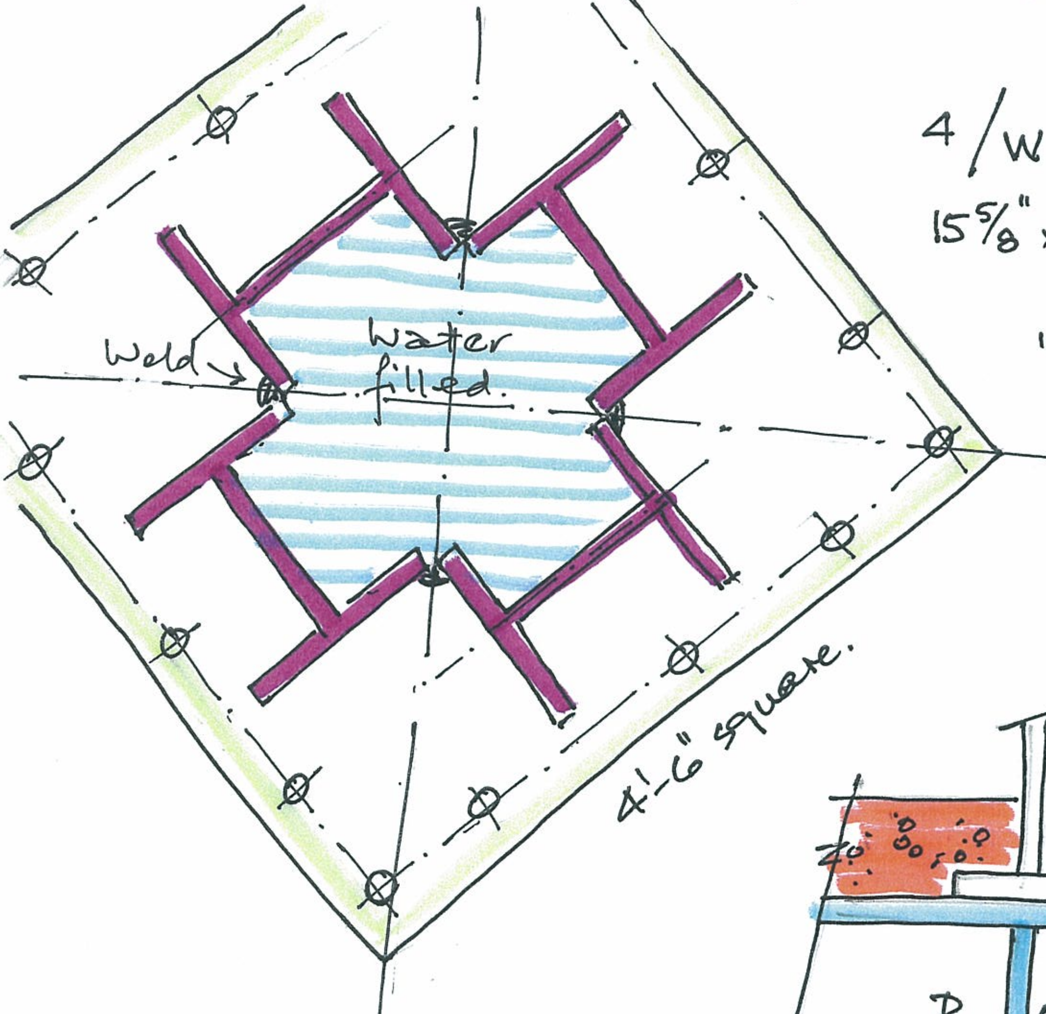


Steel sheet piling driven into weathered rock surface. Soil excavated from G.L. by backacter. Concrete placed by pump or tremie if flooded. No man entry.

800mm dia. bored pile shaft cased through waterlogged sandy gravel. Under-ream or Bell formed at rock level into weathered rock. Shaft will probably flood. Ready mixed concrete placed by tremie. No man entry.

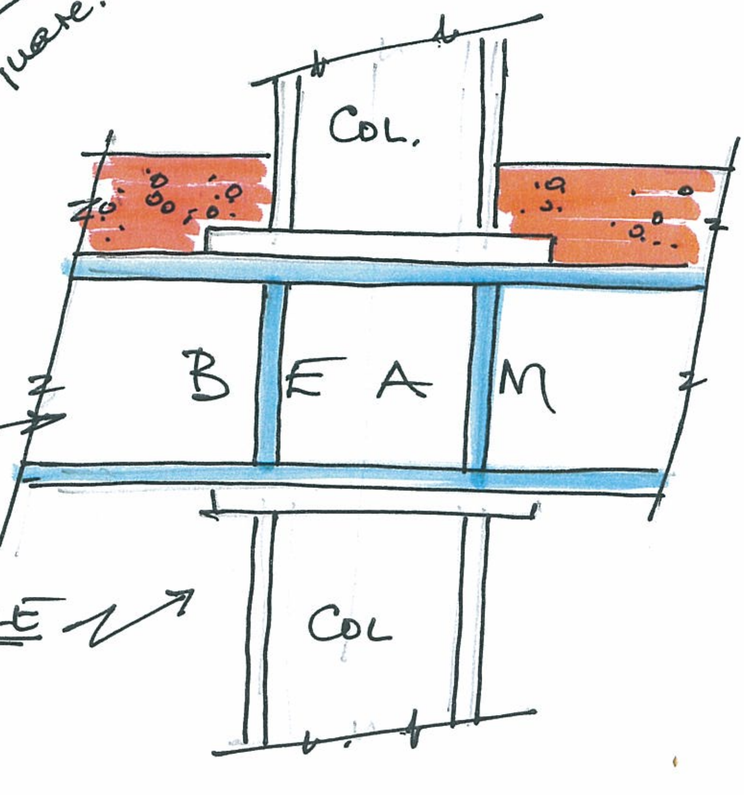
RAW

Option 'B' is essentially a compression "core" with a massive cross-shaped roof suspension system from which the floor edges are hung. The floor slabs span in a diagonal direction [see page 03] onto diagonal secondary beams. This reduces the potential span from 13.67m to 9.67m or less. The whole frame uses structural steel with profiled steel decking topped with concrete. The dominant central "core" comprises four fabricated stanchions made up from Universal column sections welded together. The hollow-section stanchion will be protected from fire by being filled with water [with full header expansion system].



4 / W14 × 202#
15 5/8" × 15 3/4" UC. 202#

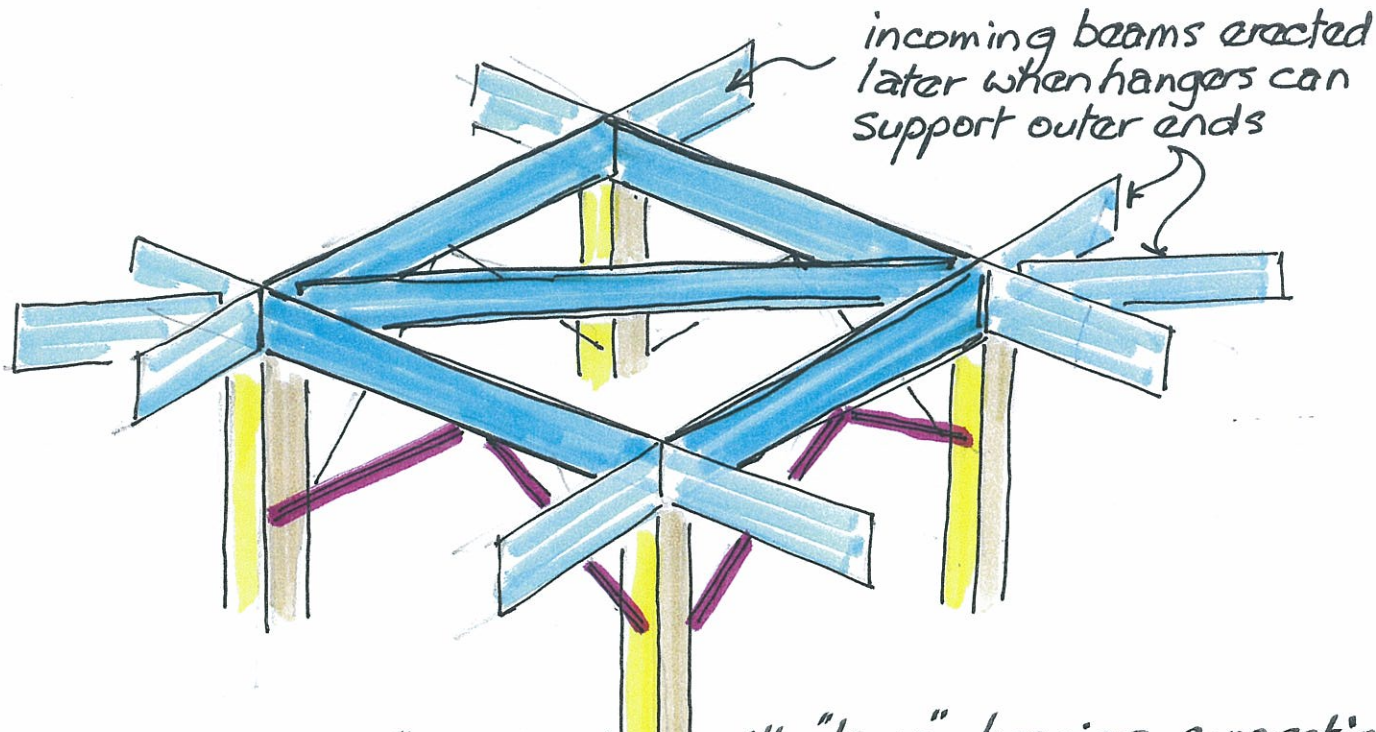
"Pinned both ends"
i.e. axial loading!



BEAMS RUN THOUGH COLUMN SPACE IN ORDER TO BENEFIT FROM CONTINUITY.

PRINCIPLE ONLY

RAW



Each "portal" is braced with "knee" bracing connecting the stanchion to the beam grid. Thus, the erection proceeds up the core from floor to floor.
The beam sizes can be sized at this stage by "guesstimation" or later in Section 2c by more precise calculation. However, it is more important at this stage to communicate the "conceptual ideas" rather than the details.
Consequently, I shall move onto the roof suspension system:

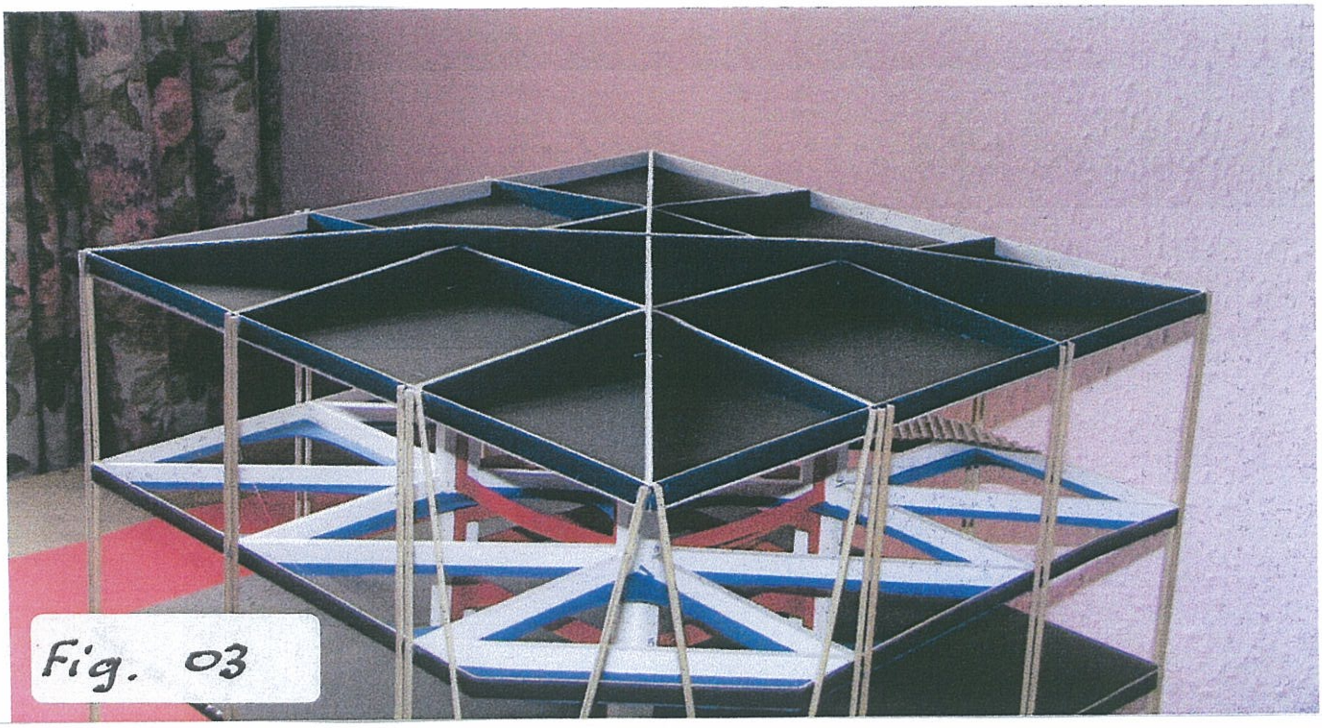
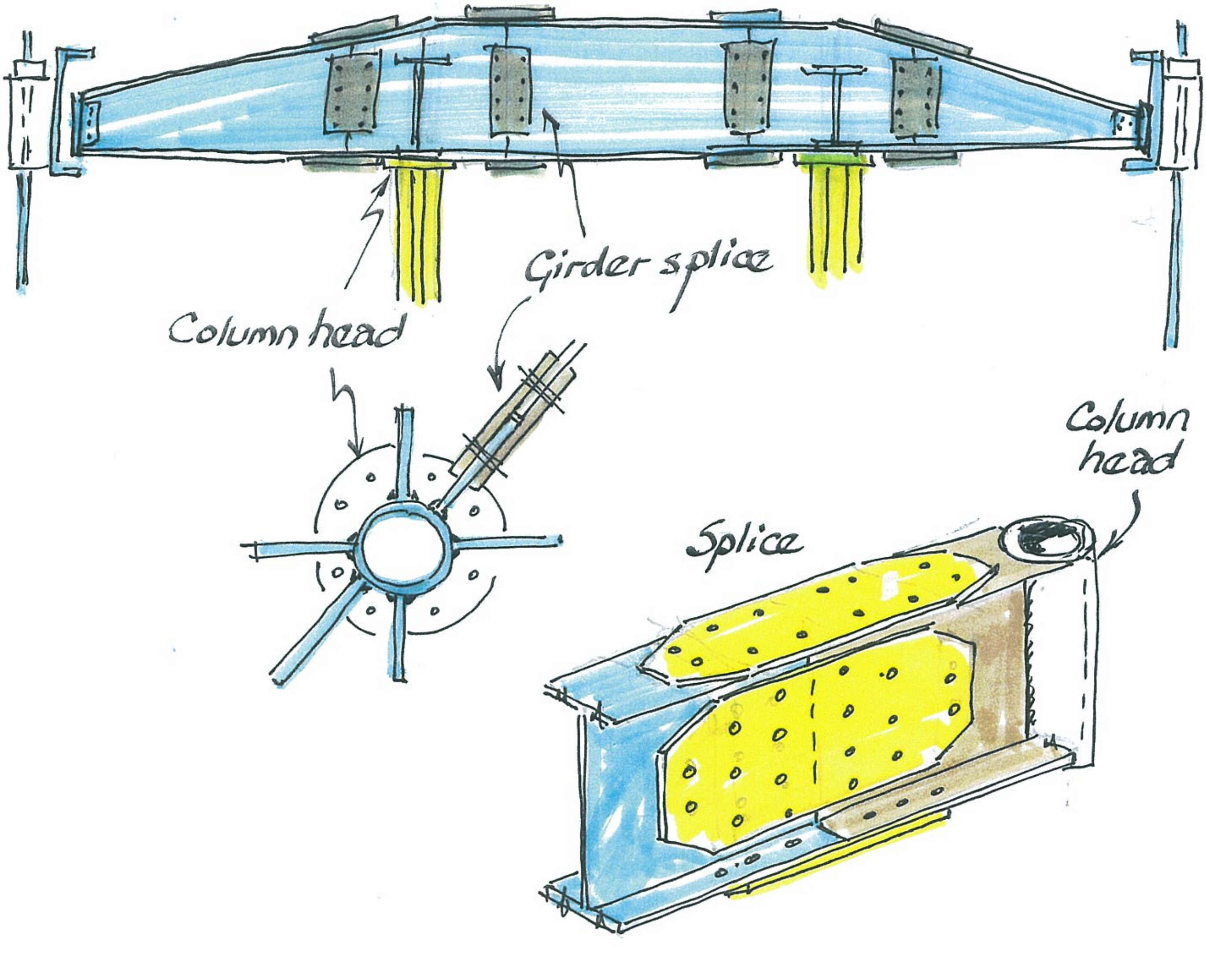
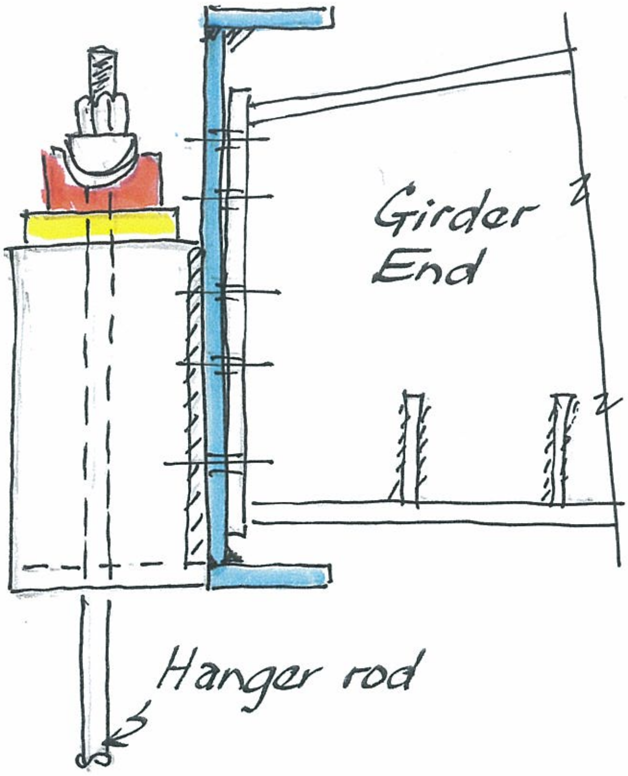


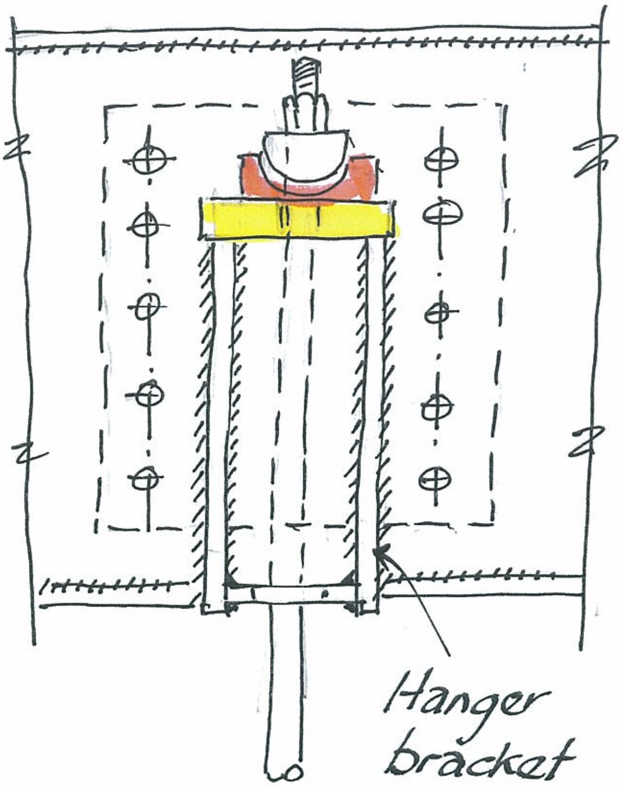
Fig. 03

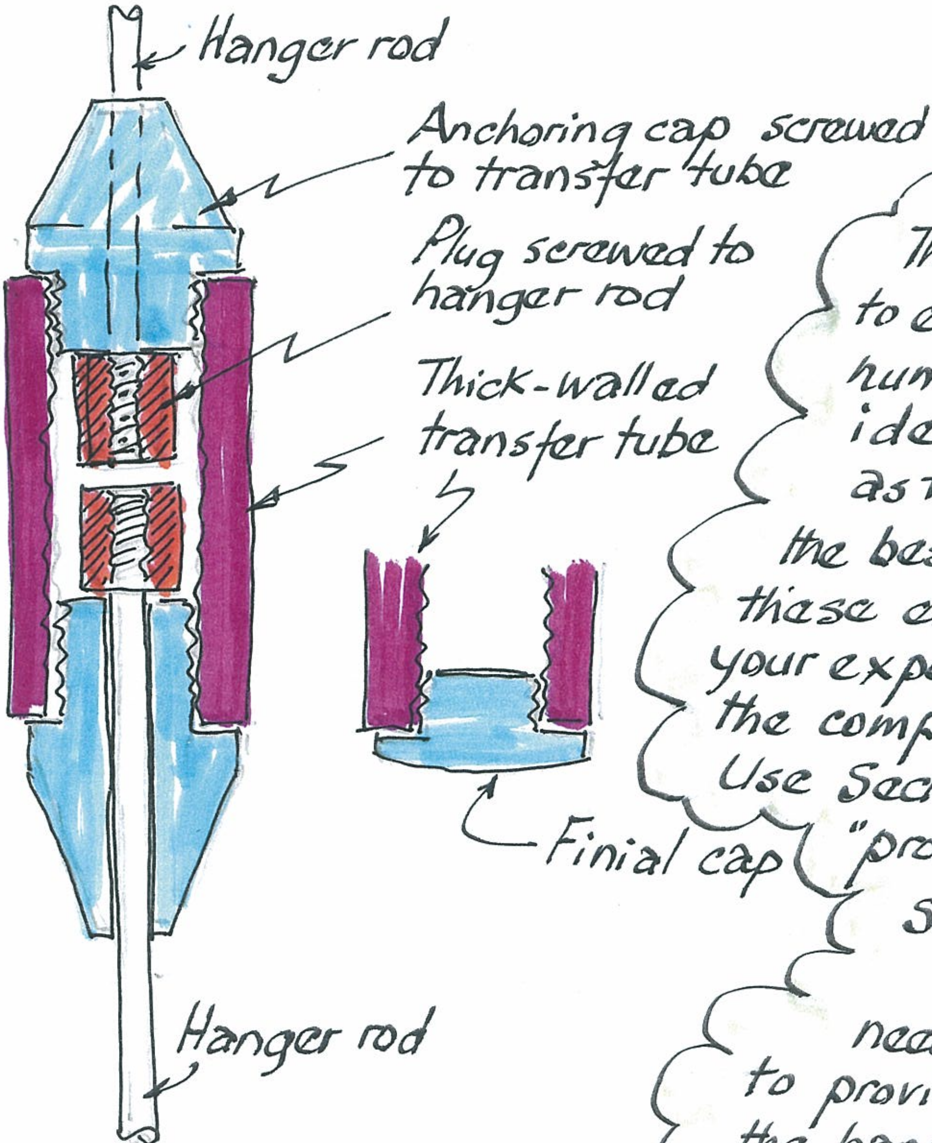
There are two intertwined suspension systems – the first supports the four corners and runs diagonally – the second supports the intermediate hangers along the sides and is on the regular grid. Around the edge there is an upstand girder. The hangers are attached to the upstand. The hangers are twinned in order to provide a "fail-safe" mechanism – one hanger can fail completely in each pair without causing catastrophic failure. the hangers at the south-eastern corner splay apart in order to pick-up the edges of the curtailed slabs below.
The intersections of the girders occur above the column heads. Each girder needs to be transported and assembled so the girders must be fabricated in sections. Splices can be located at the intersections.



RAW





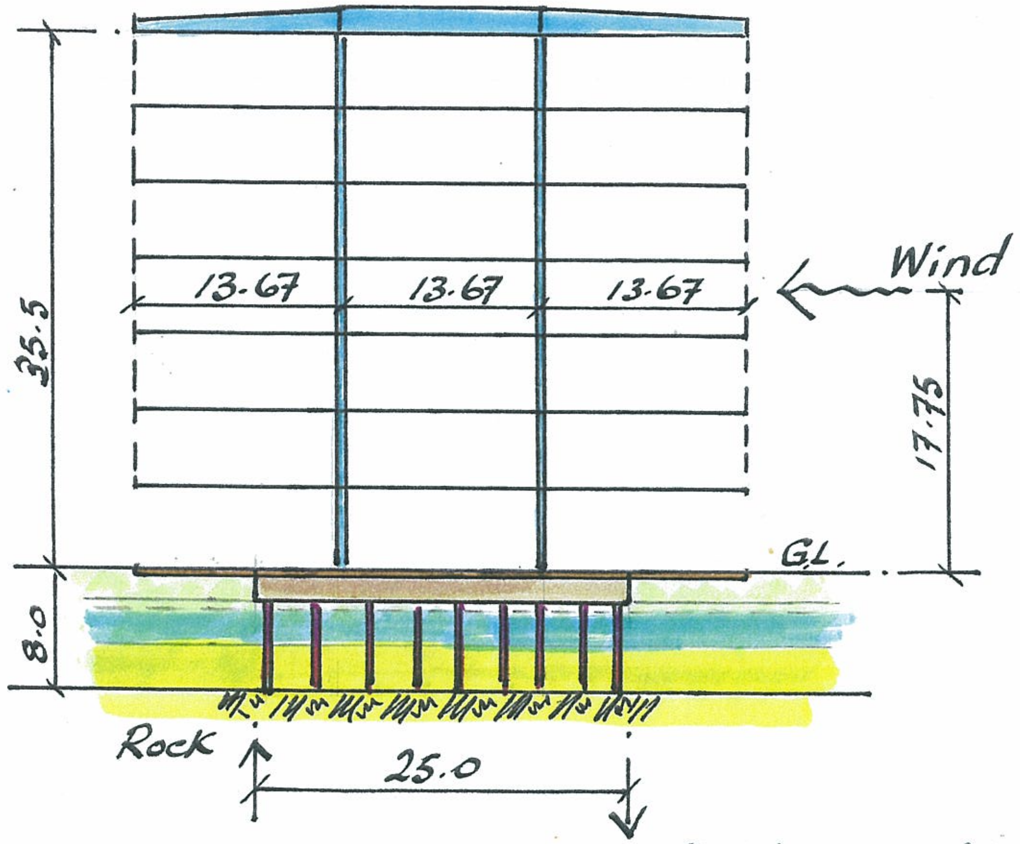


This Option needs to explain quite a number of conceptual ideas. Sketches such as these are probably the best way to make these explanations. Use your experience to draw the components in proportion. Use Section 2c for the "proof" calculations.

Several of the Conceptual Ideas need a "proof" calc. to provide a size, e.g. the hanger rods.

RAW

With reference to the Level 1 slab plan on page 03, the core will be supported on a piled raft, with the piles carrying the concentrated load directly to the bedrock stratum. This foundation must be stable under direct loads and overturning conditions



Let wind pressure = $1.2\ kN/m^2$ [$\equiv 1.0 \times 1.2$ factor]

Wind Moment = $(1.2 \times 35.5 \times 41) \times 17.75 = 31010\ kNm$

Gravity load (see page 07) = $7 \times 41.0 \times 41.0 \times 17.0\ kN/m^2 = 200\,000\ kN$

Pressure on bedrock = $\dfrac{W}{A} \pm \dfrac{M}{Z} = \dfrac{200000}{25.0 \times 25.0} \pm \dfrac{31010}{25.0^3} \times 6$

$\dfrac{bd^2}{6}$

$= 320\ kN/m^2 \pm 12\ kN/m^2$

$= +332\ kN/m^2 < 500\ kN/m^2$

or or

$+308\ kN/m^2$ $1500\ kN/m^2$

There is no uplift.

The four column loads [approx 50 000 kN each] will need to be dispersed through the raft-type pile cap – provisionally shown as 2.0 m thick.

RAW

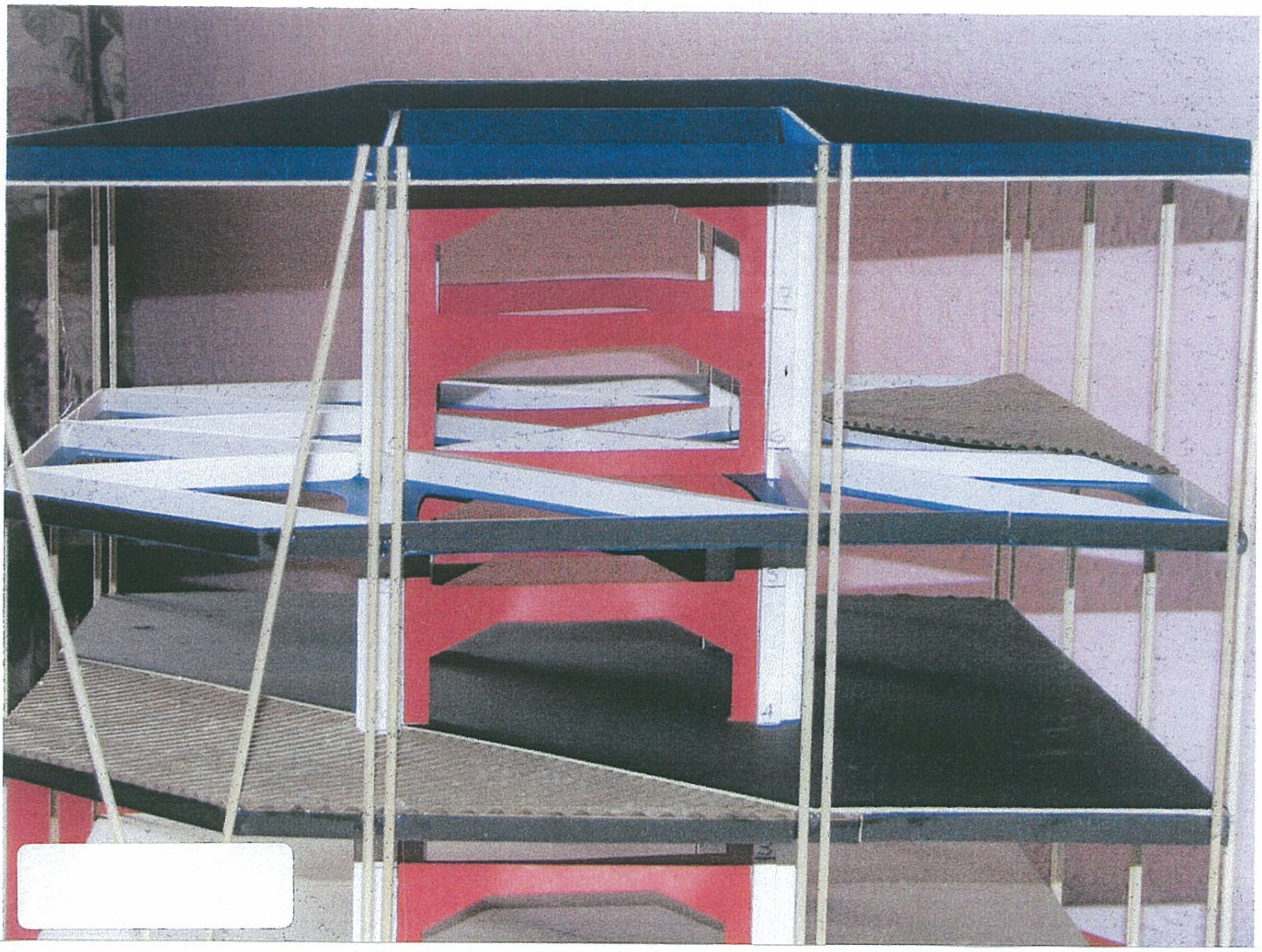
If this option is chosen for the final proposal then Section 2c will contain a number of important calculations. Check back to the question: "Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations."
Any design calculations already done in Section 1'a' and 'b' will have been marked and cannot be marked again in Section 2c! It is important that the design calculations cover new ground and develop the proposal in a positive way. It is unlikely that calculations for the composite "tin deck" will add anything to an answer obtained using manufacturer's data. On the other hand the roof girders, main stanchions and hanger rods are unique to this option and need to be "sufficiently" calculated – not in the minutest detail!
The foundations use a raft and piles – "sufficient" calculations are needed for both.
Again, when it comes to Section 2d any details already marked under Section 1a cannot be marked again unless significantly developed, e.g. by being drawn to scale and dimensioned so that the Q.S. can use them for estimating purposes. Effort should be concentrated on the G.A. drawing for the roof and typical floor, and the foundations. A cross section through the building and details of typical cladding and weatherproofing are needed.

Section 2e requires a detailed method statement and an outline construction programme. There are only 10 marks, indicating about 40 minutes work. It is probable that the examiner has provisionally allocated the marks in the proportion 6:4; "provisionally" in the sense that good work will be rewarded even if time appears to have run out and the programme is unfinished.

RAW

The Engineers Method Statement highlights the construction actinties that might influence the estimate of costs. In Option "A", a concrete construction, once the foundations have been finished (see page 08) the columns and slabs will follow conventional reinforced concrete practice of setting-up falsework, laying the slab formwork, assembling the reinforcement and placing and curing the concrete. The concrete will probably be supplied by a ready mix supplyer and pumped up to the working level. The self-compacting mix will need little spreading but will need to be "struck-off" to a level surface using a vibrating screed or "Bunyan striker" (a roller-type screed). The surface needs to be kept moist (not allowed to dry out) and power trowelled to produce the right finish. After the final finish the concrete will need to "cure". If work is to proceed the fresh surface will need to be protected before the next lift of falsework is erected. Proprietary systems like "quickstrike" allows the formwork panels to

RAW



be struck without disturbing the propping action of the falsework.
In Option 'B' the constuction of the piles and pile-cap raft should be described, but the main effort dedicated to how the structural steelwork must be erected. The various levels of the core are assembled using a large crane. The roof girders will be delivered in sections, lifted and bolted together. Some "out of balance" effects may develop and need to be considered. Once the main roof-level supports are in place the hanger rods can be hung and the first level of floor girders lifted into place - this will be Level 2. The member to be lifted is rolled into place on Level 1, the crane lowers its hook through the roof-level steelwork to raise the new beam: this will need to be pulled sideways into place. No floor decking can be laid until all the floor beams have been assembled from Level 2 to Level 7. The concrete topping would be supplied ready mixed and pumped into place. The decking will act as permanent formwork.

RAW