Possible solution to past CM examination question

Question 1 April/September 2007

Library and Exhibition Centre

by Dr Peter Gardner

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

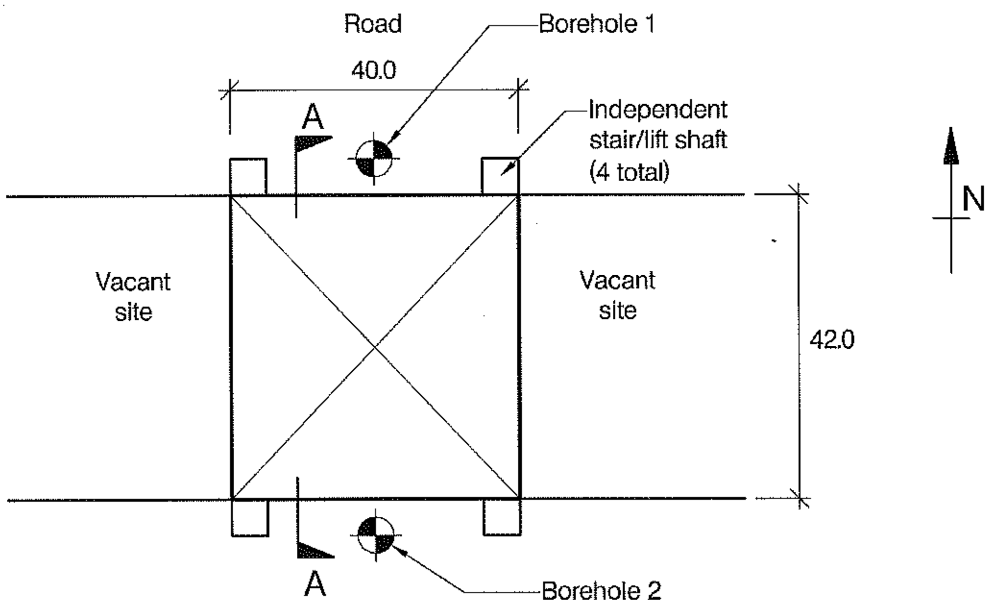
(50 marks)

For the solution recommended in Section 1(a):

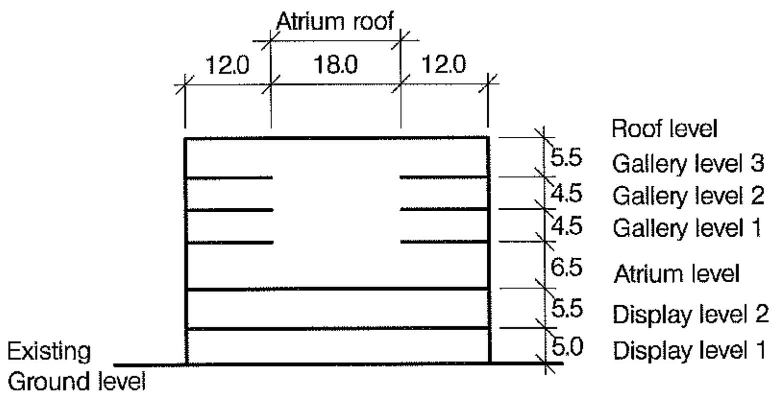
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

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)

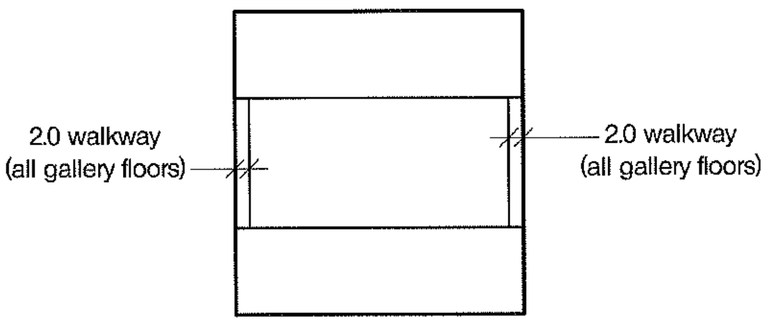
e. Prepare a detailed method statement for the safe construction of the structure and an outline construction programme. (10 marks)



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).

<u>The stability system</u>

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.

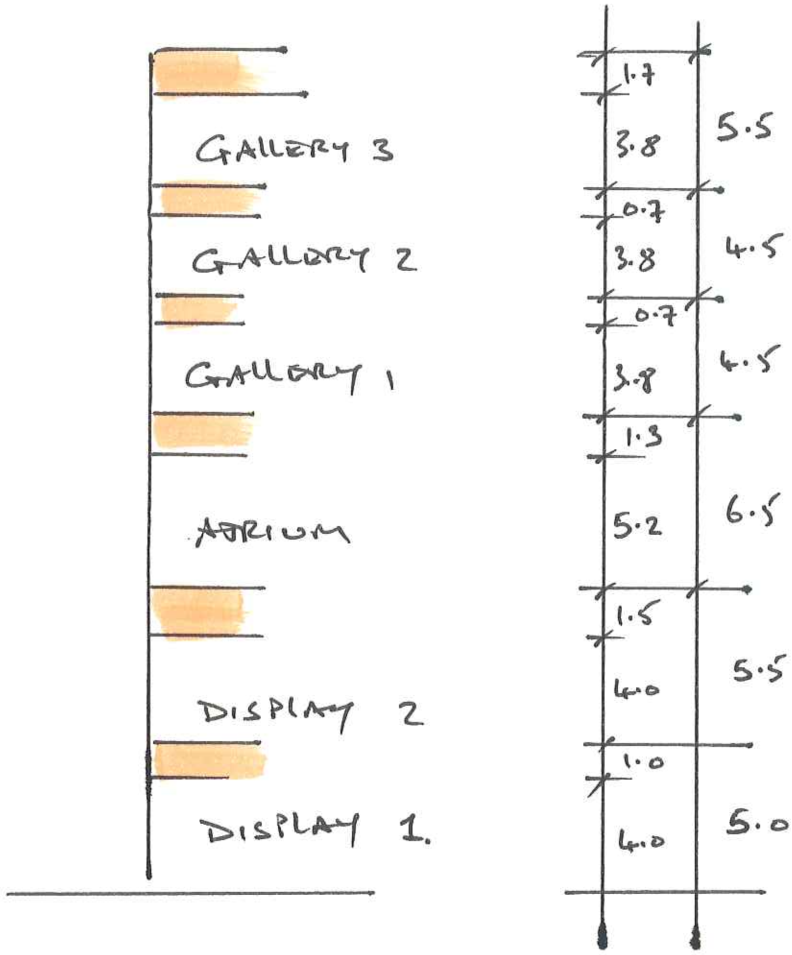
The letter.

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.

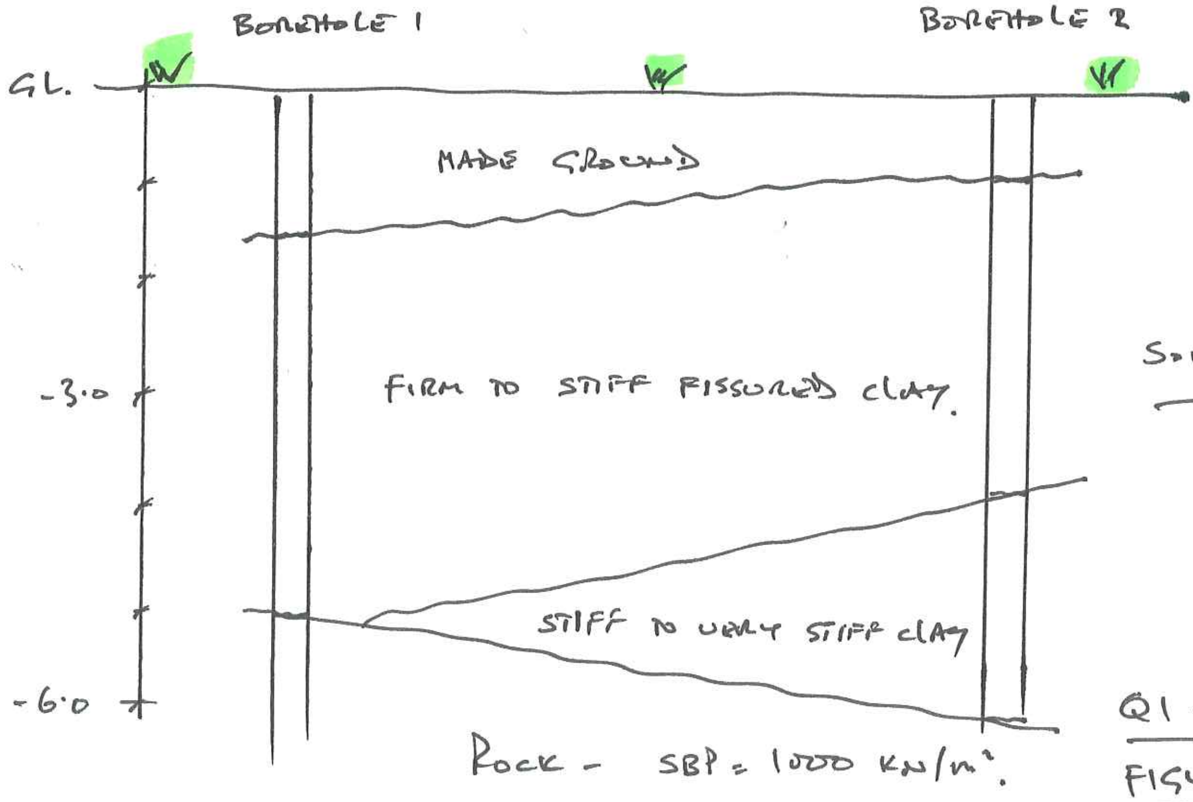
Summary.

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).

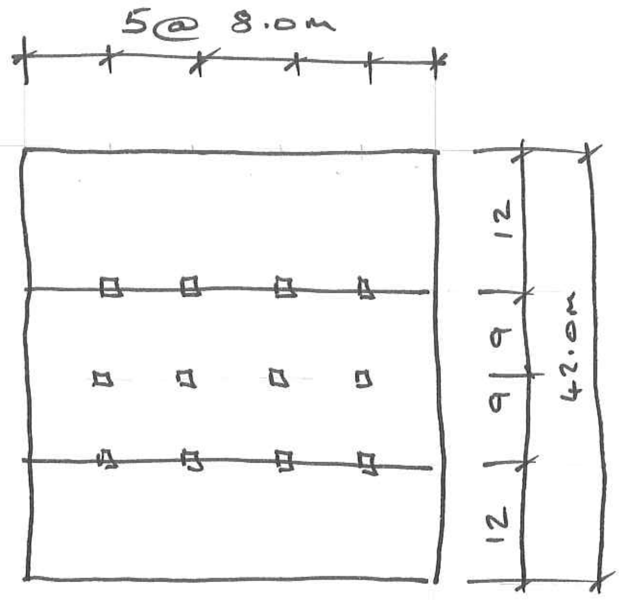
p.s. Many of the candidates who attempted this question did not take advantage of the obvious variation in columns spacings, for instance some adopted four columns running throughout the building for both schemes, depriving themselves of the obvious variation. To make matters worse some of these candidates 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).



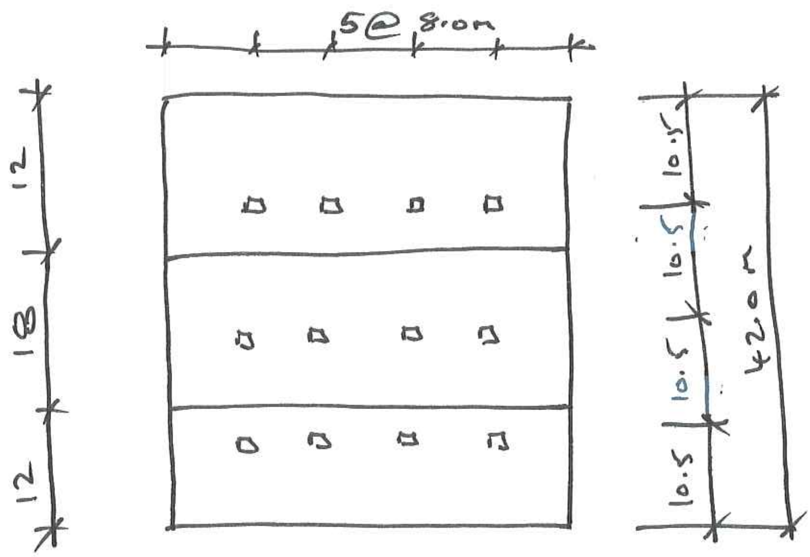
FLOOR HEIGHTS



SOIL PROFILE



OPTION 1



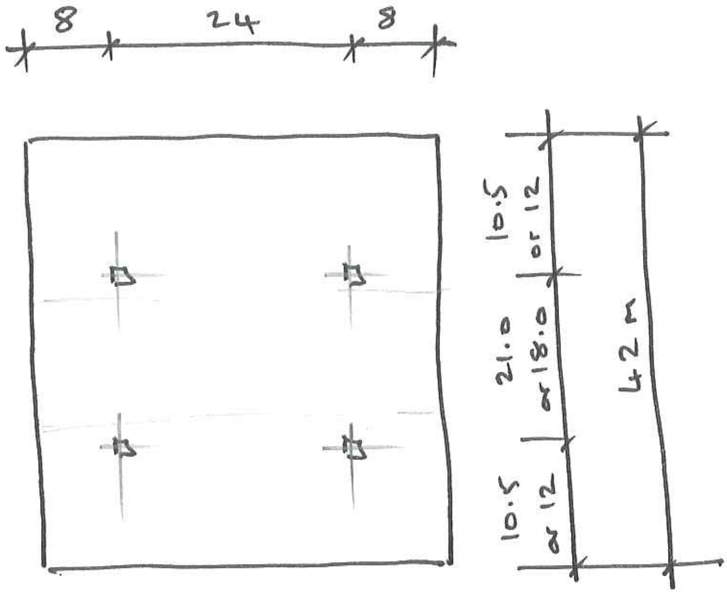
OPTION 2

COLUMN LAYOUT - DISPLAY LEVEL.

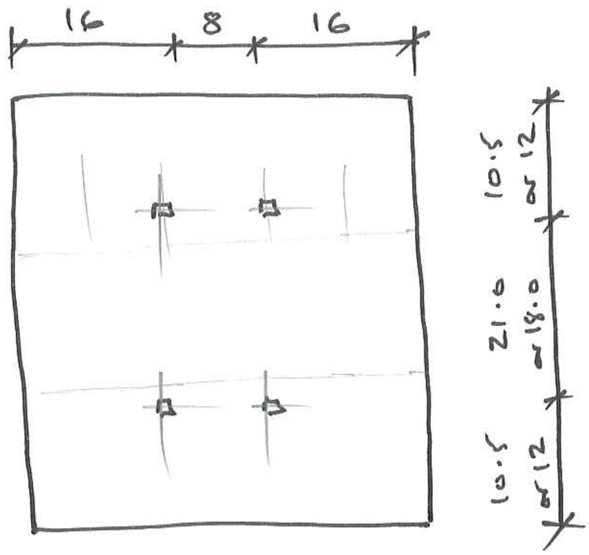
PLAN.

FIGURE 2

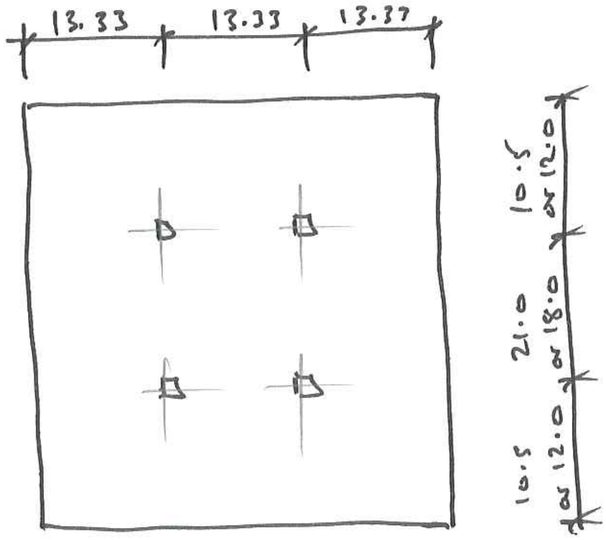
OPTION 1



OPTION 2



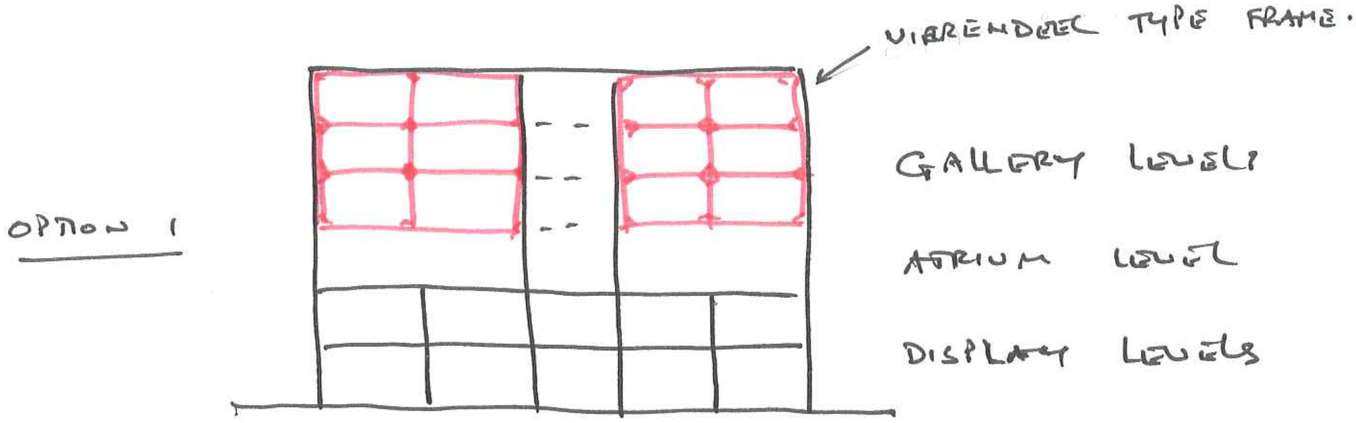
OPTION 3

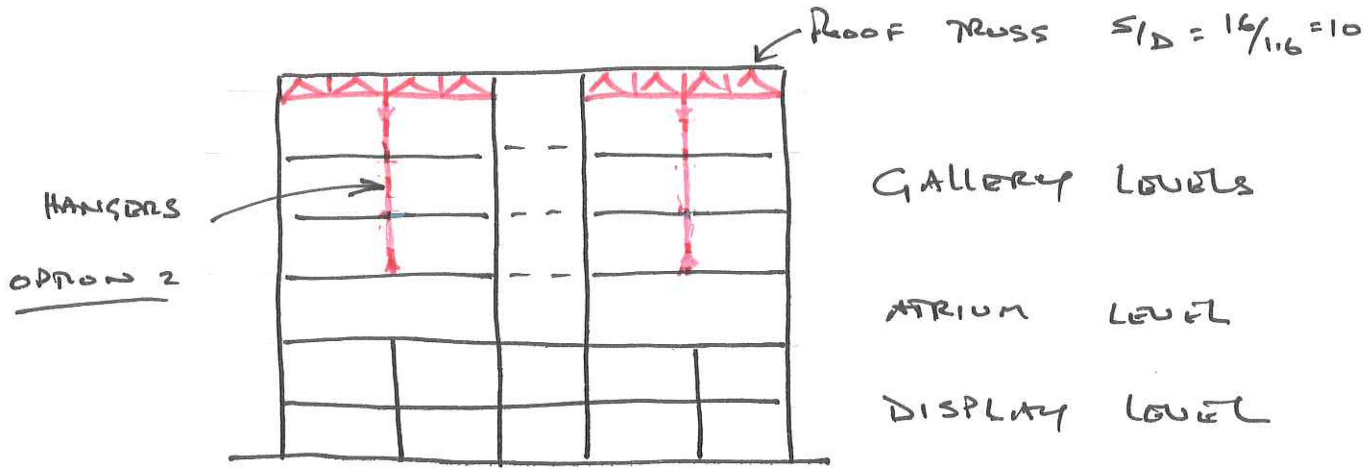


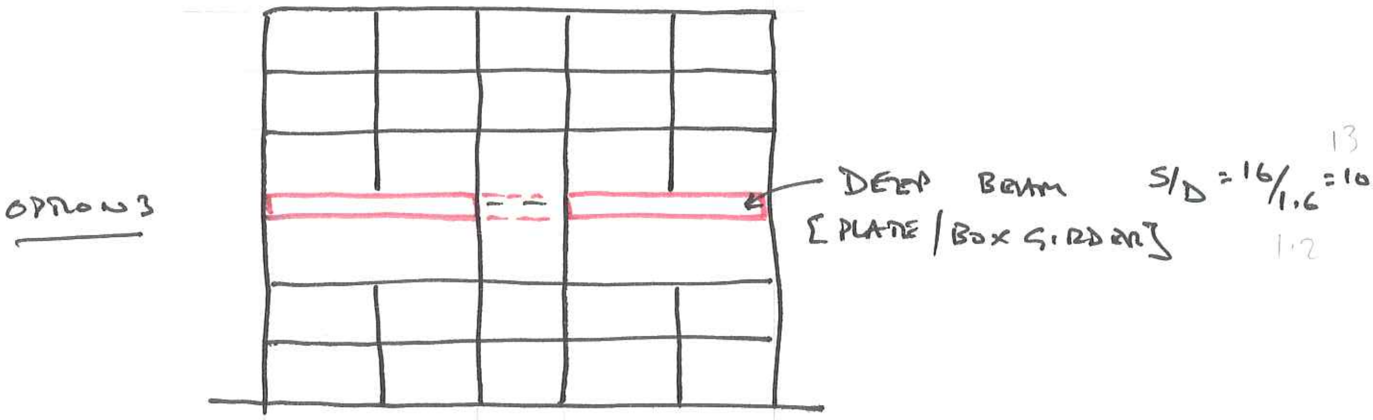
COLUMN LAYOUT - ATRIUM LEVEL

PLAN.

FIGURE 3

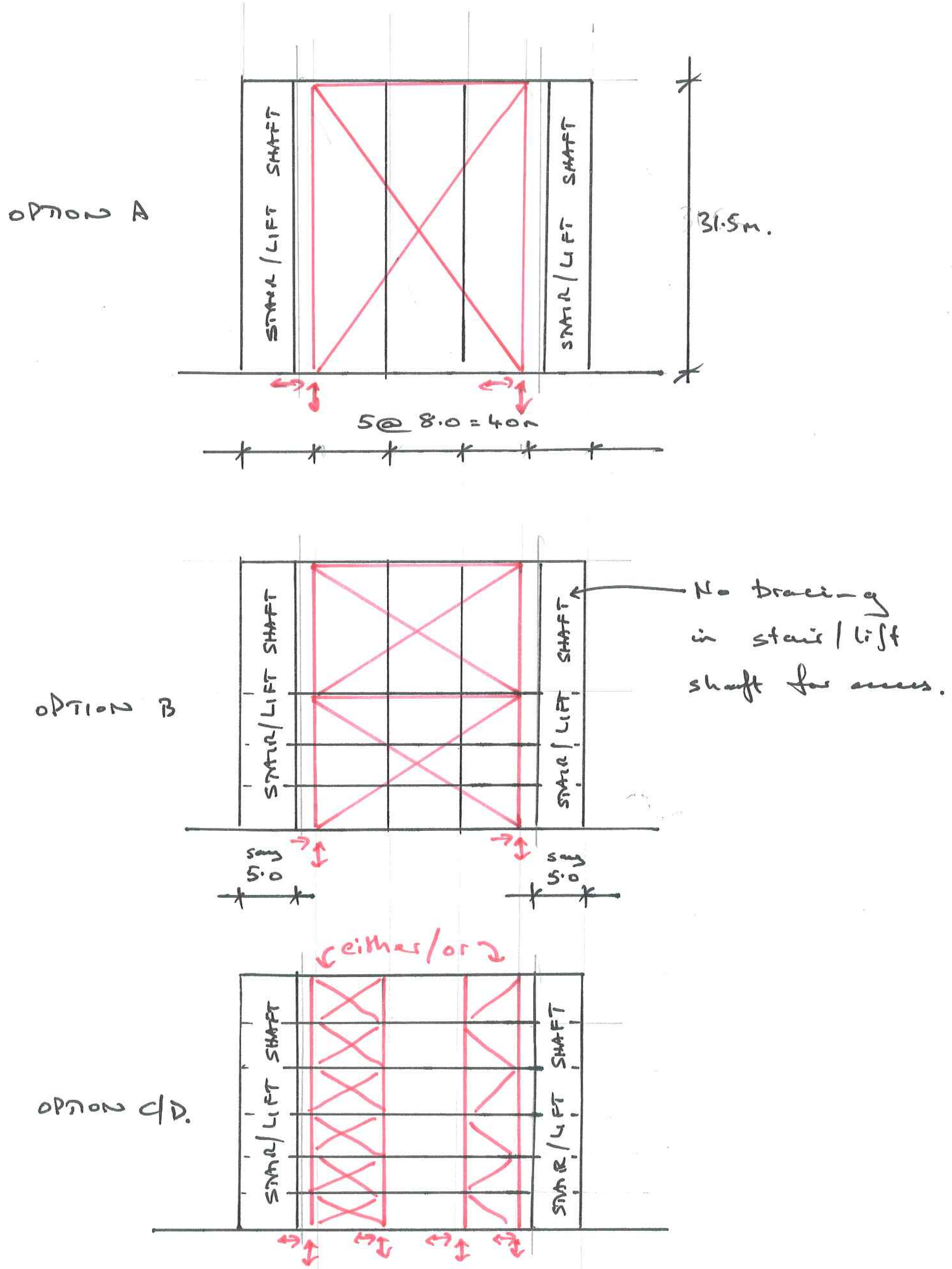






TRANSFER OPTIONS TO SUPPORT GALLERY FLOORS

FIGURE 4



LATERAL STABILITY NORTH & SOUTH ELEVATIONS.

FIGURE 5

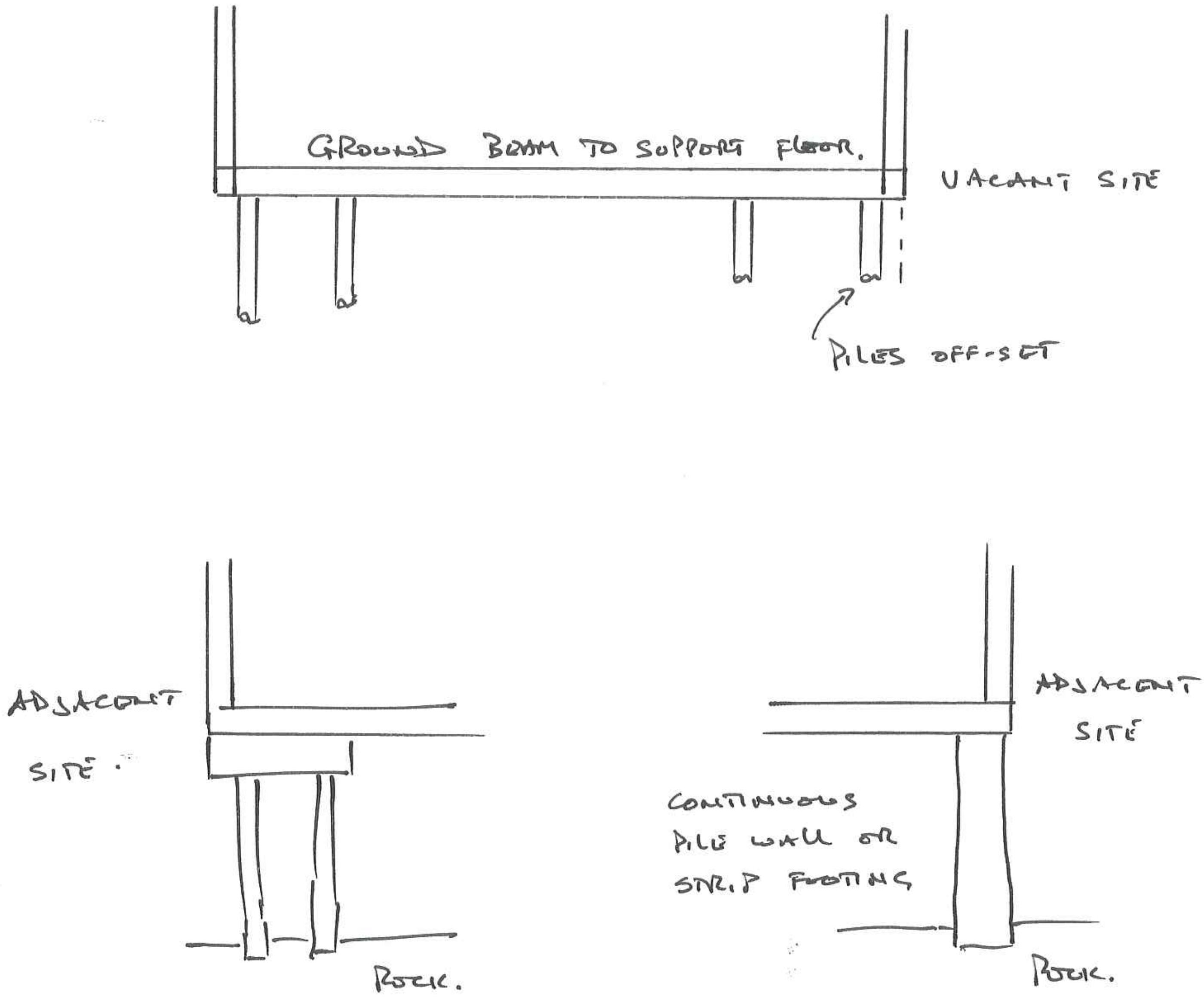

GROUND BEAM TO SUPPORT FLOOR.
VACANT SITE
PILES OFF-SET
ADJACENT SITE.
ADJACENT SITE
CONTINUOUS PILE WALL OR STRIP FOOTING
ROCK.
ROCK.

FIGURE 6. of 6

Possible solution to past CM examination question

Question 3 - April 2007

Opening Access Bridge

by Kirsten Morris

Question 3. Access Bridge with opening span

Client's requirements

1. A bridge carrying two 4.0m-wide traffic lanes and a 2.0m-wide footpath over a canal to provide access to a new waterside development: see Figure Q3.
2. The minimum headroom required above water level is 4.5m when the bridge is closed and 15.0m when the bridge is open.
3. The minimum clear channel width required is 10.0m. The water depth in the clear channel is 3.0m. The clear channel must not be closer than 5.0m to either bank.
4. There are no restrictions to the overall size or height of the bridge in either the open or closed positions.
5. The minimum headroom required for road vehicles is 5.7m
6. Approach ramps should be kept to a minimum height with a maximum gradient of 1:12.

Imposed Loading

7. Vertical traffic loading 10.0 kN/m^2
   Footpath loading 5.0 kN/m^2

Site Conditions

8. The site is located in a marine environment adjacent to a seaside town. Basic wind speed is 46m/s based on a 3-second gust; the equivalent mean hourly wind speed is 23m/s.
9. Ground Conditions:

East side	Existing ground level to 0.2 m depth	Made Ground
	0.2 m to 10.0 m	Limestone, allowable safe bearing pressure 1000kN/m^2
West side	Borehole No. 1	
	0.0 to 2.0m	Topsoil
	2.0m – 30.0m	Loose Sand and Gravel, N=5 to 10
	30.0m	Limestone

Groundwater was encountered at 2.0m below ground level.

Omit from consideration

10. Detailed consideration of the mechanical means of opening and closing the bridge.
    Accidental impact on bridge and supports.

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. The client has asked you to consider increasing the headroom above water level to 6.0m when the bridge is closed. Write a letter to your client explaining how this could be achieved. (10 marks)

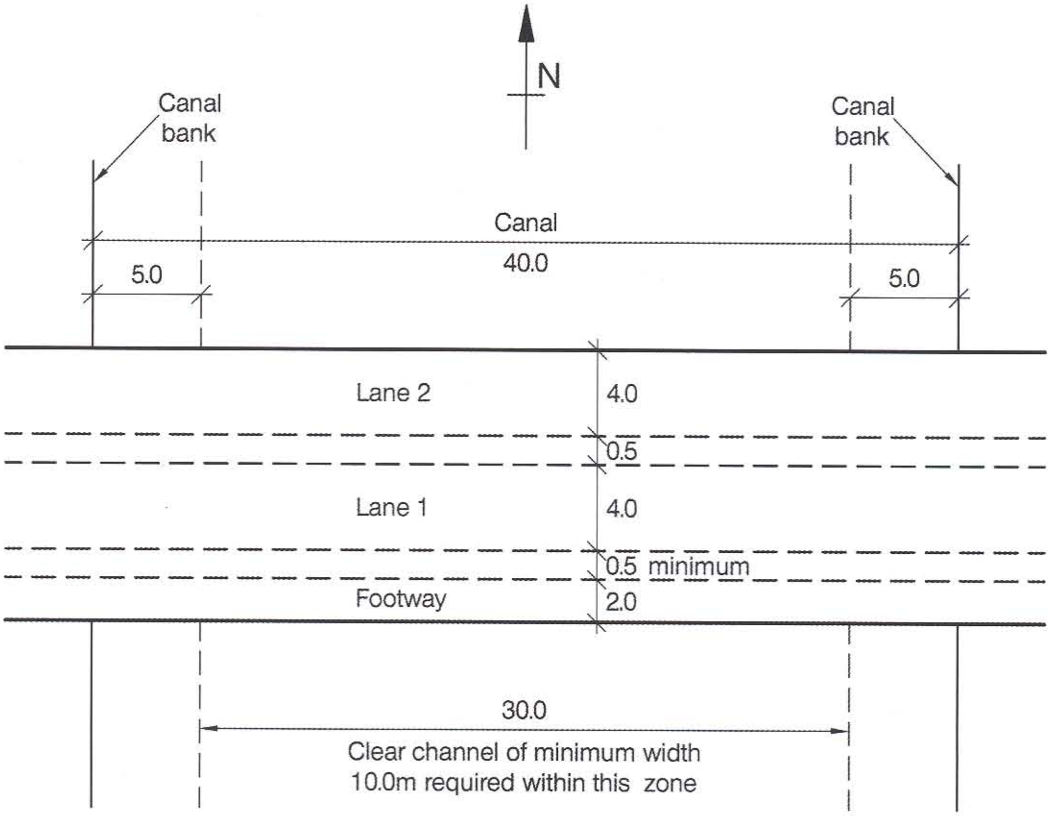
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

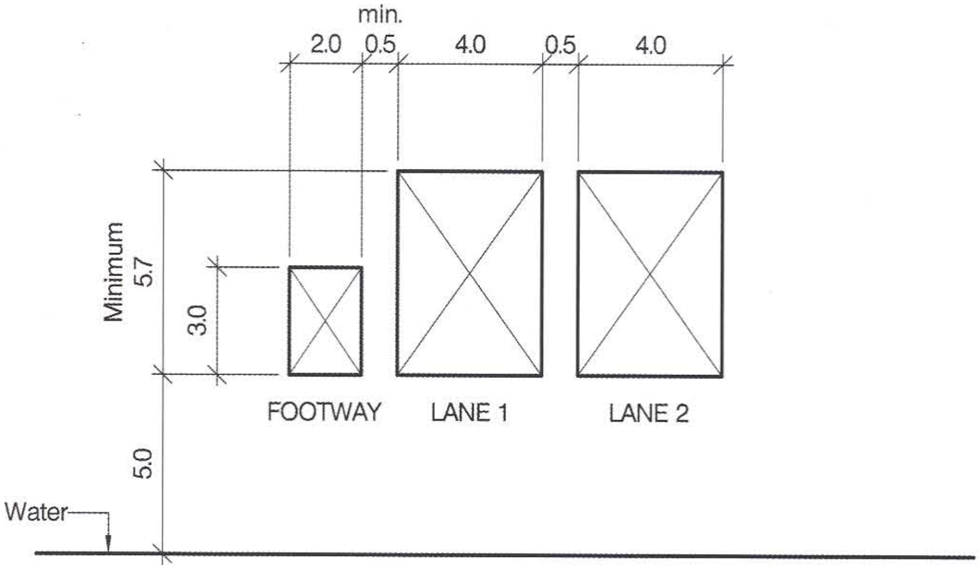
c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)

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 with diagrams showing the key elements of temporary works for the safe construction of the bridge. (10 marks)



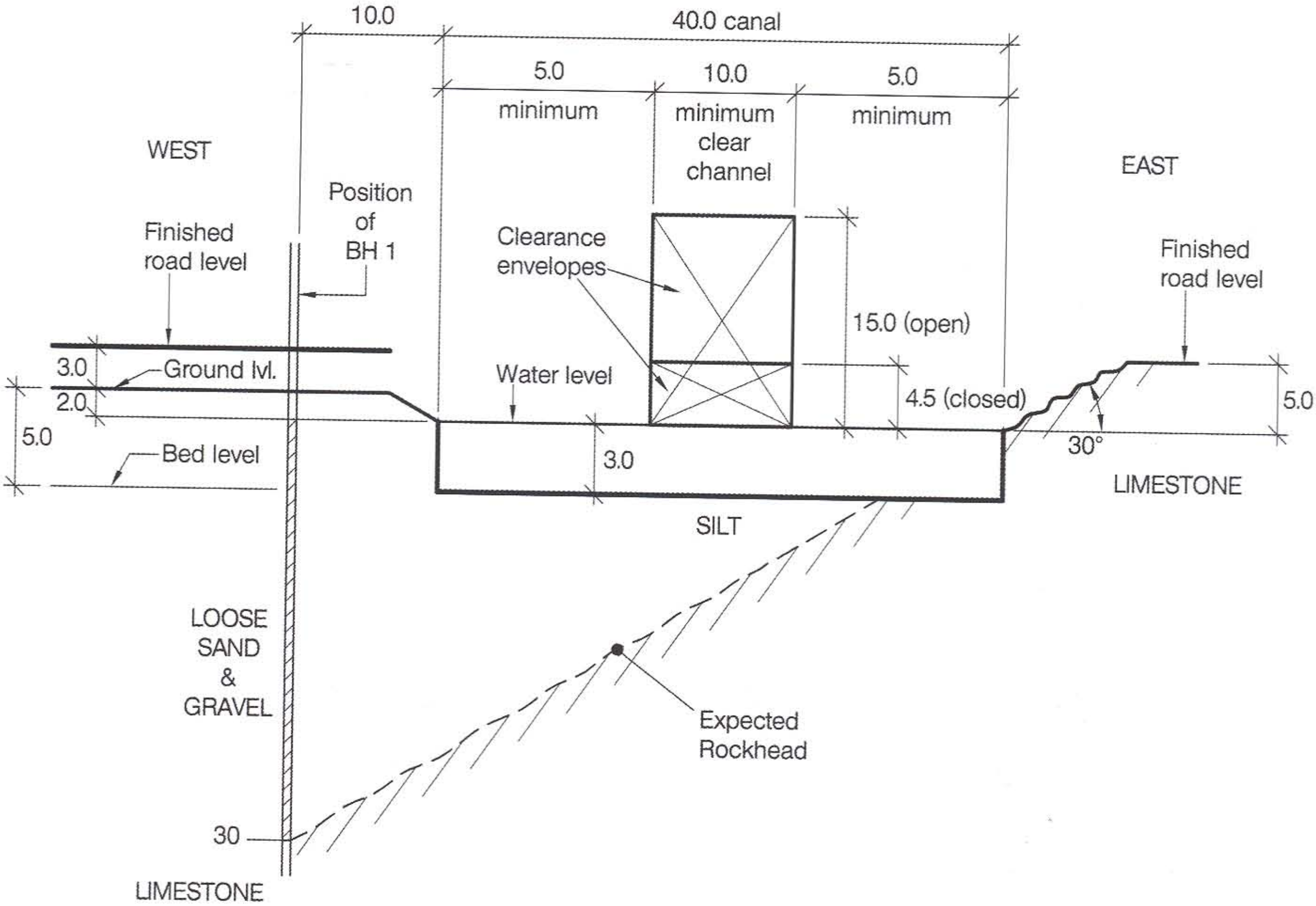
PLAN



CROSS SECTION

NOTE: All dimensions are in metres

FIGURE Q3 (Sheet 1 of 2)



LONGITUDINAL SECTION

NOTE: All dimensions are in metres

FIGURE Q3 (Sheet 2 of 2)

The problem is to design a structure to provide access over a canal with an opening span. This is outside the experience of most bridge designers but it should not be seen as a major problem after careful study as the question specifically excludes consideration of the mechanical means of opening. A question that at first glance appears difficult is often the one that provides the best opportunity to gain marks and show the candidates understanding of a variety of structural issues. i.e. You are required to demonstrate understanding of key structural principles and be able to design key elements of the structure.

The key to understanding this question is to appreciate that there are at least two distinctly separate but equally critical load conditions: in the closed and open positions partly because it is likely some reversal of load effects may occur. It is also important to consider the temporary state during erection which can also be critical. For an efficient design the moving part of the structure should be as small and lightweight as possible and the loading on bascules/ swings should be balanced to minimise lifting effort/ overturning moments respectively.

The ground conditions are very different on each side of the canal with Limestone close to the surface on the east side and at a depth of 30m on the west side with loose sands and gravels on top. This is pointing towards a possible asymmetrical arrangement for the structure and foundation construction which should at least be discussed in section a. The question also allows some flexibility in the position of the clearance envelope within the canal. There are benefits in building the larger foundation to support the fulcrum of the swing or sliding structure close to the rock embankment to minimise its' size and the amount of construction in the water. It will mean that a deeper piled foundation will be required on the other side for the approach viaduct.

Part a:

There are a number of possible options for solving this question and providing elegant structure. The lifting span could be achieved in a number of ways:

- Swing bridge using a balanced cantilever or cable stayed system. A single swing with the foundation as near as possible to the rock embankment with a longer lightweight span across the water and a heavy short back span to balance towards the embankment.
- Bascule lifting bridge. A single bascule again near the rock embankment would be most efficient. A counterweight span at road level is likely to dip into the water which is not ideal for a durability point of view so it would be preferable to have an overhead bascule with cables to lift the bridge or a decorative counterweight that rises above road level when the bridge is closed. Note that the closer the pin is to the clearance the greater angle of lift required but the smaller the span.
- Sliding bridge (sideways or longitudinal). This would be harder to set up as all the elements of the moving part would have to clear the road before sliding can be achieved. Sliding in line would need a cantilever involving uplift as well as vertical loading on the sliding bearings.
- Direct lifting. This would require two piers of similar construction in the canal so is likely to be expensive compared to alternative options. Also both sides would need to be lifted simultaneously. Wind loading in the raised condition may be a critical issue as it needs to be a lightweight structure lifted high.

It would be good practice to avoid any part of the mechanics / moving parts to be sited permanently or temporarily in the water or inside confined spaces as this presents a durability and a hazard for maintenance activities.

The loose sands that may be subject to settlement under the approach embankments so some discussion of differential settlement gained marks. Keeping the channel close to the east side will reduce the fill on the east and reduce the rock excavation on the west.

The available depth of construction with a horizontal vertical alignment is 500mm which is adequate for a number of structural solutions to span 10m clear. The road alignment does not have to be horizontal but must be within the given limits for the slope. There are no restrictions on the road level or length of the approach – other than those dictated by economy. If in doubt in exam situations you are permitted to state your understanding of the question and the examiner should mark accordingly. It is generally NOT a good idea to try to simplify the question as it is likely to limit your opportunity to gain marks. Remember you are trying to show the examiner how much you know and not just present a solution that works. Some of the options would be more complex with a sloping alignment.

The stability of the structure in the open condition must be considered and to check that the moving parts will not clash with static elements of the structure.

The key to the solution for a swing bridge is to balance the dead loads to minimise the moments around the pivot point and for a bascule is to balance the dead loading so the effort required to move the bridge is minimal.

It is suggested that candidates come to the exam with a checklist that can be described in one paragraph or even one sentence per option, as follows:

- sketch elevation and cross section (not to scale) to explain structural type adopted
- column types and abutment types
- foundation types
- articulation
- load path
- constructability
- durability and maintenance
- aesthetics

The above points can then be summarised in a table before the recommendation is made.

Part b: The question requires an increase in the clearances - the scope of the response depends on the solution chosen. It is best to aim to get as many issues as possible for discussion so do not select your option to avoid problems in part b or you may limit your opportunity to gain marks. There are a number of issues to discuss for a rise in the vertical profile. Raising the approach embankment on the west will increase fill and possible settlement. Raising on the east will reduce rock excavation on the approach. The height of the substructures will be increased as will the visual impact. Greater cost, longer construction time, possible affect on the moving mechanism, increased wind loading for the temporary condition. It may also be worth noting where your design is beneficial in this regard – i.e. Issues that will not be a problem such as no change to the lifting mechanism,

Part c: It is a good idea to do an outline calculation for the balance of loading at an early stage to allow preliminary sizing of the length of cantilever and backspan. This will allow final layout of the piers and moving section to be fixed. The size of the main beams and cantilever elements, lifting cables, and the pier and abutment needs to be established along with two types of foundations (piled and direct on rock). Two load cases must be considered for the open and closed situations. The open condition should consider wind loading effects. If the bridge is to be launched the temporary reverse loading and cantilever effects during launching must be included in the design of critical members since this can be the critical load condition. Lateral buckling / u frame action to restrain the compression members/ flanges of compression members is a critical issue in truss solutions.

Part d: Plan, elevations section, details of significant elements – bearings, joints etc.

Part e: There is a great opportunity in this question to show your knowledge of special construction issues and temporary works but make sure the basic sequence makes sense. It is helpful to be familiar with Health and Safety and environment issues but you must be able to describe temporary works required to construct their design. There are lots of issues to discuss for example:

- Working in and over water (piling/ caisson)
- Access across water
- Possible pollution to sea with debris / construction materials
- Possible sensitive area with tourists, residents etc.
- Siting a crane on soft ground.

You don't need to be familiar with methods of construction over / in water but you should be able to recognise the problems and understand basic principles.

Figures:

Fig 1 Outline scheme - Option 1
Fig 2 Outline scheme - Option 2
Fig 3 Load transfer - Option 1
Fig 4 Load transfer - Option 2
Fig 5 Bearing layout - options 1 & 2

Commentary on the figures

Figures 1 – 5 with notes

References & examples:

NCE 22/11/07 insert "The historic bridges & Infrastructure awards 2007 page 21 Wellington St Swing Bridge Kingston Upon Hull.

http://www.bardaglea.org.uk/bridges/bridge-types/bridge-types-intro.html

Tower Bridge London.

Peros Bridge Bristol

OPTION 1 - SWING BRIDGE

Location of main foundation:
close as possible to Rock ⇒ minimise depth, Cost, Risks

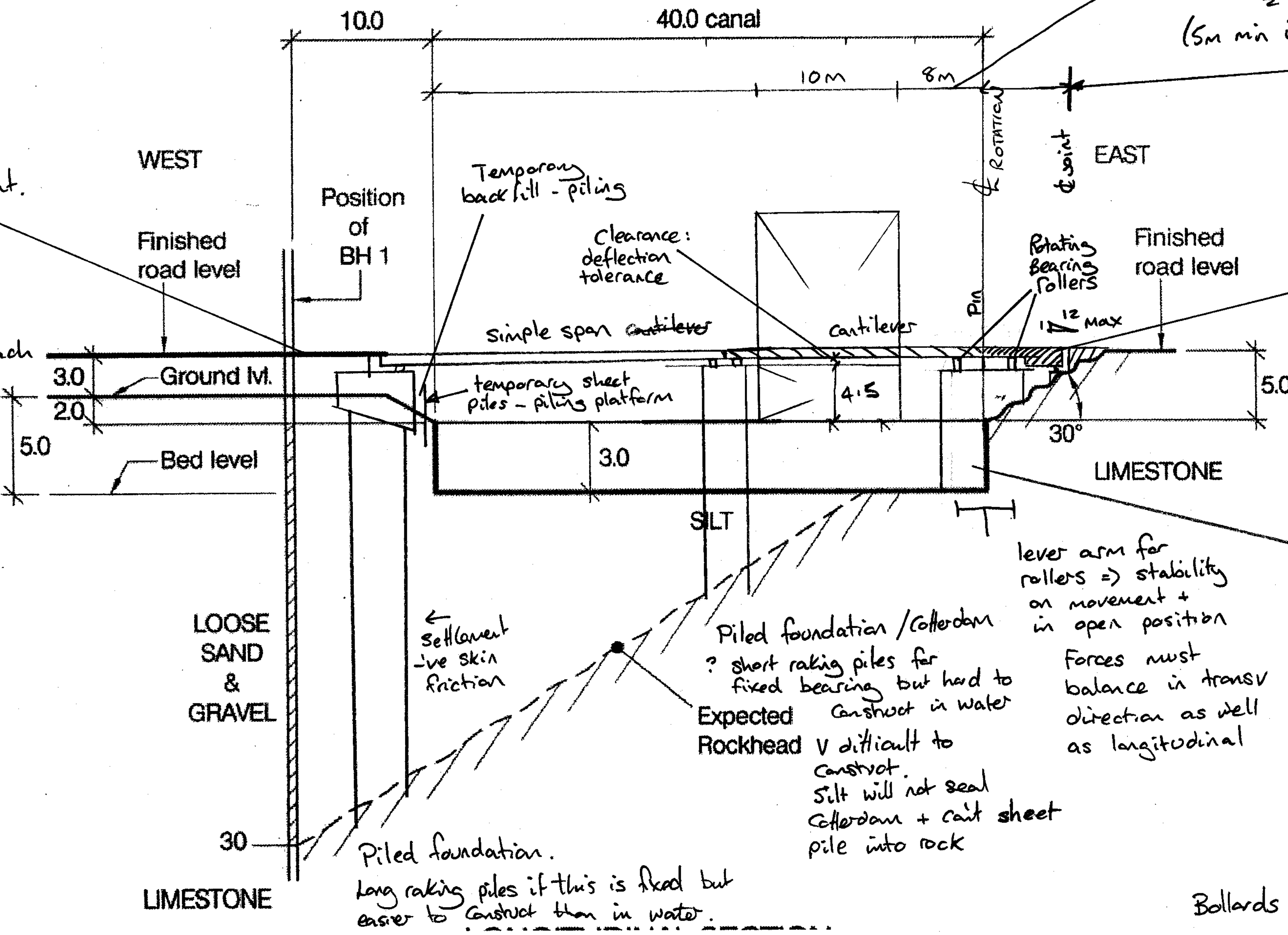
Alternative large foundation in middle with 2 equal spans ⇒ no other piers in water

Approach ~~ramp~~ span precast / steel lifted in
⇒ minimise risk working over water

Construction depth ≈ Cantilever span/8 at bearing. - but can be reduced as only DL.
⇒ likely to raise level above that shown.
simply supported span/16 for DL+LL.

a) deck balanced Cantilever

b) Cable stay



Clearance when open:
Width = 11m min ⇒
Allow 16m/2 = 8m
(5m min in Question)

Min distance to joint to ensure clearance during rotation.
note joint at slight angle to prevent jamming

Roller bearings ⇒ must be Controlled
Locked in position in open position
⇒ wind loading.

Possible run on slab to deal with settlement.

Early Construction of approach embankment: settlement prior to abutment construction

Piled foundation / cofferdam
? short raking piles for fixed bearing but hard to construct in water
V difficult to construct.
Silt will not seal cofferdam + can't sheet pile into rock

lever arm for rollers ⇒ stability on movement + in open position

Forces must balance in transv direction as well as longitudinal

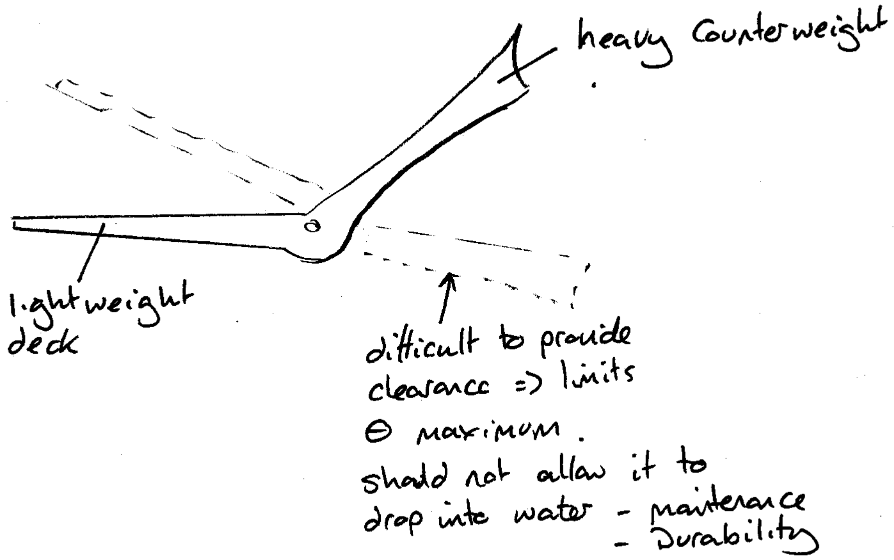
PIER / ABUTMENT
Built in caisson / cofferdam
Hollow to minimise Concrete?
Fixed for horiz loads.
Access for machines maintenance
Avoid Confined spaces
: spaces likely to flood

Approach span.
Cost alternative choices for fixed end : And Compare CDM risks.
Decision not obvious

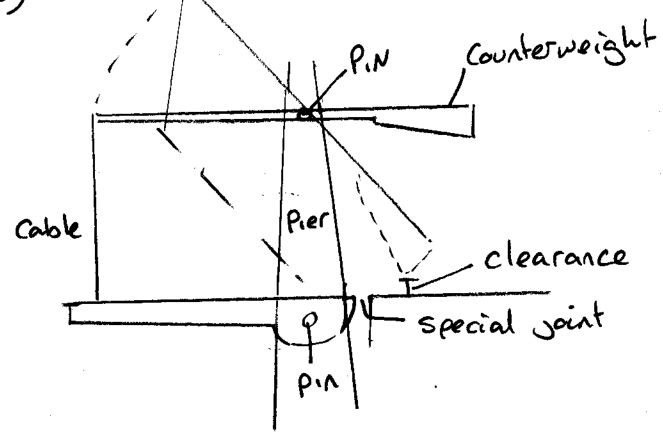
Piled foundation.
Long raking piles if this is fixed but easier to construct than in water.

Bollards to prevent ship impact.

a) Counterweight deck bascule



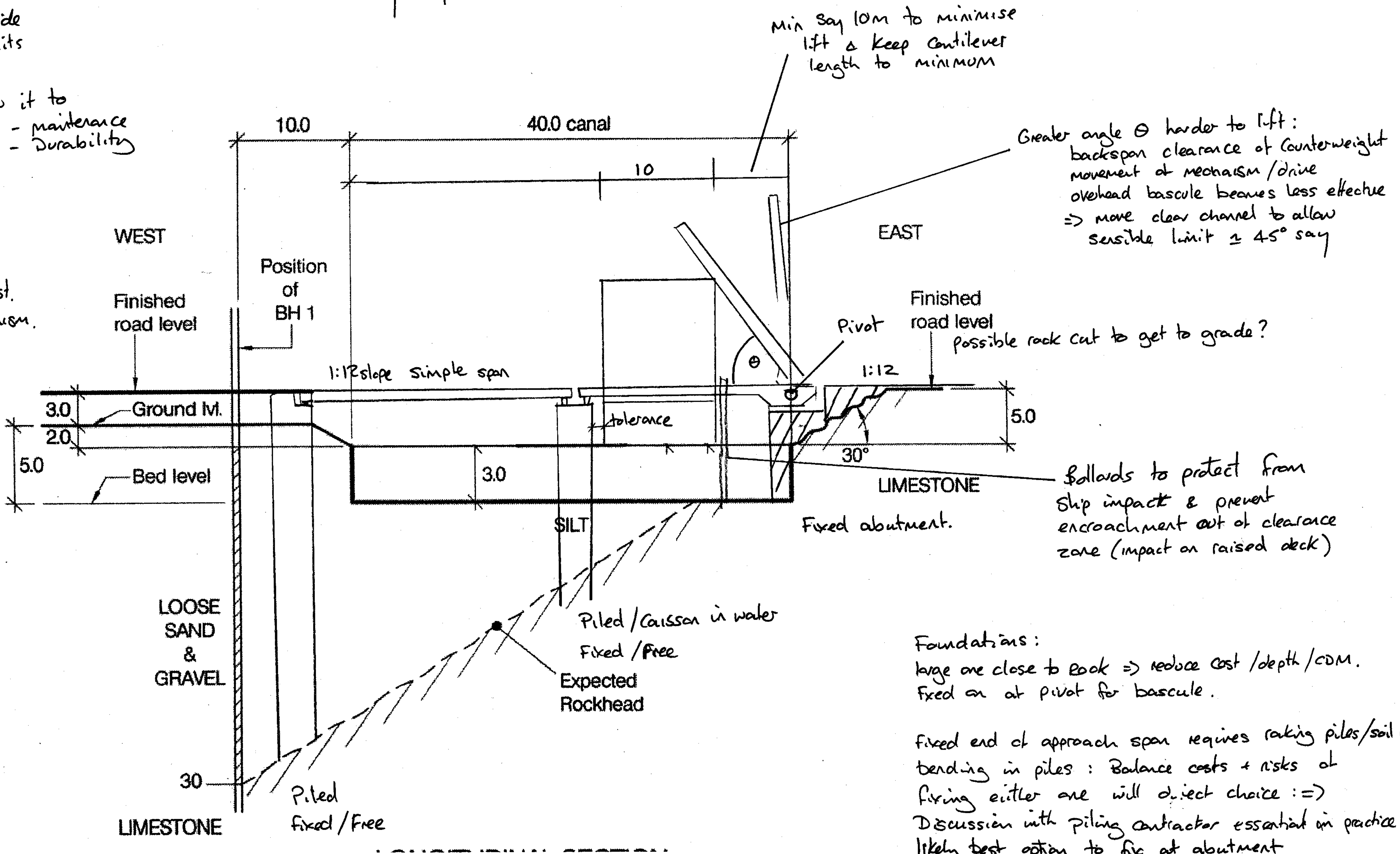
b) overhead bascule



OPTION 2 Bascule

Depth of deck ≈ L/16 overhead bascule. ≈ L/8 cantilever bascule } Cantilever depth can be reduced as only supports DL but stiffness required during lifting.

In plane stiffness during lift in case drive mechanism not aligned, vibrations ~~possible~~ Need to look at wind causing twist when open. and load on hinge and mechanism.

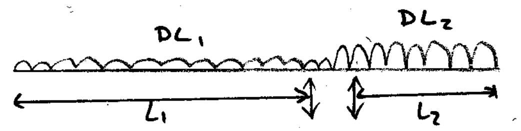


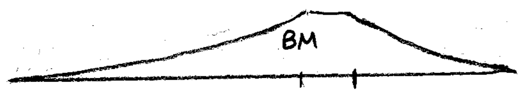
Foundations:
large one close to Rock => reduce cost / depth / CDM.
Fixed on at pivot for bascule.

Fixed end of approach span requires raking piles / soil resistance / bending in piles: Balance costs + risks of fixing either one will direct choice :=> Discussion with piling contractor essential in practice likely best option to fix at abutment.

LOAD TRANSFER – SWING BRIDGE OPTION 1

Balanced Cantilever: open



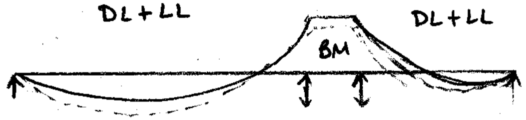


MAX BM = $\frac{wL_1^2}{2} \simeq \frac{wL_2^2}{2}$

Minor corrections to balance taken by bearing reactions preferably all in compression : ie forces close to balance

BM diagram curved due to effect of UDL

closed



DL as above

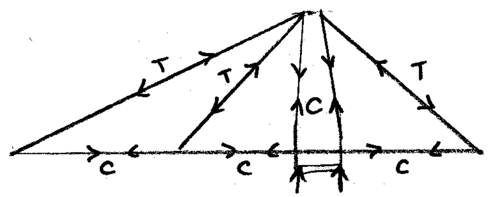
LL each span separate + Both together

⇒ max sag in each span, max hogg, max bearing load

⇒ envelope of BM.

wind not significant in closed position

Cable stay



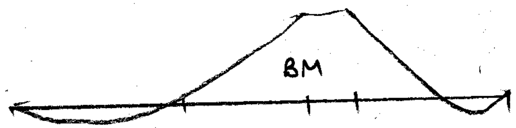
T - tension

C - Compression

Bridge should lock down onto end bearings in closed position to avoid bounce/uplift

single cable.

open

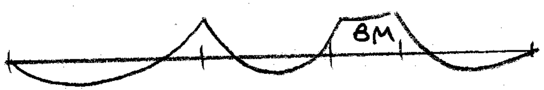


Longitudinal + transv loads in pin

Transv loads at abutment/pier when closed.

Multiple cable

open

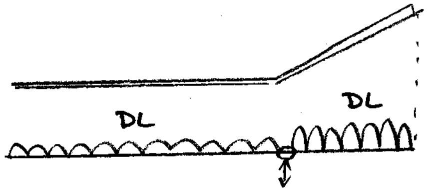


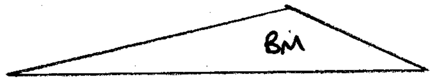
closed ⇒ similar but vertical end reactions will modify envelope

LOAD TRANSFER - BASCULE

OPTION 2.

BASCULE DECK

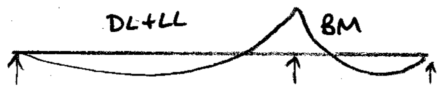




open

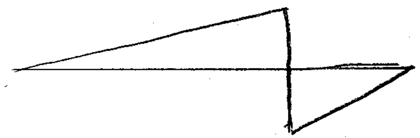
$WL^2/2$ OPEN: wind load on bearings + drive mechanism (both options)

closed



DL + LL Envelope loadcases as option 1.

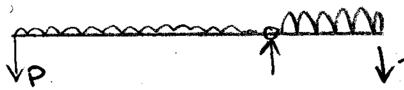
open



shear force diagram (more load on counterweight side)

Bascule high level

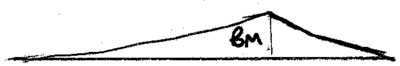
BOOM.



drive force?

BM open $= P \times L_1 + \frac{wL_1^2}{2} = \frac{wL_2^2}{2}$ + drive force

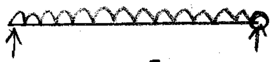
open + closed



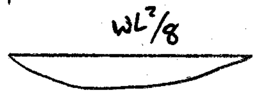
BM closed P=0 (or near 0) drive = 0

BM diagram slightly curved due to UDL

Deck



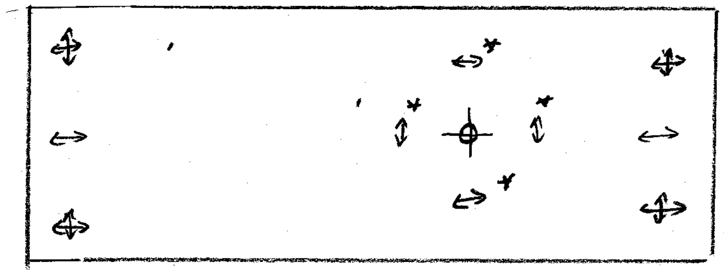
open + closed



BEARING LAYOUT.

SWING

Specialist rotating bearing - will be large



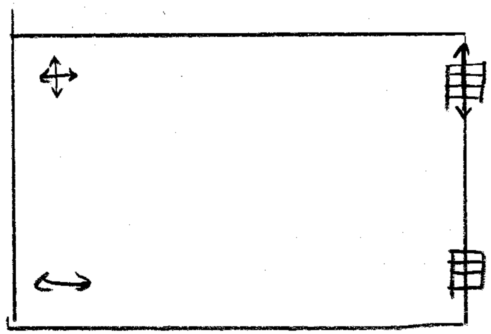
Guided bearings must be parallel to line of expansion to prevent locking

- ⊕ central pin - fixed both directions free to rotate.
- ↔* MIN 4 roller bearings in circular channel - must take transv wind load + movement loads.

✥ free bearings.

↔ sliding guided bearings - transv wind load when closed. (option to put combine with one side of free bearings)

Bascule



Roller bearing / pin specialist - free to rotate + slide transverse fixed longitudinal

Roller bearing / pin specialist - free to rotate fixed in plan

✥ free bearing

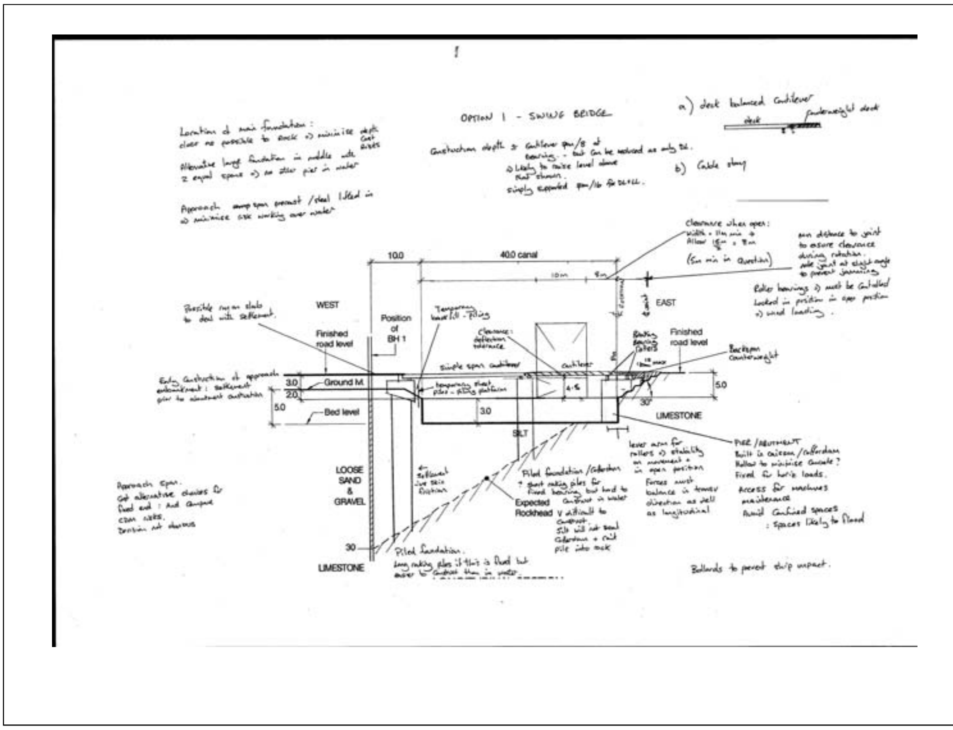
↔ sliding line up with fixed roller to avoid locking.

- possible additional free bearings / free roller each end.

Commentary to accompany diagrams

Question 3, 2007

Access Bridge with Opening Span



At the beginning of the examination it is recommended that you start with drawing and writing notes in a rough plan to collect your thoughts and this will help develop your ideas. This is a quick way of setting out your ideas and, where you have been unable to finish, these notes can be invaluable to get marks. You will notice the volume of information on the sketches on the following slides and this will all count for marks. This form of presentation is much quicker to do and easier for the examiner to understand than lengthy essays. This is particularly relevant if English is not your first language. It is helpful to draw up the problem roughly to scale so you can try out ideas and check dimensions to make sure the solution will work. You cannot rely on the drawings in the question to be to scale. All of the notes above are likely to get marks for section a and some for e for the temporary works. The examiner is looking for you to show that you understand the issues around the problem and arguments for why certain solutions are better.

My initial idea was to put the pin of rotation well onto the east embankment but then realised that I was wasting the back span and having to cut into the rock. This type of issue can only be appreciated by drawing up the problem. It may be more cost efficient to provide a single large central pier to support the pin with two cantilevered spans to be supported on each abutment when closed.

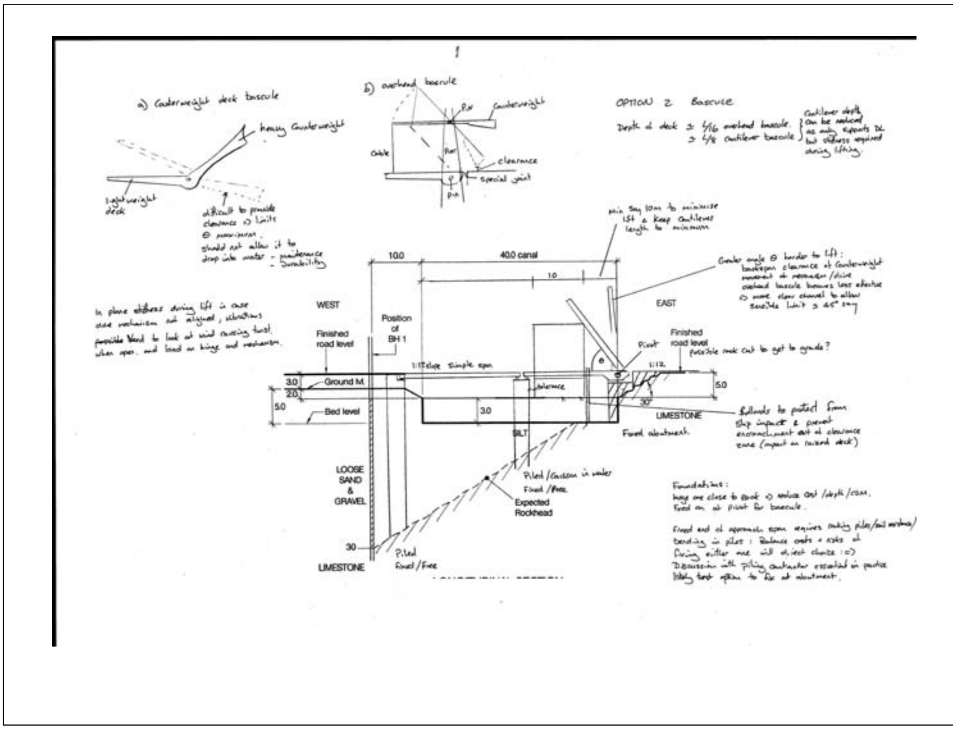
It is critical to look at the movement on plan. The back span cantilever is probably too short as drawn here to prevent the corner of the deck being obstructed by the abutment during rotation. The joints can either be curved (centre of curvature at the pin) or angled to ensure release of opening which is the cheaper / simpler option.

Note that the rough working shown here probably took slightly more time than people have in an exam but there are many points to be had from legible scribble. I don't think it is necessary to put much more description on the paper to pass part a other than some description of stability under various load conditions open / closed and reasons for your selection to follow up.

Deck construction. You can prepare span: depth tables for various types of construction to use as a lookup in the exam. This will save time deciding what solutions are viable. Note that the depth shown on these diagrams is probably too shallow. Preliminary rough sizing of the depth of construction using span : effective depth ratio's of 1:6 for a cantilever or 1:12 for a simply supported span or 1:15 for a continuous span can be helpful. IStructE "manual for the design of reinforced concrete building structures" gives these values which are a good start. You could of course use your own experience to prepare rules for different types of bridge structures.

It is a good idea to prepare folders with information on different bridge types such as railway, river, footbridges, motorway, aqueduct, moving etc. for quick reference in the exam. The same applies for construction types: truss, bow string, arch, composite steel beam & slab, prestressed beam, cable stay, suspension etc. and for different foundations. There are many websites and references you can use to give you information.

Study also construction methods and associated health and safety and environment issues: Launching, top down / bottom up, caissons, cofferdam, Lifting material delivery.



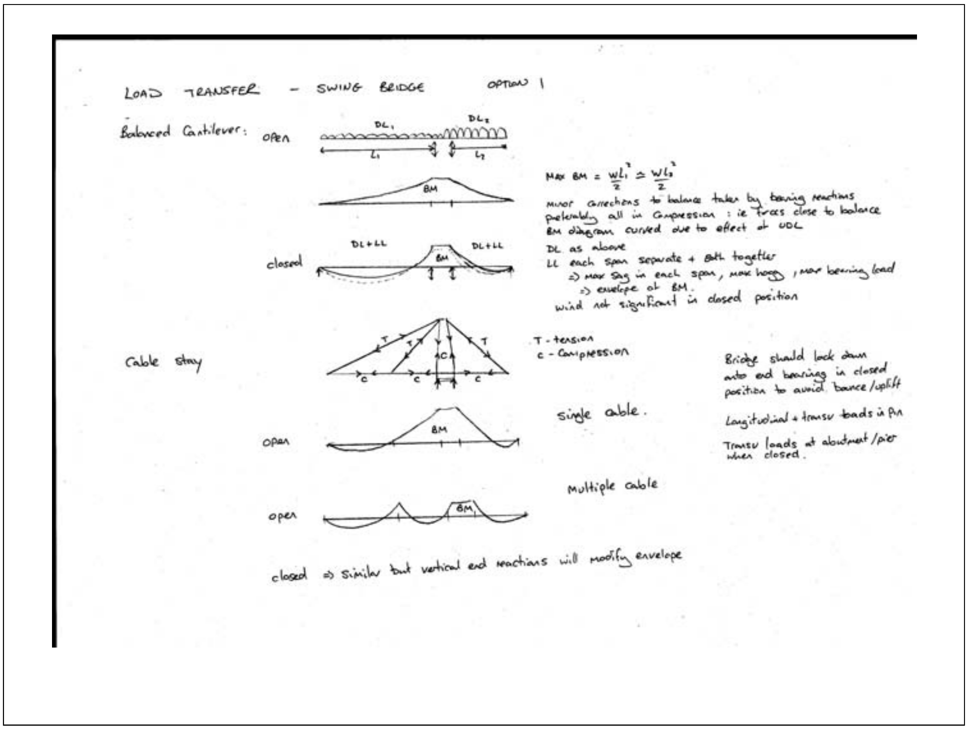
It is ideal if the second solution is significantly different to the first so you can show as much knowledge as possible

Do not bother to repeat issues mentioned in solution 1 as it will not get extra marks but it is worth mentioning where elements are the same/ similar.

I have ignored detail of the simply supported span but some marks can be gained by discussing it and it is better not to ignore issues. Certainly do not ignore issues deliberately because you don’t know exactly how to solve them or try to simplify the question. This will limit your available marks as you will get some for recognising a problem even if you don’t know the best solution and you could lose marks because the examiner thinks you haven’t identified a key structural issue to the question.

The foundations options are subject to discussion as one end of the approach span must be fixed. It would be more structurally efficient to do this on the shorter piles but construction in the water is significantly more complex. You would not be expected to know the best answer but you will get marks for discussing the issues which would in practice be resolved by discussion with specialist contractors.

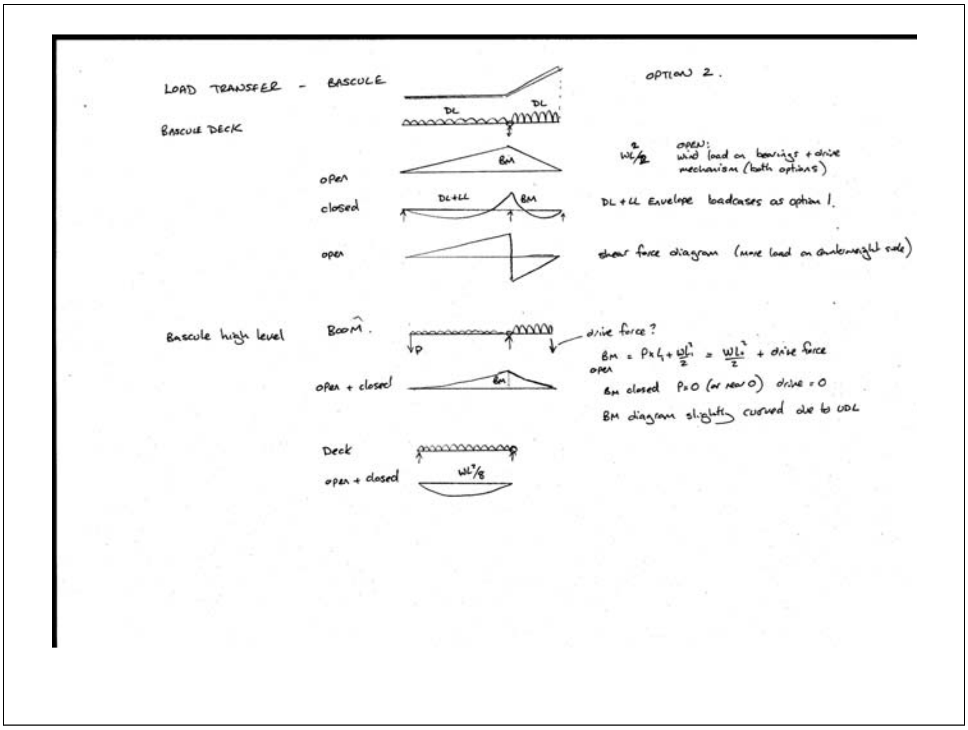
For this solution it is important to protect the headroom when open with bollards to prevent shipping getting too close. Generally ship impact should either be included in the design or prevented by the installation of barriers in the water.



The examiner will be looking for simple diagrams to show that you understand the structural behaviour of your structure. If you can’t draw these simple diagrams for the main types of bridge structure then this is a key area for further study. The diagrams above clearly show how the load transfer is working within the deck.

Don’t forget to discuss the foundations as well – particularly why they are different at each end. How are torsional loads carried by the deck, bearings. Longitudinal braking (each separate span), transverse loads from wind (each span).

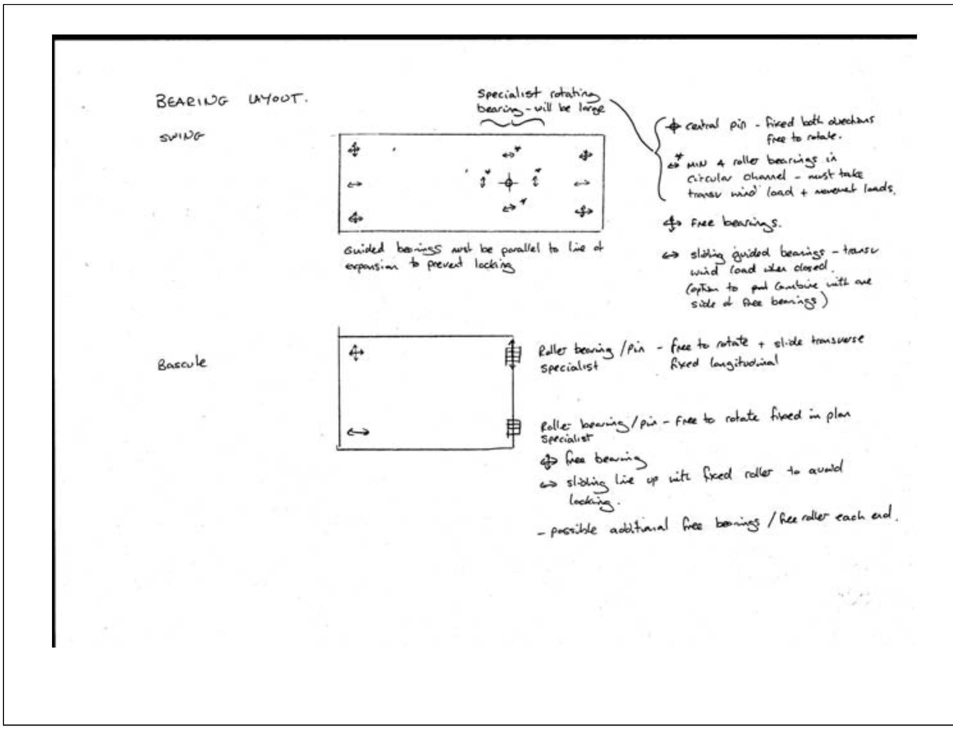
I originally drew the bending moment diagrams with straight lines but the UDL effect causes a slight curve. This is a minor effect and the formula is correct.



It is important in this question for you to show you understand the different load conditions both open and closed. The examiner will be confident in your abilities if you can present good bending and force diagrams.

These diagrams can also be helpful to assist your answer to section c calculations.

I originally drew the bending moment diagrams with straight lines but the udl effect causes a slight curve. This is a minor effect and the calculation is correct.



A bearing diagram is a useful way to gain additional marks but can also show lack of understanding. It is good to provide a key to your diagrams in case you mix up and draw them the wrong way round in haste. Each deck must be fixed at each end in each direction but too many points of fixity will prevent free movement on expansion of the deck. It is best to look at each direction separately. It is important if the deck is curved to make sure the direction of the sliding bearings is towards the fixed bearing and not on the tangent of the curvature. Uneven loads on the deck must be supported by a bearing that can support torsion or two bearings that create a couple. A single bearing at the end of a span is unlikely to be acceptable unless it can support torsion.

The swing bridge deck would probably need bearings that can resist uplift (unless sufficient kentledge is provided) to prevent it lifting with traffic loading / wind actions.

Due to the complex working of the problem it is likely that the above has taken a significant time so it would be better to set out some pro's and con's for the choice of structure and then tackle the rest of the question and return to tidy up text for section a if there is time.

Possible solution to past CM examination question

Question 4 April/ 2007

Swimming Pool

by Bob Wilson

Question 4. Swimming Pool

Client's requirements

1. A swimming pool with car-parking and a 2-storey basement: see Figure Q4
2. Car-parking is required on levels 2 to 4. Entry and exit to the car-park is via two curved access ramps, integral with services cores, lifts and staircases. The services cores serve all levels including the roof. A swimming pool 50.0m long and 15.0m wide is required on level 1. The pool depth is to vary linearly from 1.5m to 2.5m. Floor-to-floor heights and minimum headroom requirements are shown in Figure Q4. There is no restriction on the roof height.
3. Each parking bay is to be a minimum of 2.5m wide and 4.8m long. 6.0m wide traffic lanes are required on each parking level as shown in Figure Q4. No structure is permitted in any parking bay or traffic lane.
4. A fire resistance of 2 hours is required for all structural elements.

Imposed Loading

5.	Roof	$1.5kN/m^2$
	Car park floors and ramps	$2.5kN/m^2$
	Level 1 floor and basement floors	$5.0kN/m^2$

Site Conditions

6. The site is level and is located in a city centre.
   Basic wind speed is 40 m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20 m/s.
7. Ground conditions:

Ground level – 1.0m	Made ground
1.0m – 18.0m	Sand and gravel. N values vary from 10 to 40
Below 18.0m	Rock. Allowable bearing pressure = $1500kN/m^2$

Groundwater was encountered at 6.0m below ground level

Omit from consideration

8. Detailed design of the lifts and staircases.

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. After completion of your design, it is discovered that groundwater levels are slowly rising and are predicted to reach 1.0m below ground level in the long-term. Write a letter to the client explaining the implications and how your design could be modified to accommodate the rising groundwater. (10 marks)

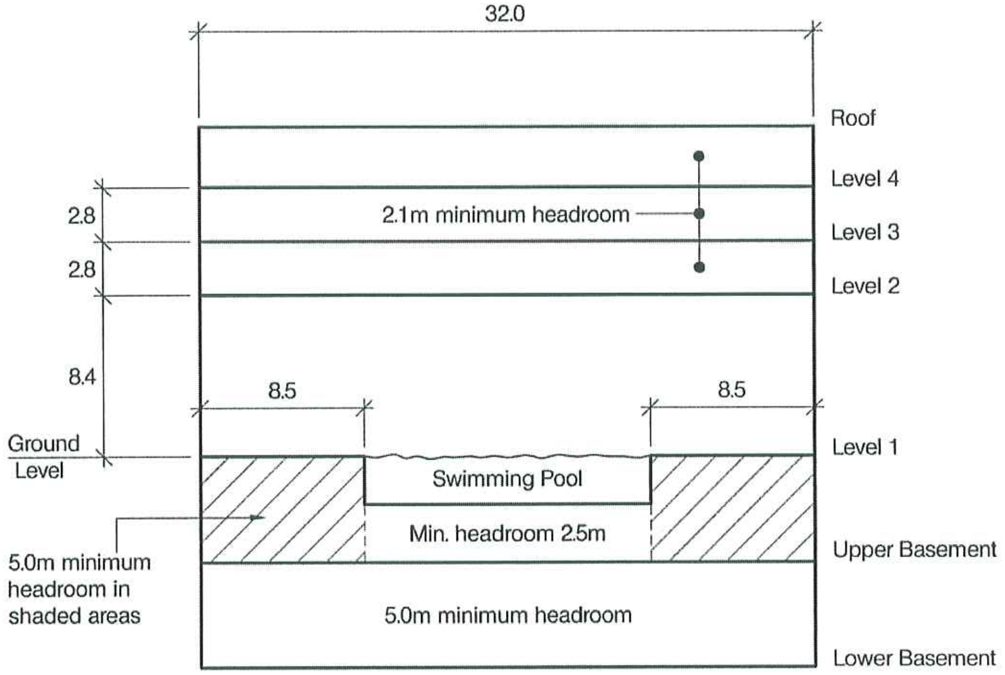
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

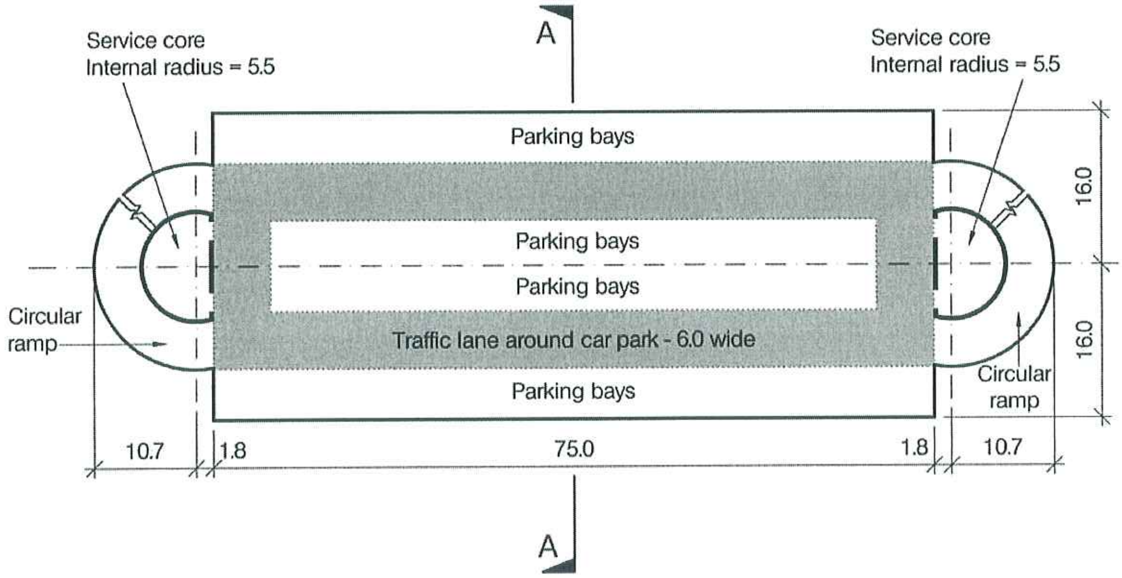
c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)

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)



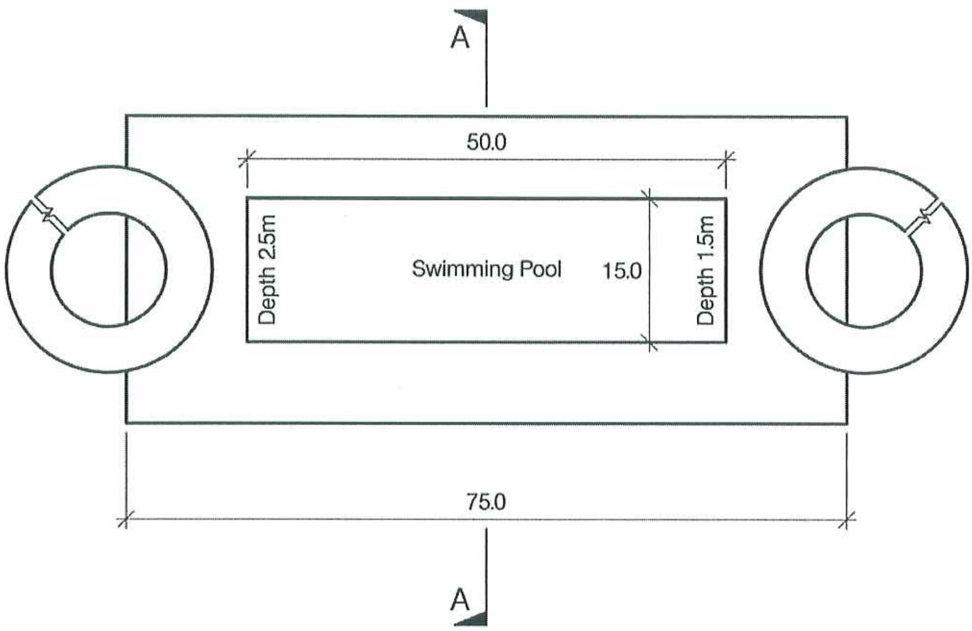
SECTION A-A



TYPICAL FLOOR PLAN OF CAR PARK (LEVELS 2 TO 4)

NOTE: All dimensions are in metres

FIGURE Q4 (Sheet 1 of 2)



PLAN ON LEVEL 1

NOTE: All dimensions are in metres

FIGURE Q4 (Sheet 2 of 2)

Q4/2007 – SWIMMING POOL

Before marking I like to review the large number of choices presented by this question. This is characteristic of the versatile questions set by this Examiner: answers can be assembled from a wide variety of structural forms and materials, giving candidates with diverse experience the widest scope in their attempt at an answer.

This does not mean to imply that a “Good” answer would need to be, or would have time to be, as comprehensive!

I believe that the key to identifying the two viable alternative solutions required by Section 1a is to have the widest possible knowledge of the different **construction** procedures [as distinct from a facility with different analytical techniques].

So, I have set down a couple of ideas for the pool, the basement, the frame [four ideas], the floors and the wind-stabilising elements. These ideas are not exhaustive and I fully expect to be delighted by another, quite different, answer when I come to mark the scripts.

I have also used a “picture-with-notes” style of presentation. I find that this is an efficient and pragmatic form of communication: I also suppose that it may not suit everyone! It takes some practice to become fluent in this “language”. However, it generally avoids ambiguity [often found in wordy presentations] and makes direct contact with the other person in the discussion – in this case the Examiner.

Remember, we can only mark what you draw and write! You may have had any number of brilliant ***thoughts*** during the examination, but if you have not written them down they are not available to us! So you **must** get all your ideas down on paper. Only practice and experience will allow you to do so in a professional [neat, tidy and orderly] manner. Mistakes are “painted out” using correction fluid if you are using ink [as I have, because I knew it was going to be printed]. Pencil is a better medium for the examination as it can be rubbed out and does not show your errors.

I have used various colour washes, but then I admit that I am not working against the clock! The ubiquitous Highlighter™ is one source of several colours; however I have used Tombo™ dual-brush-pens that come in 144 brilliant colours and a wide range of Grey tones. I suggest that you select perhaps six from the range to represent water/steel [blue], concrete [grey], soils [yellow and brown] and another two, say, red and green. Colouring is a quick way of defining materials.

As soon as I have set down a couple of sensible ideas for each component of the building [floor, cladding, frame and foundations], I can assemble the two alternative and viable solutions required. As you do this I find that the preferred choice emerges and all you need to do is to keep a note of your thoughts as you go along.

In a real-life situation you discuss the two solutions with your colleagues – especially the QS [and Contractor if you have one aboard at this time]. You will, of course, express your preferences – and this is what you have to do at the tail-end of your answer to

Q4/2007 – SWIMMING POOL

Section 1a. This is generally called the "Review", but as a Marking Examiner I would be content if the candidate wrote "I prefer this because …" In this manner you can review the Floors, Frame, Foundations and any special features specific to the question.

My approach to this would be "What is the best value for money?" in this question a Bentonite-slurry Diaphragm basement wall is a "good buy" because it can be installed before the dumpling is excavated, retains the sides of the excavation, keeps out most of the groundwater and eventually supports the superstructure. Using top-down basement construction [and a lot of planning!] allows the Contractor to erect the superstructure while at the same time excavating the basement. What other system gives you all this?

Section 1b – "the letter" needs to be addressed in a professional way – not used as an opportunity to make-up time! There are ten marks allocated, and at 4 minutes per mark this allows 40 minutes for a proper answer. Sadly, many candidates regard this as a five-minute respite to write some trite and general remarks about an increase in time, costs and professional fees! This approach does not address the question asked and certainly does not resolve the problems that are posed. Half a page of scribble does not earn 10 marks – at least, not in this examination!

Your Client has asked a question and expects to be led through the answer in a sensible way. You need to express quite complicated engineering concepts related to rising groundwater without being superficial or patronising!

You explain that there will be greater water pressure and how you propose to deal with both the construction and permanent problems raised by the increased pressure. You will also explain that although waterproofing was provided in the original scheme that the waterproofing needs to be extended.

As your remarks are actually going to be read by an experienced engineer – the Marking Examiner – many of the concepts will transmit themselves or be recognised if you incorporate some sketches in your answer and "bullet point" the main issues. The sketches and diagrams can of course be used in "discussions" with other members of the design team and so become a handy way of circulating ideas. The letter is written after the sketches and accompanies them to add brief written explanations. I believe that only in rare cases can this answer be limited to a couple of pages of text.

The Method Statement and Outline Programme – Section 2e – is another area where candidates skimp their answer and effectively throw away marks! Being at the very end of the examination, the last-gasp task, if it is not answered or skimpily answered it is a strong indication that the candidate has not managed their time well – a most unprofessional practice! Avoid creating this impression! Make sure that you allow yourself 40 minutes to address these last two tasks. There will be five marks for each part – the method statement and the programme – although the examiners are given discretion as to how the marks are divided. It should not be difficult for you to pick up 3/5 for both parts – equivalent to 60% for Section 2e and a pass!

Q4/2007 – SWIMMING POOL

What is wanted in this Method Statement is the Designer's view of how the building will be assembled – the effects of the design on the method of construction and the consequential sequence that must be adopted. In real life these matters are incorporated into the Specification and BoQ and may have significant effect on cost and programme.

The Outline Programme must indicate to the Client and QS where construction time will be spent. Basements take a considerable time to build and usually everything else has to wait until it is finished. Steel superstructure goes up quickly, but then the programme slows down while floors and enclosing cladding are assembled. The building is not weather tight until the roof and cladding have been finished, and may delay the fitting of services and fitting-out the interior of the building. Delays can be caused if large items of plant have to be "built-in". Deadlines may have to be observed if the Client's business is seasonal.

If the answer can indicate that the Candidate has an appreciation of the wider planning process, this will improve the marks. Examples might be: identifying activities on the critical path; specific plant requirements such as heavy lifting equipment for the new crane girders or long trusses; and resource levelling using "Float" available in the non-critical items. Most candidates sketch a Bar Chart but incorporate a large number of activities; this gives them a lot of work cascading the duration times in a sensible manner. Many of the duration times are faulty because they have been blind-guessed. Personally, I believe that the best approach is related to the four quarters that are used to monitor the cost in the form of an S-curve.

Candidates should not become obsessed with the pass mark [40%]. A Pass in the Examination is the final confirmation that you are a competent structural engineer. In an ideal world you would be given time to develop your concepts and provide your Client with a full and exhaustive professional service – viz. a 100% solution! The reality is that you are only given seven hours! Consequently it must be expected that your "service" may be less than 100%.

Would you consider it professional to give 10% or perhaps 15% less service? This would put your examination target at 85%.

Again, if you received only 40% of a full professional service would you be satisfied?

So your objective in the examination should be to pass with a really good mark – 60 to 80% - and not merely scrape through with 42%. A good pass will confirm to both yourself and the rest of the World that you are a competent engineer. In actual fact you will never know what your marks were, but you will know within yourself if you made a good job of it.

This time I have not attempted the calculations – Section 2c – nor the drawings – Section 2d. Advice is given elsewhere on this CD. I have made a list of the principal elements that I would expect to see being calculated. There are 20 marks for the calculations and I have identified four elements – the swimming pool floor, the basement walls [for soil and water pressure], the pool supports and the selected main frame. The allocation of marks would probably be five per element: perhaps two for the loading, one for the moments and shears [the analysis] and two for designing the section to resist the forces on it. Resolved into "working minutes" this is 8 minutes for determining the ***essential*** loading [not every possible load case], 4 minutes for analysing the ***critica****l* Bending Moment and 8 minutes for determining [***at the critical section***] the rebar or selecting a steel section ***and drawing a sketch for the detailer!*** There is no time for contemplation! You should have decided the structural model during the work on Section 1a – that is what is meant by the "functional framing, load transfer and stability aspects".

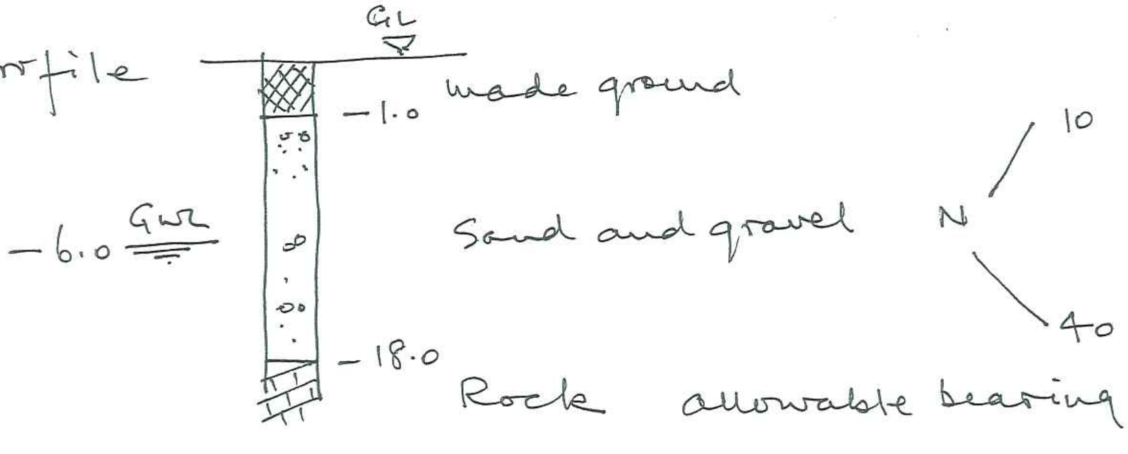
Section 2d – the GA and Details, will need a plan or plans to show the supports for the pool – after all, the question is headed "Swimming Pool" and this goes with a cross section though the basement and upper storeys. A part-elevation may be necessary to show the external column features. The cores and ramps might take up too much time to draw in detail but something must be shown if you are relying on them for overall stability. Cross sections of the main elements will be needed – the transfer beam and the supporting columns; the basement wall and the lower basement slab. Details of the rooftop waterproofing and the finishes to the pool would earn "Brownie Points" and boost your score in this section. Think about this section as a huge field of corn with patches where the corn has grown thicker, and make the best harvest you can from it in a limited time! Candidates with the traditional drawing skills fare best in this part of the question. If your regular work uses CAD drawing this does not prepare you for the examination. You must find time to learn how to draw and letter in the old way: with pencil, setsquare and tee square. Find someone who can teach you the basics and then practice at home. To give you some idea of the effort needed, the old-time apprentice had to fill an A0-size sheet with alphabets drawn by hand before they even started to draw lines! Actually, it can be very satisfying to prepare drawings this old-fashioned way: the way of the craftsman.

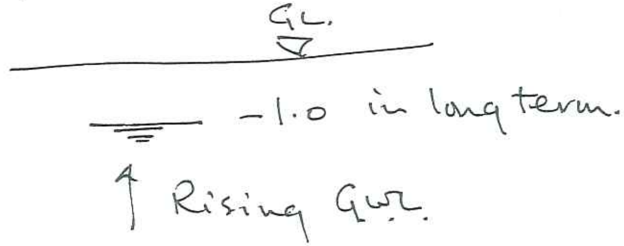
Q. 4. / 2007 SWIMMING POOL

- The question is about a swimming pool 15.0 m wide × 150 m. long. × 2.5 m max depth
- Secondary issues are: Car parking on levels 2 to 4 2.5 kN/m²
  Two curved access ramps with service cores.
  Two basement levels. 5.0 kN/m² Lev 1 + Basements.
- Restrictions are! Parking bays minimum 2.5 m wide and 4.8 m long.
  6.0 m. wide traffic lanes – two on each parking level.
  No structure is permitted <u>in</u> any parking bay or traffic lane.
  Minimum headroom – basements 5.0 m & 2.5 m
  parking levels 2.1 m

  2 hour fire resistance

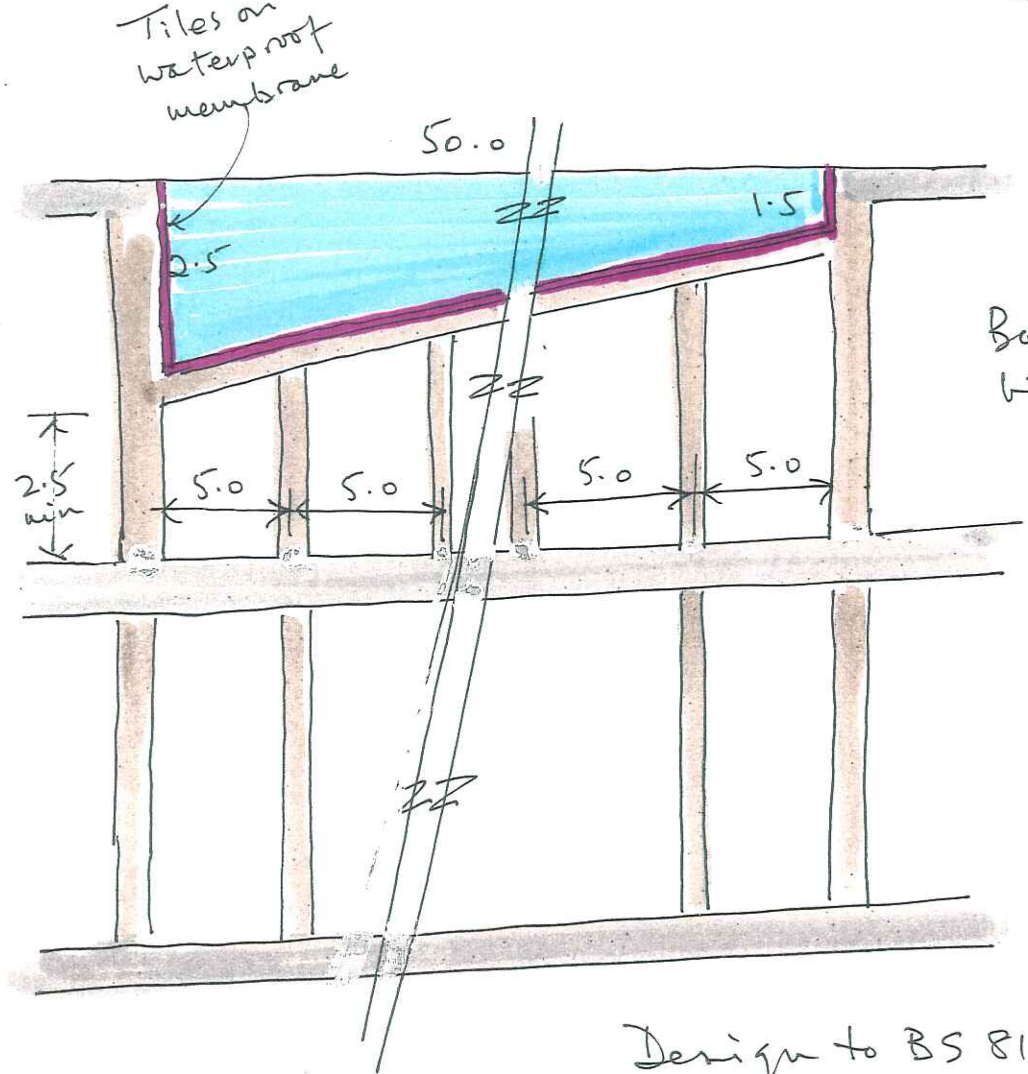
- There is no restriction on the roof height. 1.5 kN/m² allows access.
- Soil profile

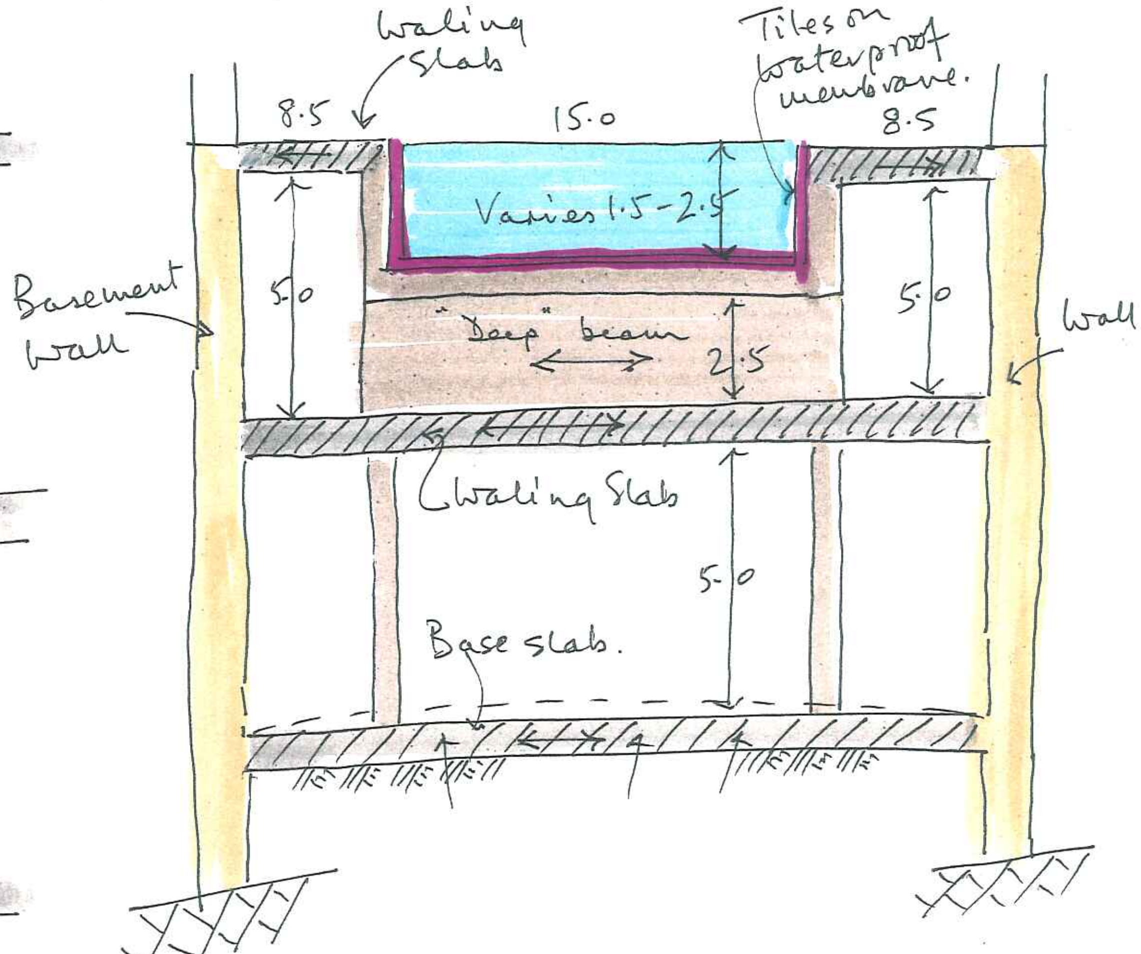




- Swimming pool.
  - Steel } purpose made by specialist
  - fibreglass } purpose made by specialist
  - reinforced Concrete
    - BS 8110 + Lining.
    - BS 8007 + cracks limited to 0.1mm.

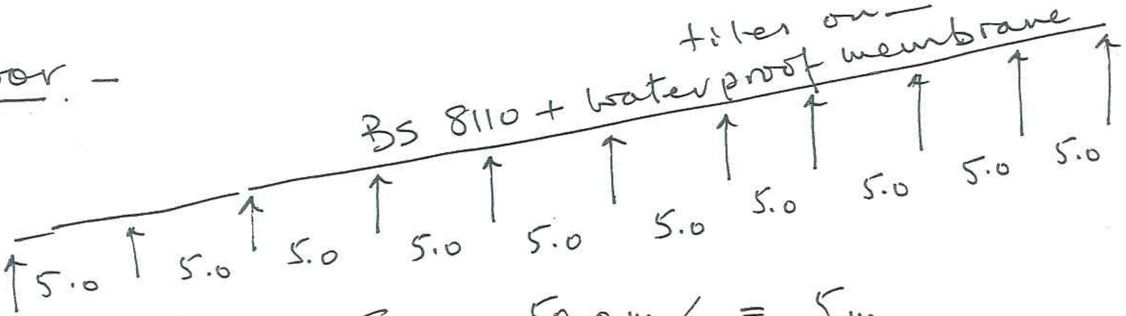
Heavy rebar!





Design to BS 8110
Transverse pool supports (Deep beams) onto columns.

Pool floor. –



Approx. Span $50.0\,m/10 = 5\,m$.

Make "stiff" – reduce sag

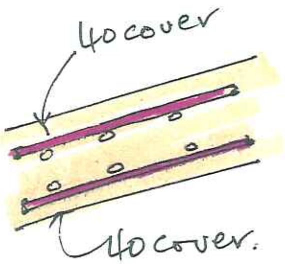
Continuity one-way.

$$d \simeq \frac{5000}{20} = 250$$

$+ \; 10 \quad \phi/2$

$+ \; 40 \quad$ Cover.

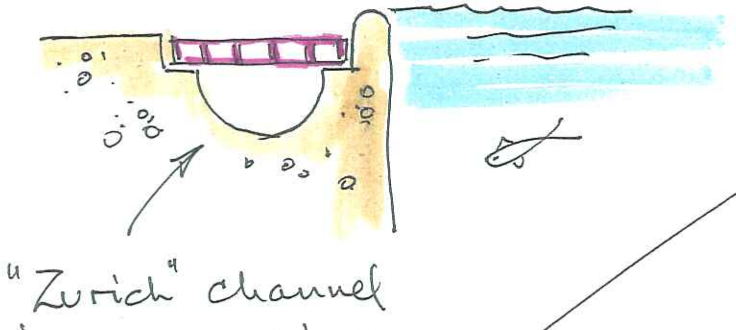
$\therefore \; h = 300$ min.

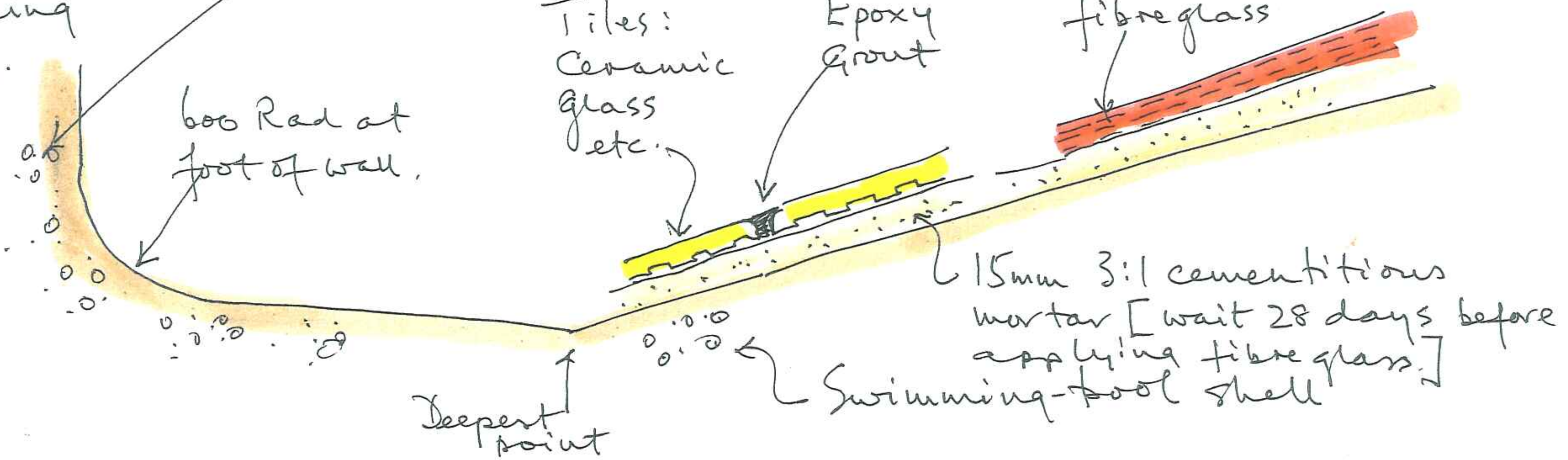


Rebar in both faces and both ways

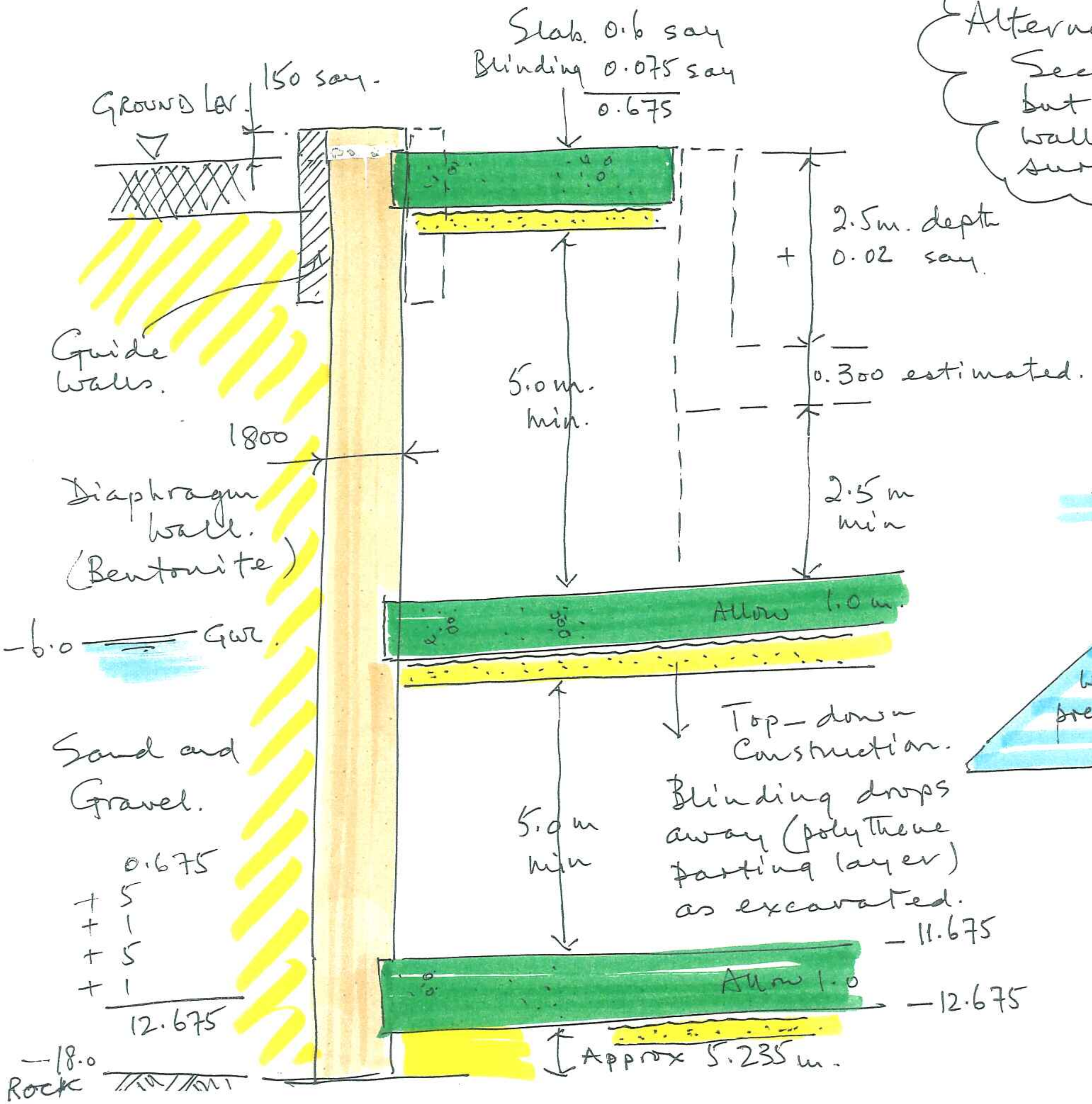
Swimming pool shell < poured concrete / sprayed concrete

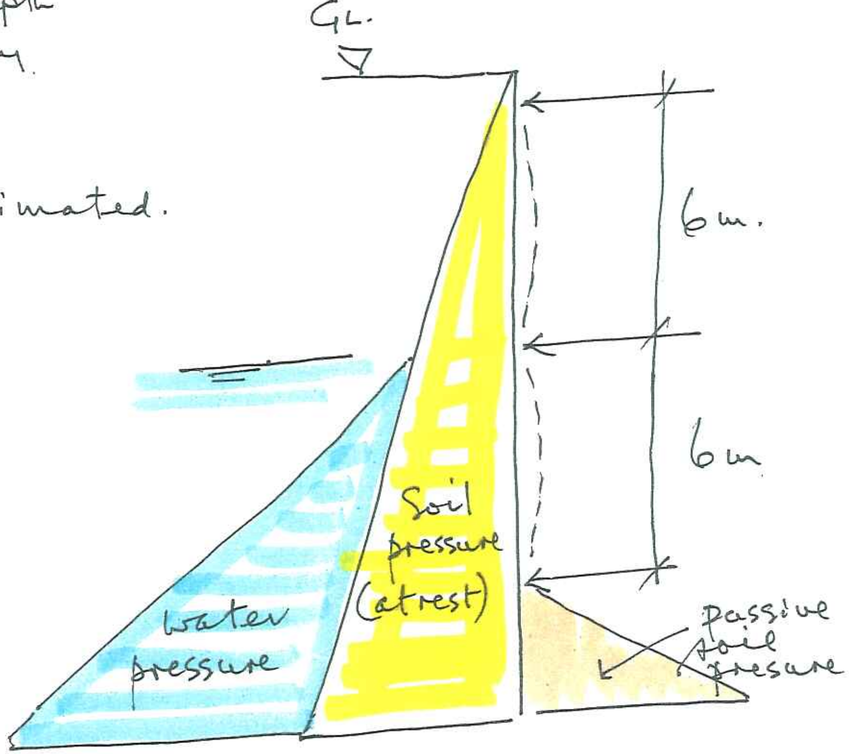
Y12 both ways both faces at 200 c/c.

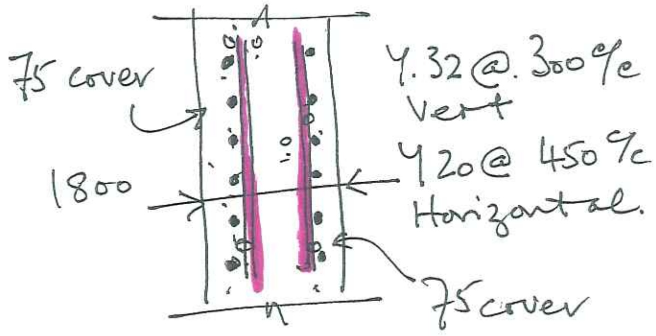




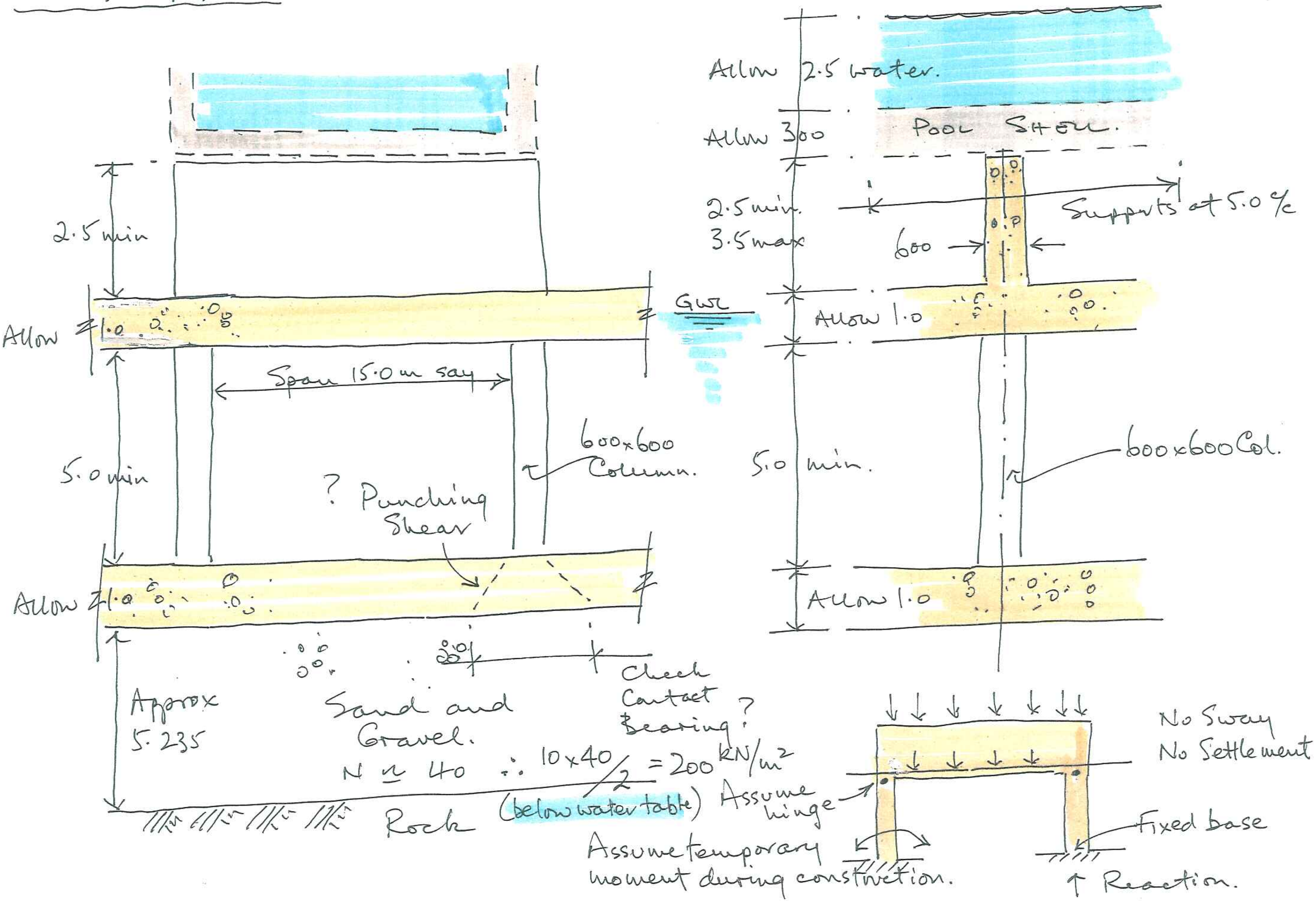
Alternative wall:
Secant interlink piling; but requires internal skin wall to requalarise the surface.



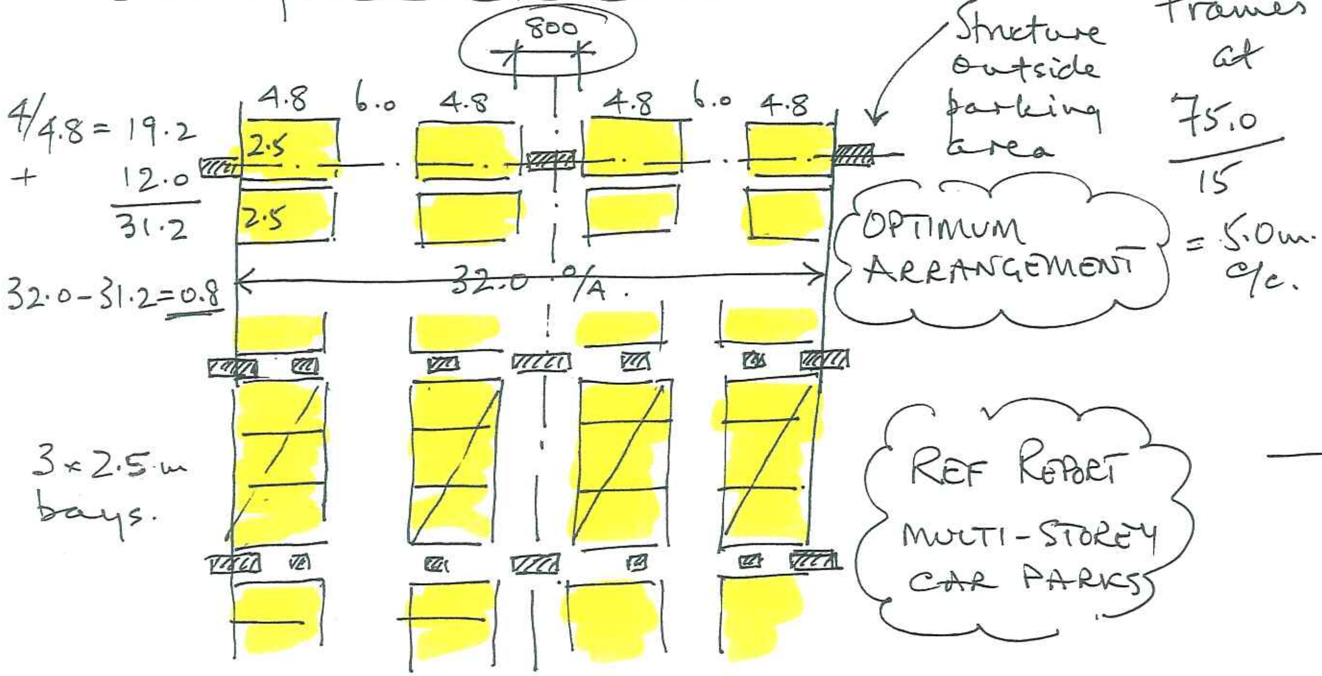


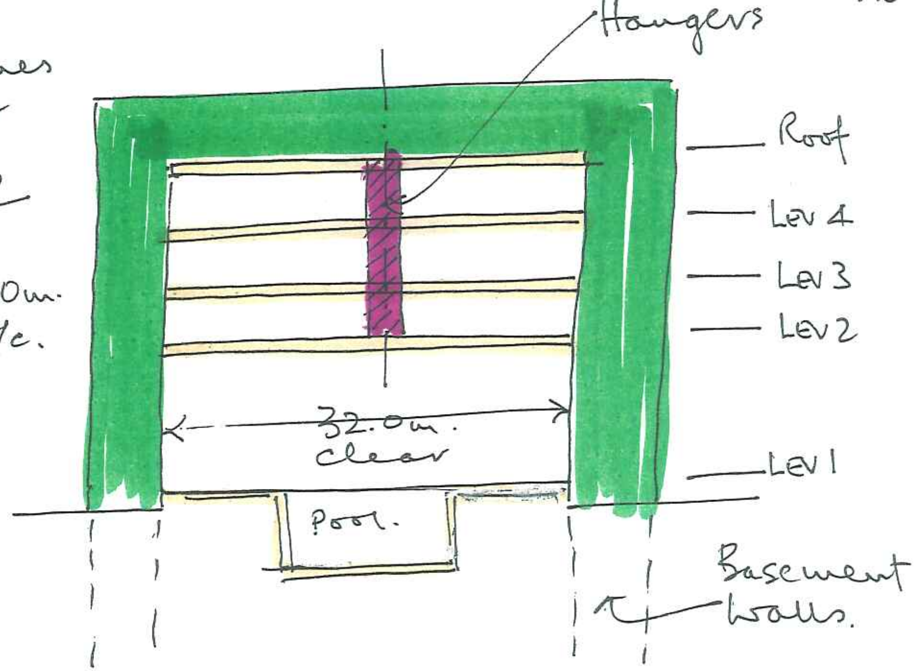


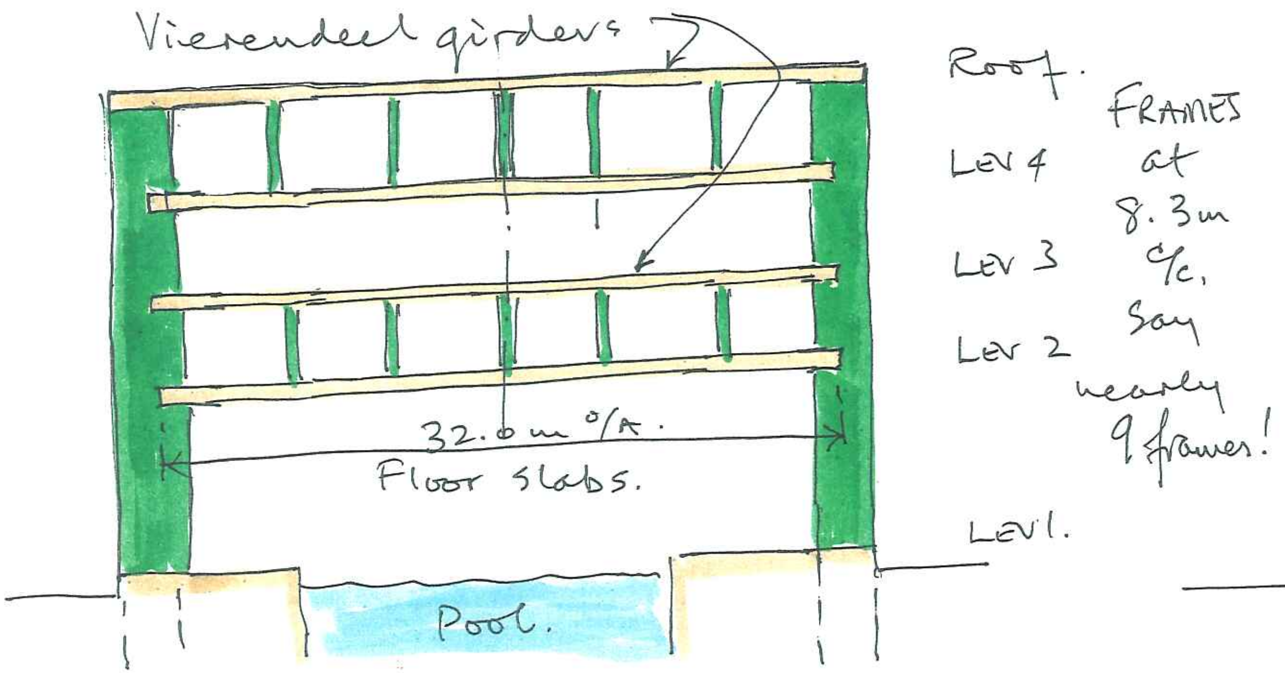
Pool supports

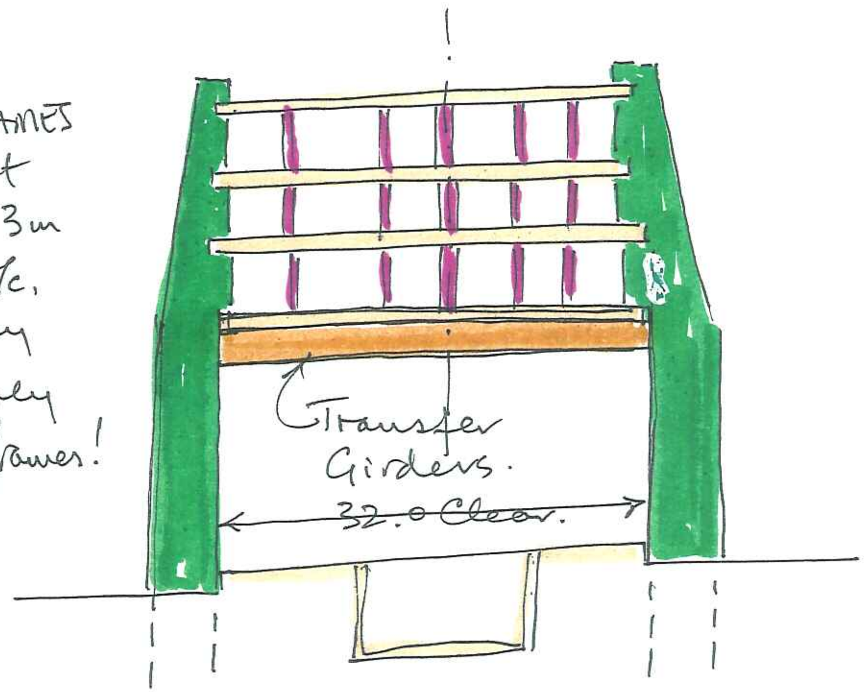


Car parking levels.

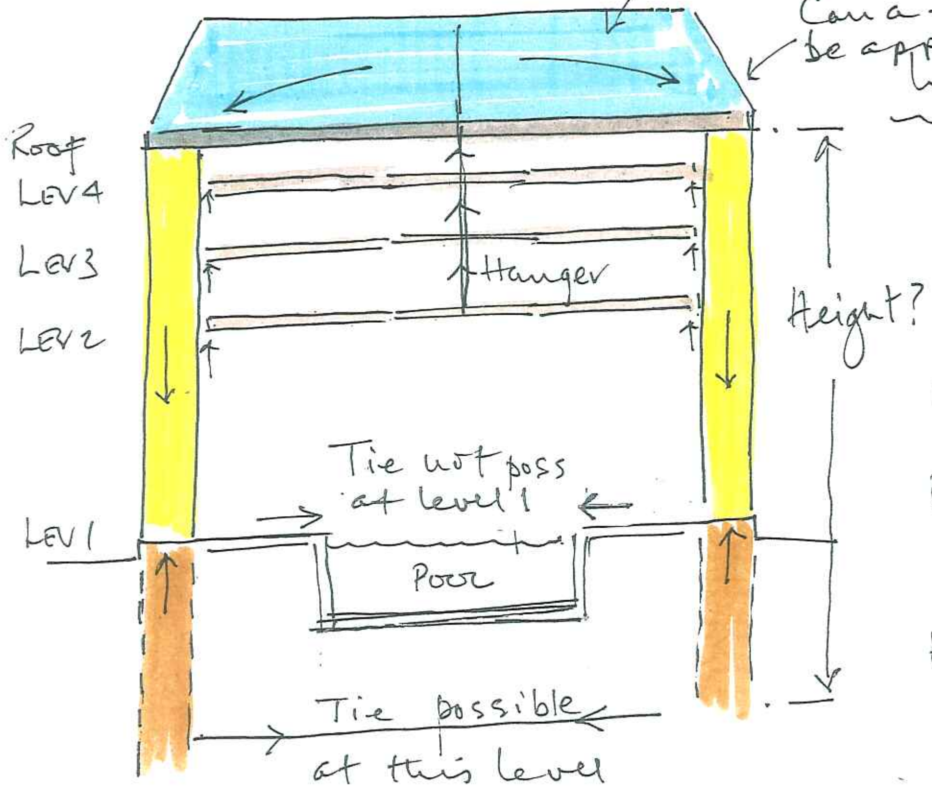


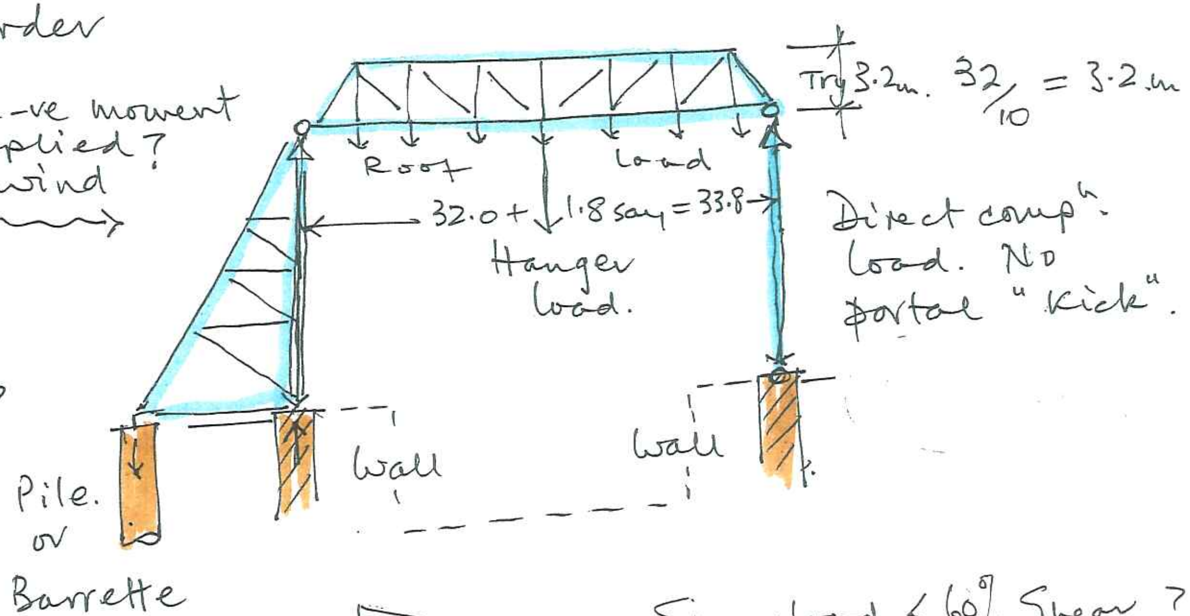






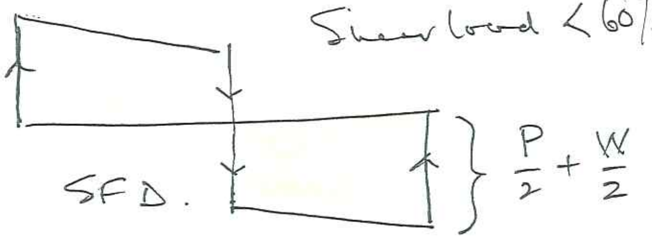
Frame models





$\frac{SF}{H \times t}$ = actual shear stress $< 0.6 p_y$

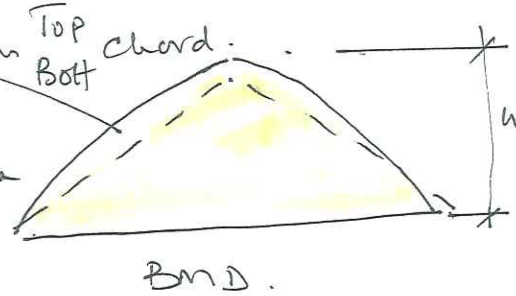
Shear load < 60% Shear ? Capacity



$\frac{M}{\text{Depth } H}$ = Force in Top / Bott chord.

$\frac{\text{Force}}{\text{Allowable stress}}$ = Area

275 N/mm² ?

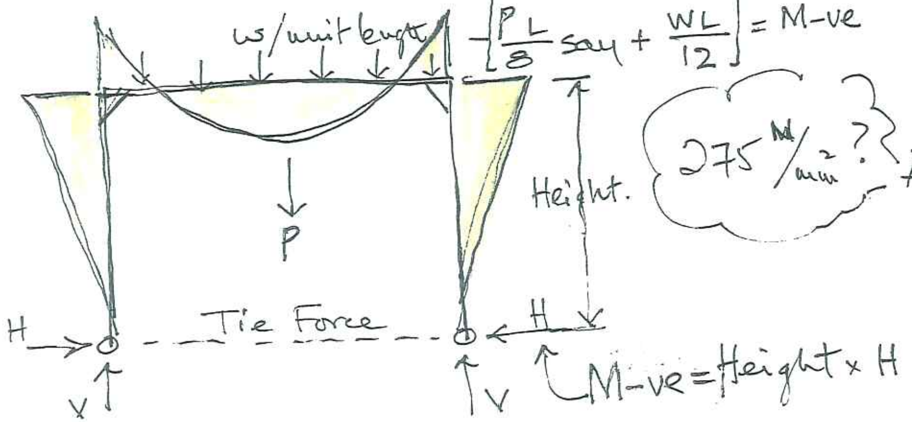


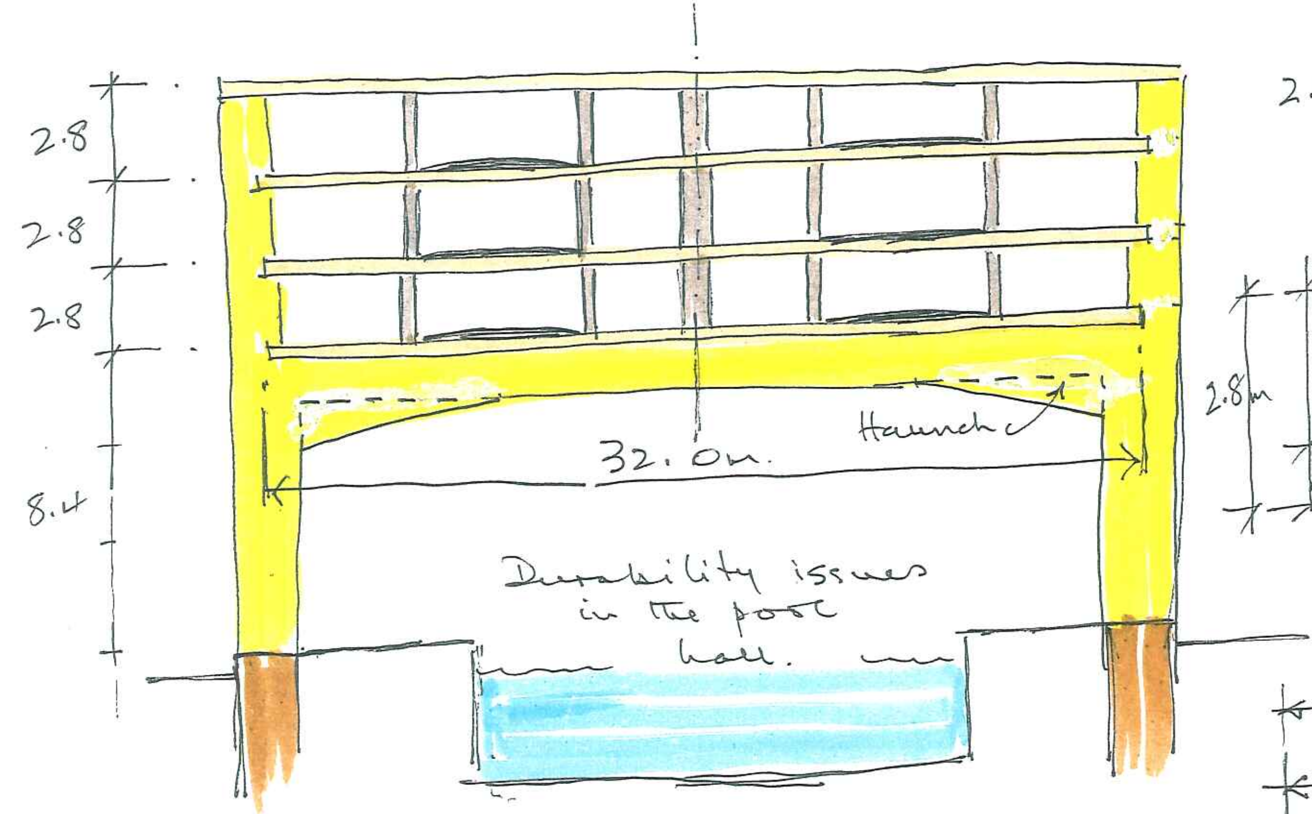
$I \approx a \cdot \bar{y}^2$

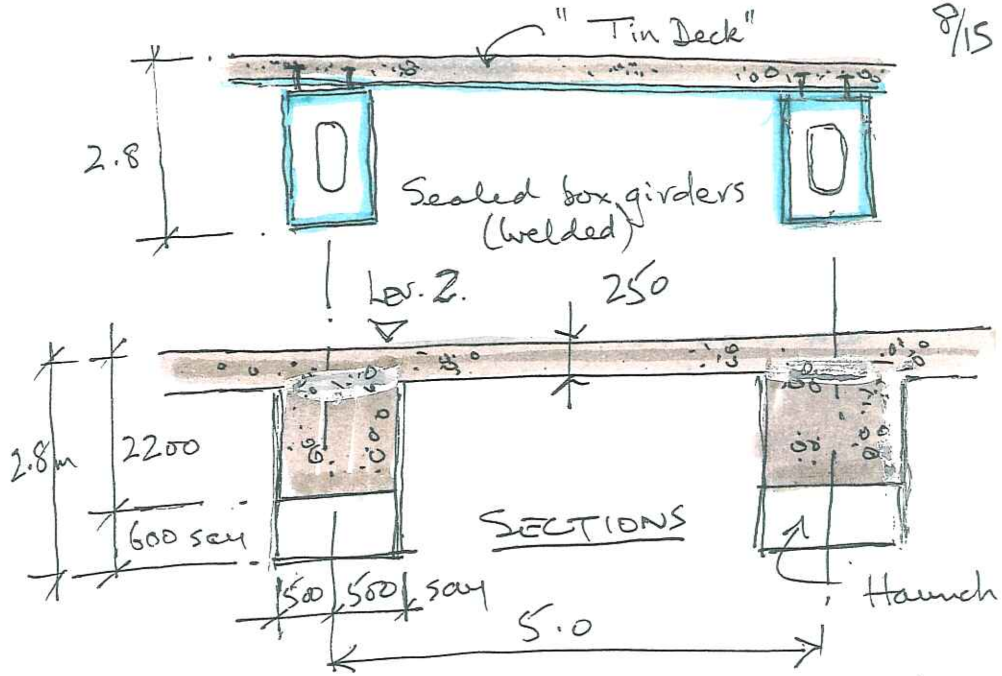
$E = 205$ kN/mm² $= 205 \times 10^3$ N/mm²

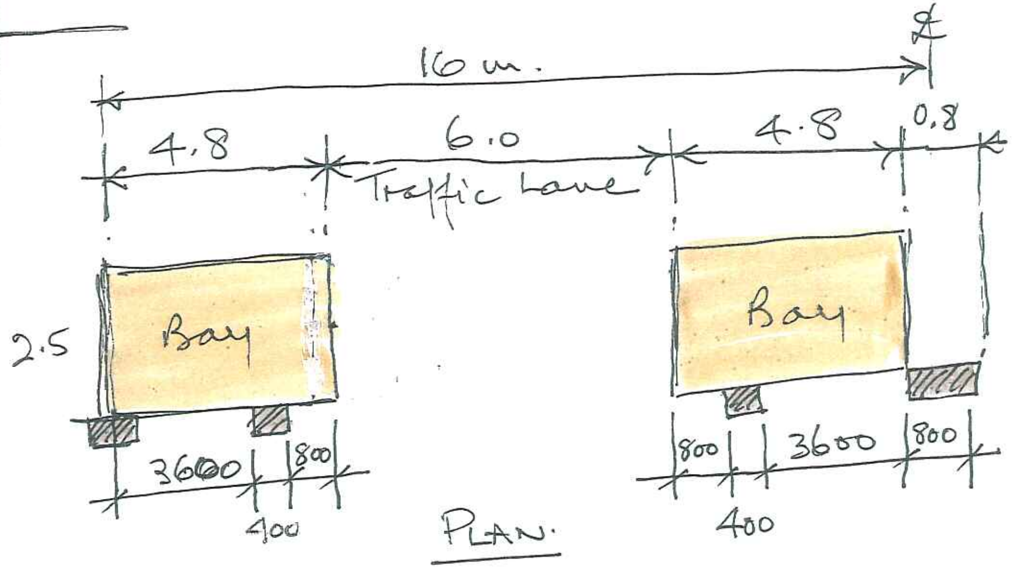
deflection $= \frac{PL^3}{48EI} + \frac{5WL^3}{384EI} \not> \frac{\text{Span}}{360}$

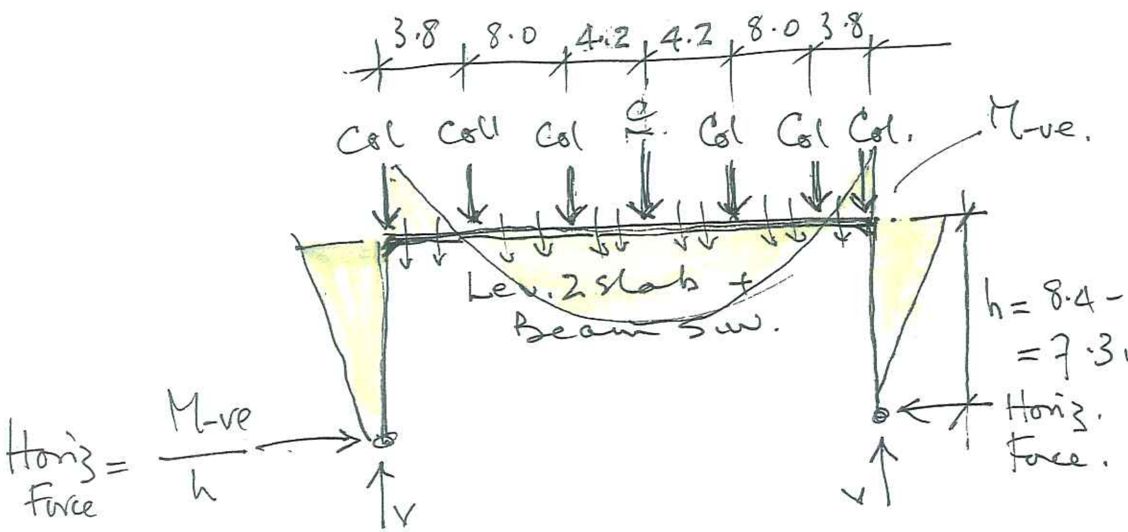
$-\left[\frac{PL}{8} \text{ say} + \frac{WL}{12}\right]$ = M-ve



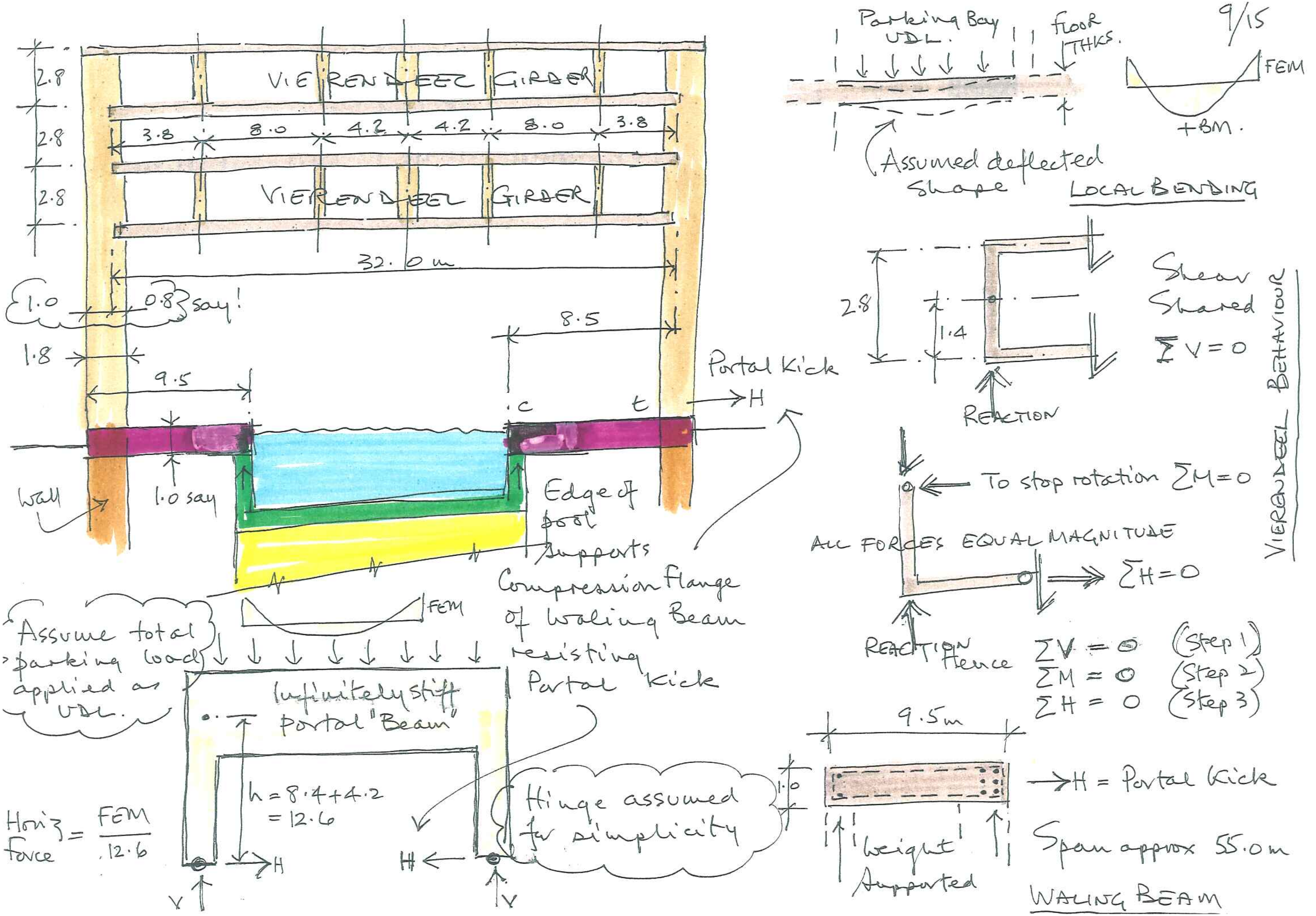




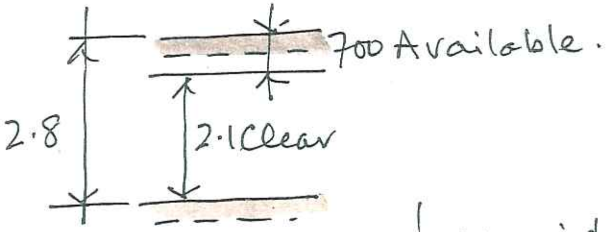




Ref: Design recommendations for Multi-storey and Underground car parks. [Fig 4.2]

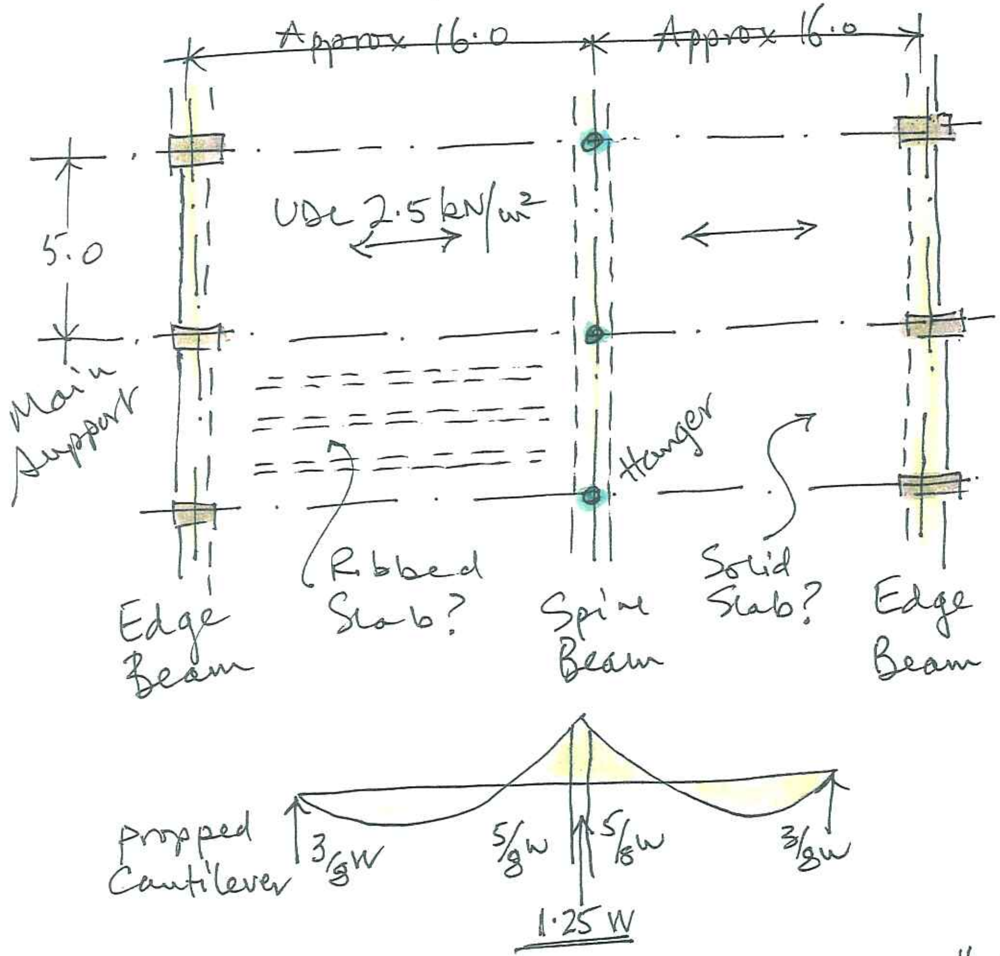

VIERENDEEL GIRDER
VIERENDEEL GIRDER
2.8
2.8
2.8
3.8
8.0
4.2
4.2
8.0
3.8
32.0m
1.0
0.8
say!
1.8
9.5
8.5
c
t
Portal Kick
H
1.0 say
Wall
Edge of pool supports
Compression flange of Waling Beam resisting Portal Kick
FEM
Assume total parking load applied as UDL.
Infinitely stiff portal "Beam"
h = 8.4 + 4.2
= 12.6
Horiz force = FEM / 12.6
H
H
V
V
Hinge assumed for simplicity
Parking Bay UDL.
Floor THKS.
FEM
+BM.
Assumed deflected shape
LOCAL BENDING
2.8
1.4
Shear Shared
ΣV = 0
REACTION
To stop rotation ΣM = 0
ALL FORCES EQUAL MAGNITUDE
ΣH = 0
REACTION
Hence
ΣV = 0 (Step 1)
ΣM = 0 (Step 2)
ΣH = 0 (Step 3)
VIERENDEEL BEHAVIOUR
9.5m
1.0
H = Portal Kick
Weight Supported
Span approx 55.0m
WALING BEAM

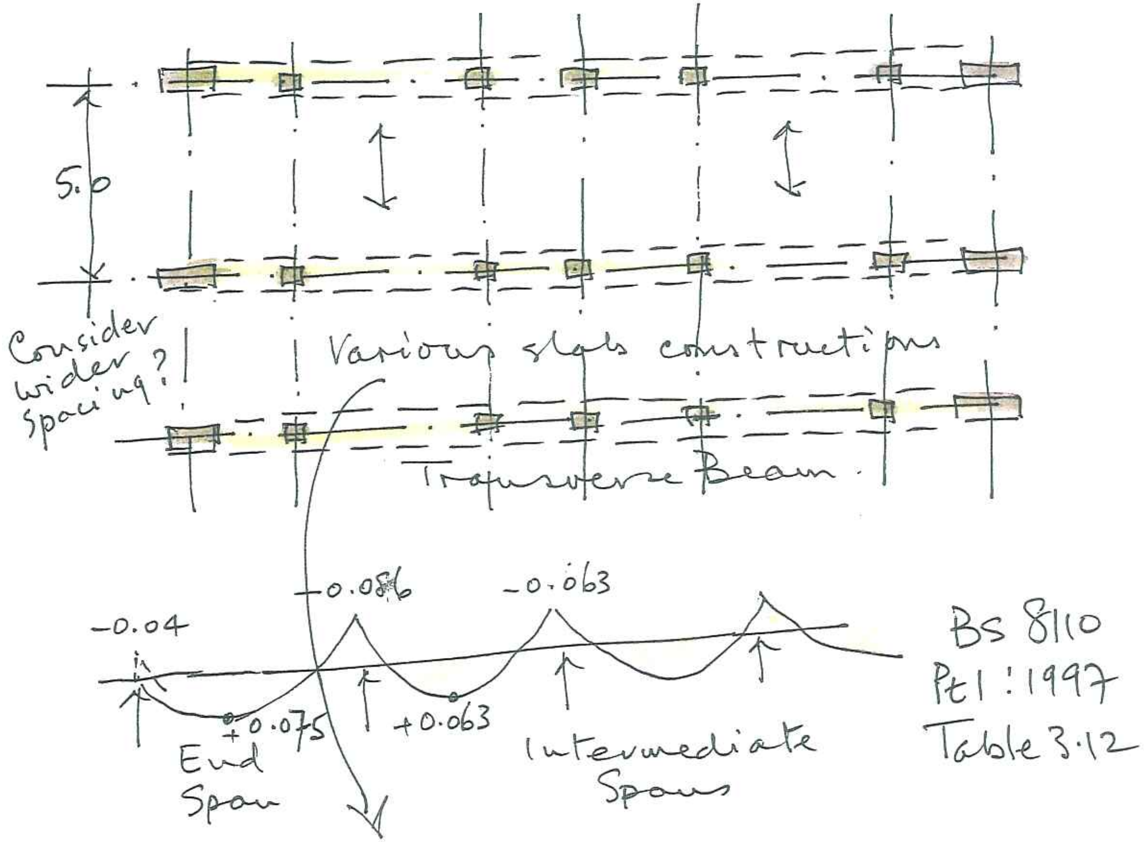
Parking-floor slabs



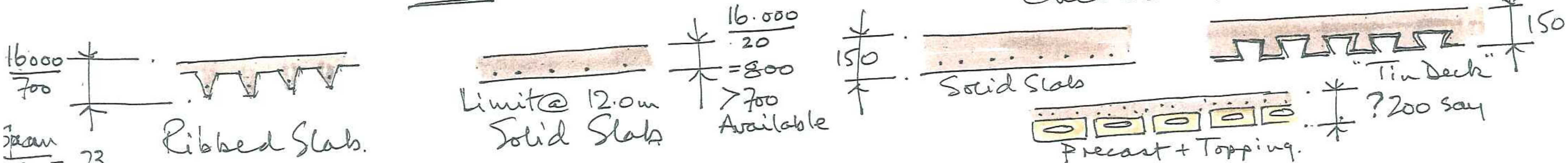
Transverse spanning —

Longitudinal spanning —





Check 2hr. Fire resistance

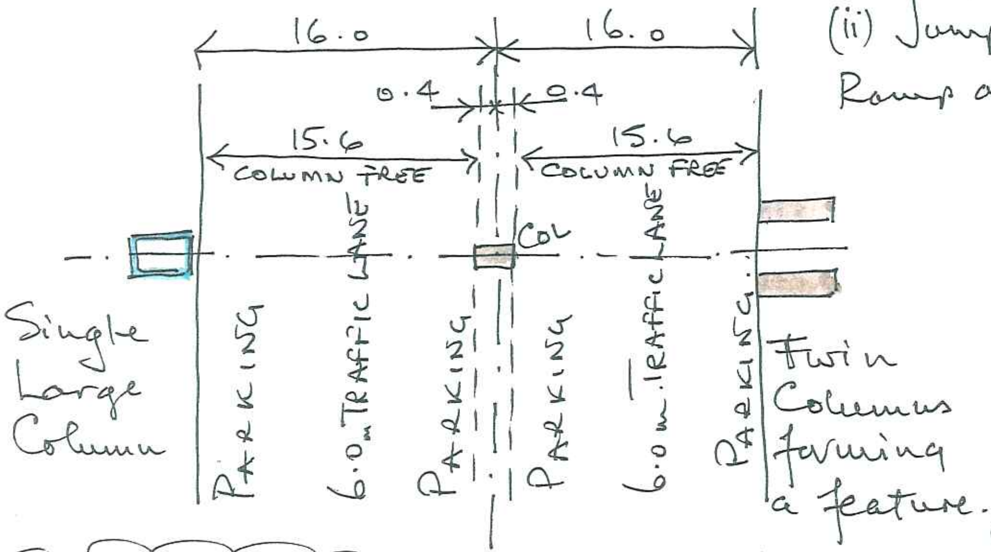


Span/d = 23
Probably at limit

? Formwork ??

Reference: Concrete Buildings - Scheme Design Manual

Main Supports.

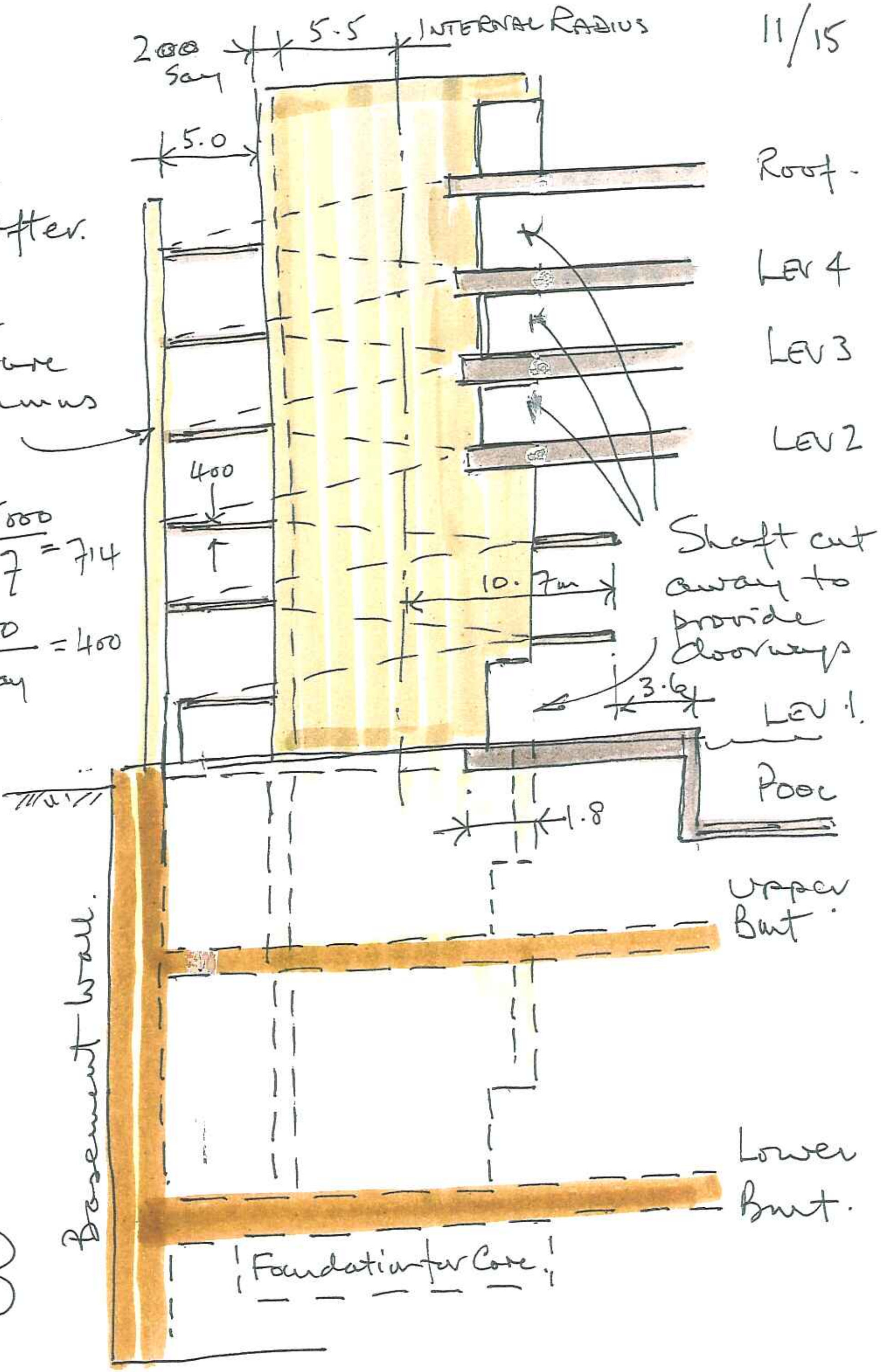


Core

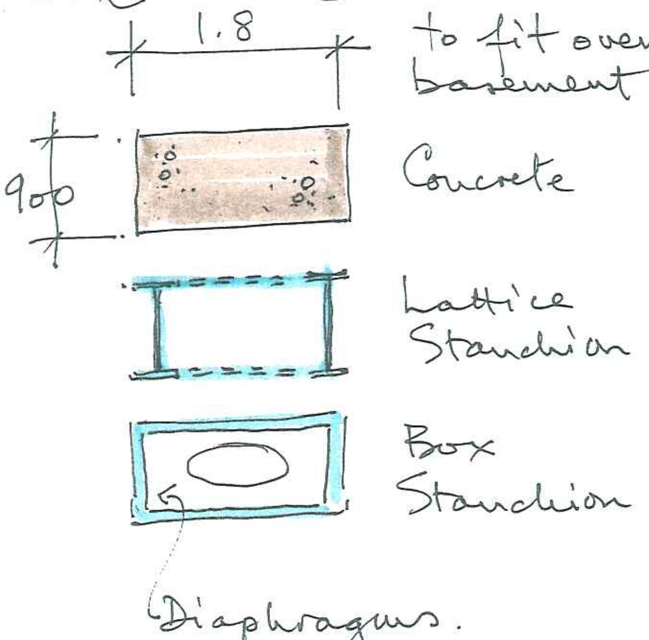
(i) Slip formed

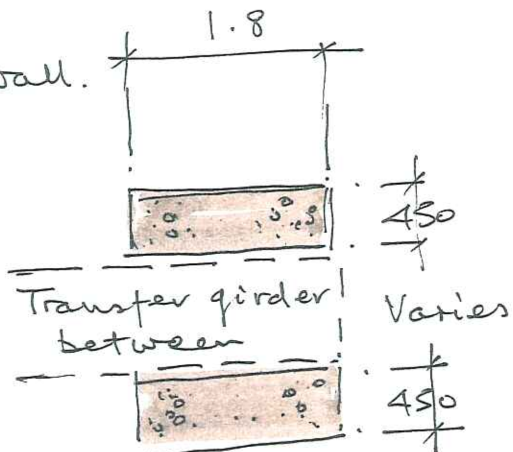
(ii) Jump formed

Ramp added after.



Wind onto Service Cores.



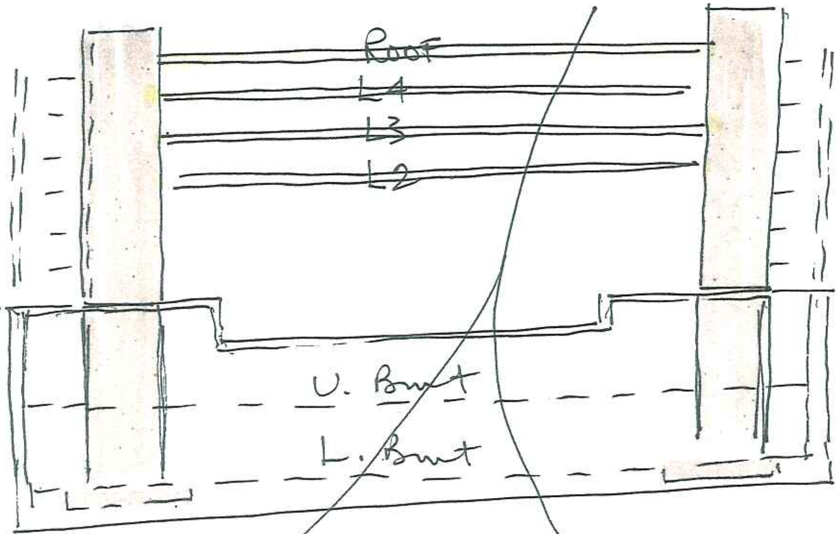


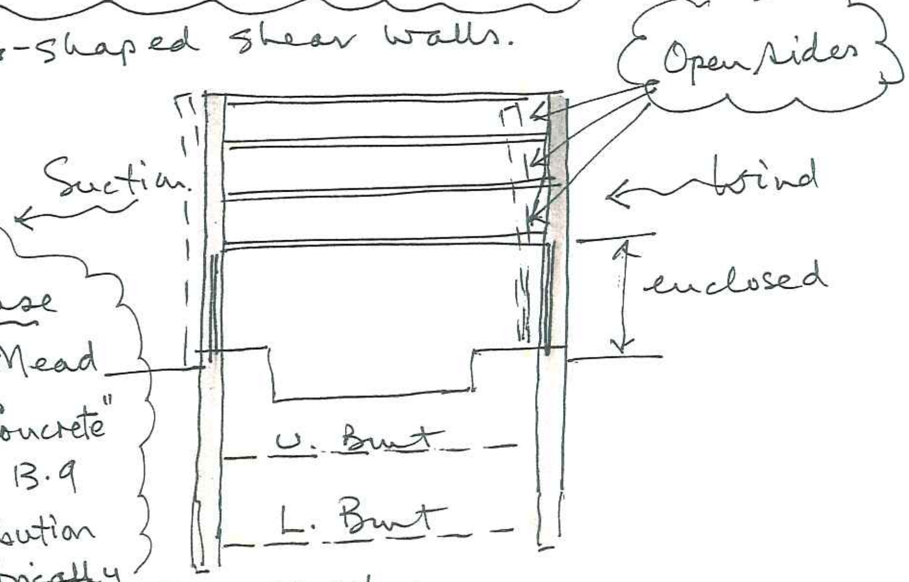
Probably able to resist longitudinal wind forces.

Wind stability

Approximate treatment on each axis. Real behaviour much more complex.

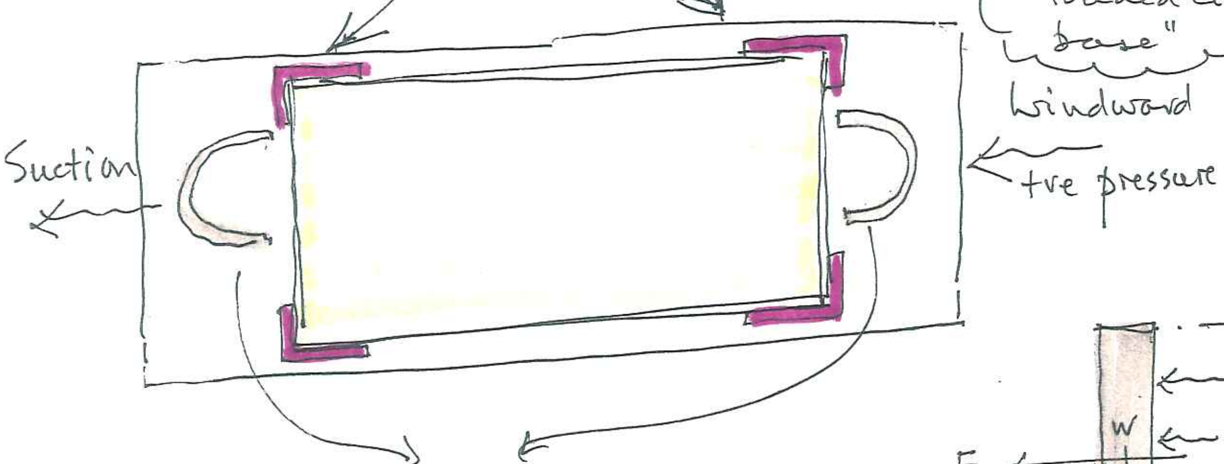
Altenative could use L-shaped shear walls.



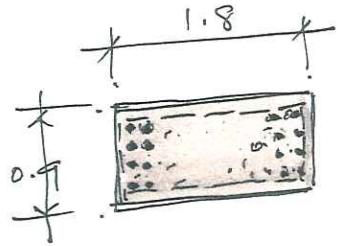


Circular Base

See Faber + Mead "Reinforced Concrete" p. 427 – Fig 13.9 "Pressure distribution under eccentrically loaded circular base"



For simplicity: Assume wind moment taken on column section(s) as a cantilever

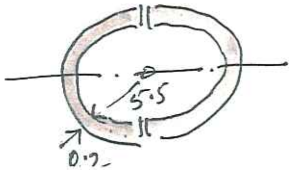


@ 5.0m c/c.

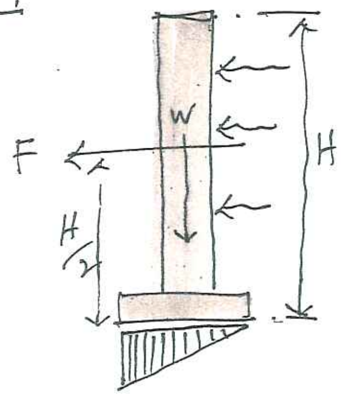
and combine with "portal" moments as appropriate.

Reinforce symmetrically.

Equivalent to:



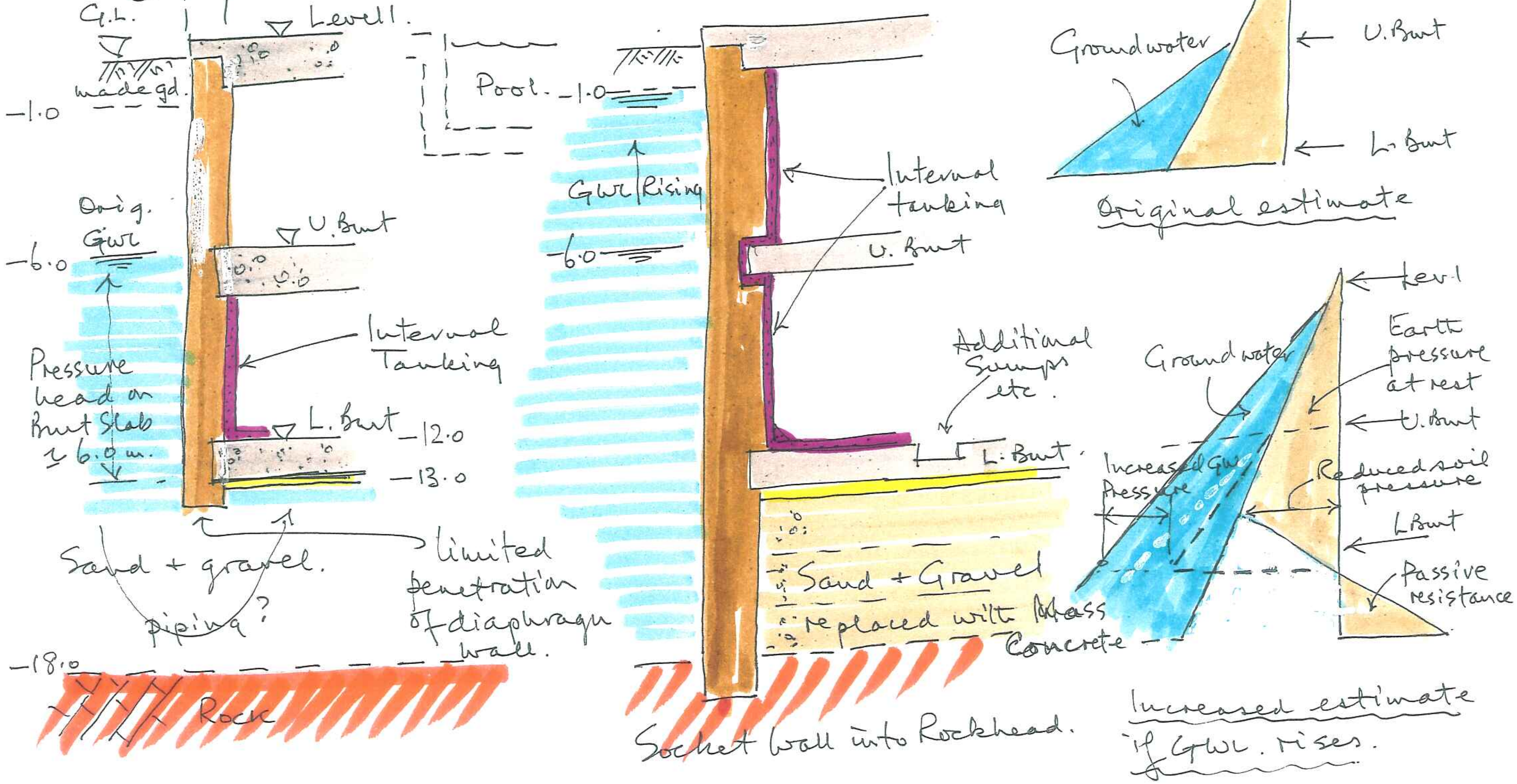
Single core



Letter

Issues: (i) Uplift increase unless cut-off used.
(ii) Lateral pressure on wall increases.
(iii) More elaborate waterproofing needed.

Weight of superstructure not included in calculation of uplift stability.



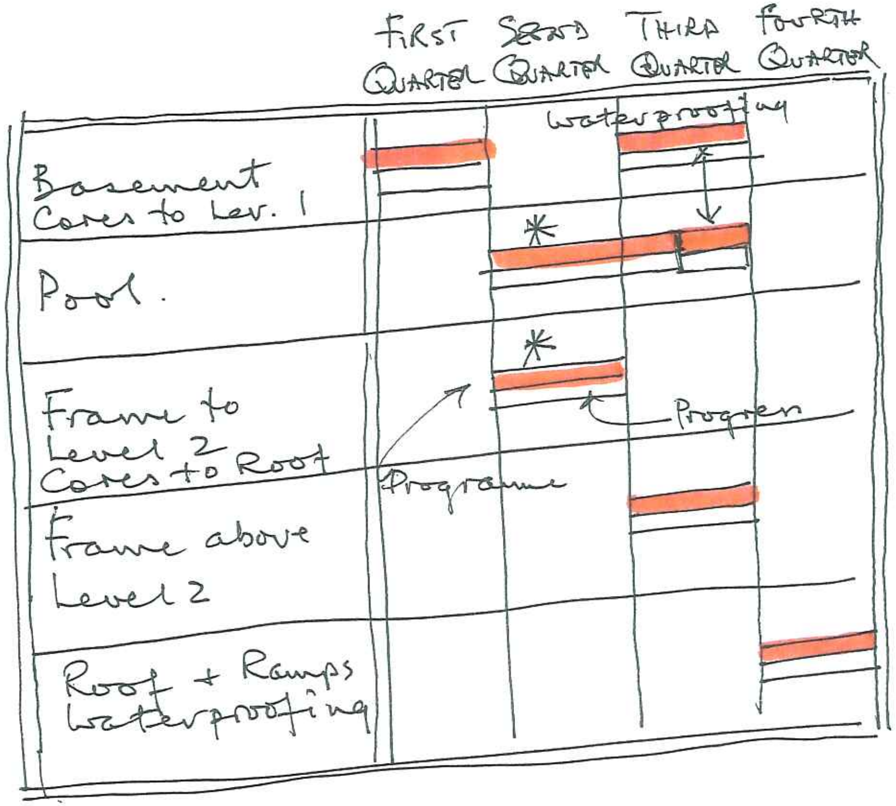
Method Statement & Programme

Ⓐ Top-down basement construction assumed with external diaphragm walls. Level 1 slab, U. Bmt + L Bmt act as struts

Danger of piping under external wall — Install wellpoints <u>OUTSIDE</u> and control water until L-Basement slab has been constructed.

Ⓑ Swimming pool has been designed as an R.C. structure with internal waterproof membrane — i.e. concrete shell is <u>not</u> watertight!

Ⓒ The superstructure frame has been designed as a "Portal Frame". Neither the columns nor the transverse beam can be considered to be stable until the parking level slab at Level 2 is in place and can be loadbearing. Above this level the construction is "traditional" insitu concrete using falsework + formwork. Minimum concrete strengths are required at various stages.



Matters to be resolved:

- Critical path
- Seasonal construction
- Resource levelling.
- Cash flow.
- Safety if working over the pool *

Principal design elements

From page 3 — Swimming pool floor (assume walls similar)

From page 4 — basement walls for soil + water pressure.

From page 5 — pool supports, check punching shear and contact bearing.

From page 6 — main frame – either
- transfer girder + cols
- portal frame
- Vierendeel girders.

(See also pp. 7–9 incl)

Possible solution to past CM examination question

Question 5 April 2007

Visitors' Centre

by Bob Wilson

Question 5. Visitors' Centre

Client's requirements

1. A visitors' centre is to be constructed on a hillside: see Figure Q5.
2. The roof will be covered with 0.2m of topsoil over fill to a maximum total thickness of 0.75m. The ground level is to be raised around the building on three sides so that the finished building will appear to be set into the hillside.
3. The front retaining wall is to be stone-clad. The three-storey entrance area and the internal walls overlooking the entrance area are to be glazed.
4. No columns are permitted inside the entrance area. Elsewhere columns must be spaced at not less than 5.0m centres in either direction and must be positioned not less than 5.0m from the rear and side walls.
5. Allowable structural zones:

Level 2	0.7m
Level 3	0.7m
Roof	1.0m

Loadings

6. Imposed loading

Roof	5.0kN/m²
Floors	5.0kN/m²

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

Site Conditions

7. The site is located in open country. Basic wind speed is 46m/s based on a 3-second gust; the equivalent mean hourly wind speed is 23m/s.
8. Typical ground conditions relative to floor level 1 at +0.0m datum:

Below +2.85m	Sandstone, allowable safe bearing capacity 3000kN/m²
Above +2.85m	Glacial clay, internal angle of friction $\phi' = 28^o$, bulk density = 1950kg/m³.

Topsoil and vegetation 0.2m deep overlie the hillside. Groundwater level is at the top of the sandstone.

Omit from consideration

9. Detailed design of the service cores and 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 you have completed your design the client wishes to add a further 1.0m depth of fill over the building. Write a letter to your client advising the implications of the proposal. (10 marks)

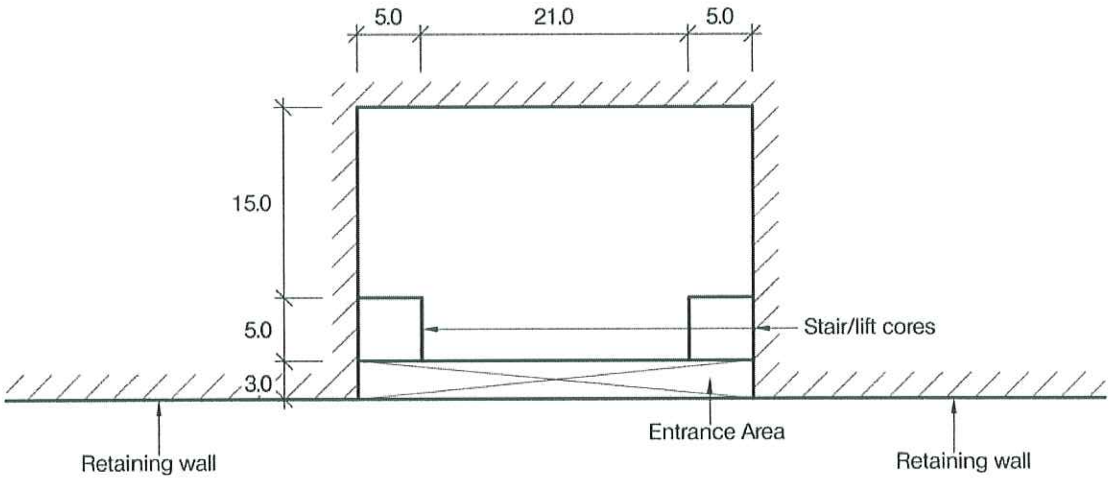
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

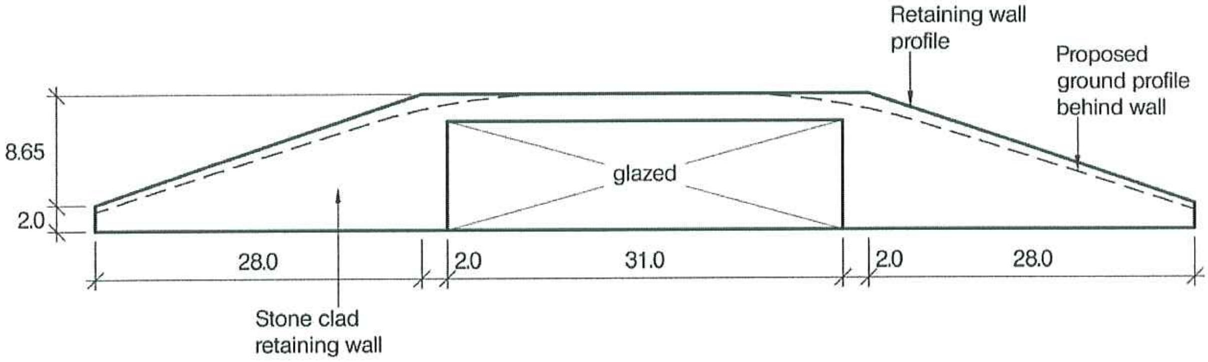
c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)

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)

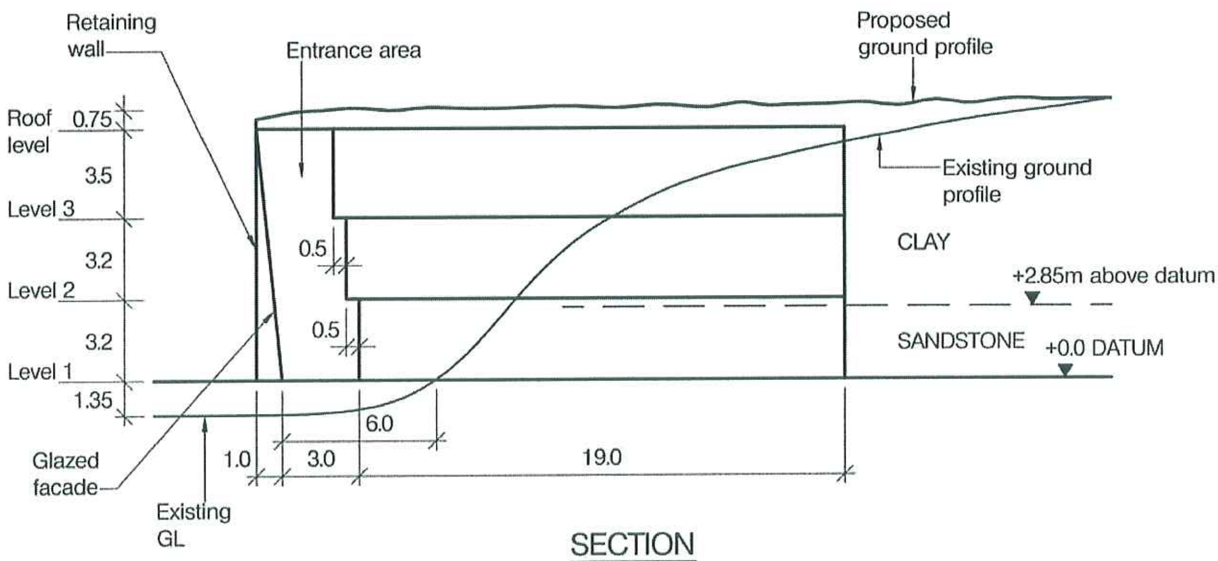
e. Prepare a detailed method statement for the safe construction of the building and an outline construction programme. (10 marks)



PLAN ON LEVEL 3



FRONT ELEVATION



SECTION

NOTE: All dimensions are in metres

FIGURE Q5

Q5/2007 – VISITORS' CENTRE

In preparing my thoughts for the answer to this question I have realized that I have taken much longer that any candidate would have in the examination. However, the notes and sketches that are attached do, I think, provide much of the detail that would be required in real life: thereby providing a basis for the ideal 100% answer.

I certainly found myself caught-up in the detail of the excavation, the groundwater control and the waterproofing – both to the walls and to the roof. I was distracted [just a little] by the lift not having a motor room or lift pit: so I ignored them! Too bad if the initial scheme is faulty – however I did note the missing details in my answer.

The drawings for the question – Figure 5 – helped with the column grid, which I made as large as I dared. I had to pause about the spacing of the columns beside the retaining walls – the question says "Columns must be spaced at not less than 5.0m *centers* in either direction ***and must be positioned not less than 5.0m from the rear and side walls***." I decided that the wording must mean that the 5.0m must be a clear dimension between the face of the wall and the face of the column. Once I had plumped for a column size of 600 x 600 the grid fell into place [see my sheet 11].

I decided that I could not manage the design of the glazed façade, a specialized element if ever I saw one! So I sketched the bare bones [see my sheet 15] and consoled myself that I might only loose a mark or two: marks that I would have to work hard for and might make up as 'Brownie Points' with my more detailed answers to the waterproofing, etc.

This is the type of decision that you may have to make when you don't have the specialized information or experience. In this case the glazed façade itself is not, in my opinion, a critical element of the scheme – providing it is allowed for and not totally ignored. I would not do this with other elements such as the waterproofing or groundwater control. These are elements that are both critical and that I should know about as the Engineer for the scheme. One must be careful when 'bypassing' anything in the question and mentally weigh-up what you might loose. If your 'bypassing' alters the question and makes it significantly easier then you must not do it as it will become your 'Failure Point'. In this case, examples would be:

- Ignoring the groundwater problem,
- Deciding not to backfill and cover the roof.

The answer divides itself into five main parts:

1. constructing the wing walls that are free-standing and do not need to be cut into the existing slope,
2. the excavation and groundwater control for the large area to be occupied by the new building,
3. the construction and waterproofing of the basement walls,
4. the spacing of the internal columns and the direction of span of the two floor spans,
5. the roof as a structure carrying backfill and requiring to be waterproof, and the 'beam' over the glazed façade.

Q5/2007 – VISITORS' CENTRE

Secondary issues that you might or might not resolve, depending on available time:

1. how to dispose of the excavated materials – the clay and the sandstone,
2. the extent of the stone cladding, and the fixing details,
3. drainage from behind the retaining walls and from the roof area.

I found that it was difficult to identify two distinct and viable solutions for this question. I found that as I worked through the tasks I quickly eliminated alternatives because the 'favorite' already stood out clearly. In retrospect I think I should have stated more clearly what alternatives I saw and then discussed their merits in more detail. This would have taken more time and hindered my train of thought! I was on the crest of a wave of thought and did not want to stop. This is part of the design process and something that we all enjoy and look forward to in new projects: it is very exhilarating! But quite wrong in this examination where you must slow down and explain yourself at every stage of the process.

The alternatives have to be described and set down on paper, consequently:

- The wing walls could be mass concrete, gravity-style walls with or without the stone cladding making a contribution. Alternatively they could be in reinforced concrete and have a non-structural facing. Because of the height of the wall the question of using buttresses or counter forts should be asked: buttresses are the exposed projections on the face of the wall, and counter forts are the hidden projections on the back of the wall [in tension]. Other alternatives might be reinforced earth, crib walling or gabions.
  You have to think of the calculations – the ones you can do! Here you must be able to develop the earth and water pressures and then demonstrate the stability of the wall. A reinforced wall will also require you to determine the reinforcement and show a rebar detail! Consider the available marks! Perhaps five marks are available? The earth pressure must be determined so there go two of the marks! Stability must be shown [instability is a 'Failure Point'] – another two marks? It will be a hard-won mark if you work out the rebar too!

- It is reasonably clear that the groundwater must be controlled: the design should not allow the water to build up behind the walls. The alternatives are to collect the water and drain it away or to intercept it uphill and divert it away from the new structure. If you opt for the drainage solution you need to anticipate that in the lifetime of the building [60 years?] the drainage can become clogged and ineffective: the system needs to incorporate a maintenance facility.

- The alternatives for the basement walls are probably limited to L-shaped, full-height cantilevers or a wall propped by the floors and roof. If you decide to incorporate the floors this will influence your direction of span for the floor slab, or it might direct you to different wall structures in the sides and back wall. The waterproofing will probably be your choice between external or internal tanking. You should indicate to the Client what the different standards of waterproofing and vapour-proofing are: this is a Visitor's Centre and must at least be habitable!

But would you go to a 'drained cavity' system?
With this soil profile and original ground levels I consider that bored-pile or bentonite-diaphragm walls are not the answer.

- The two lift shafts will contribute to the support of the front edge of the floor slabs: in other respects it will be possible to have one or two transverse rows of columns. The allowable structural zones [Client's requirements number 6] seem to be quite generous. Even with only one transverse row of columns two slab-span arrangements are possible [see my sheet 13]. This gives the fewest number of columns, which should recommend itself to the Client! In selecting the column grid do not overlook the support of the heavy roof.
  I chose the simple-to-design one-way spanning arrangement of slabs on beams [see my sheet 18]. I have also provided wall-type supports between the lift shafts: this turned out to be a saving grace when it came to the roof [see my sheet 19].
  There are no sensible alternatives for the roof slabs and beams: they follow the pattern below. It is possible to consider different forms of slab [waffle slab or ribbed] in order to reduce the self-weight of the structure. However, the 31m-long 'beam' over the glazed façade is deceptive. Initially I saw it as a sort of 'portal frame' when combined with the 2.0m-wide edges to the opening. However, there are two commanding reasons why this 'beam' must not deflect [as it surely would in reinforced concrete because of creep and elastic movements]: the first reason is because of the glass façade; and the second is because the roof must not sag and upset the drainage under the fill.
  This forced me to consider an alternative [see my sheet 18]. The alternative is to support the Upstand above the glazed façade with cantilever beams projecting from the walls of the lift shaft and the walls between [see my sheet 13]. The ceiling of the Entrance Area can be featured with 'downstands' or may be left plain.

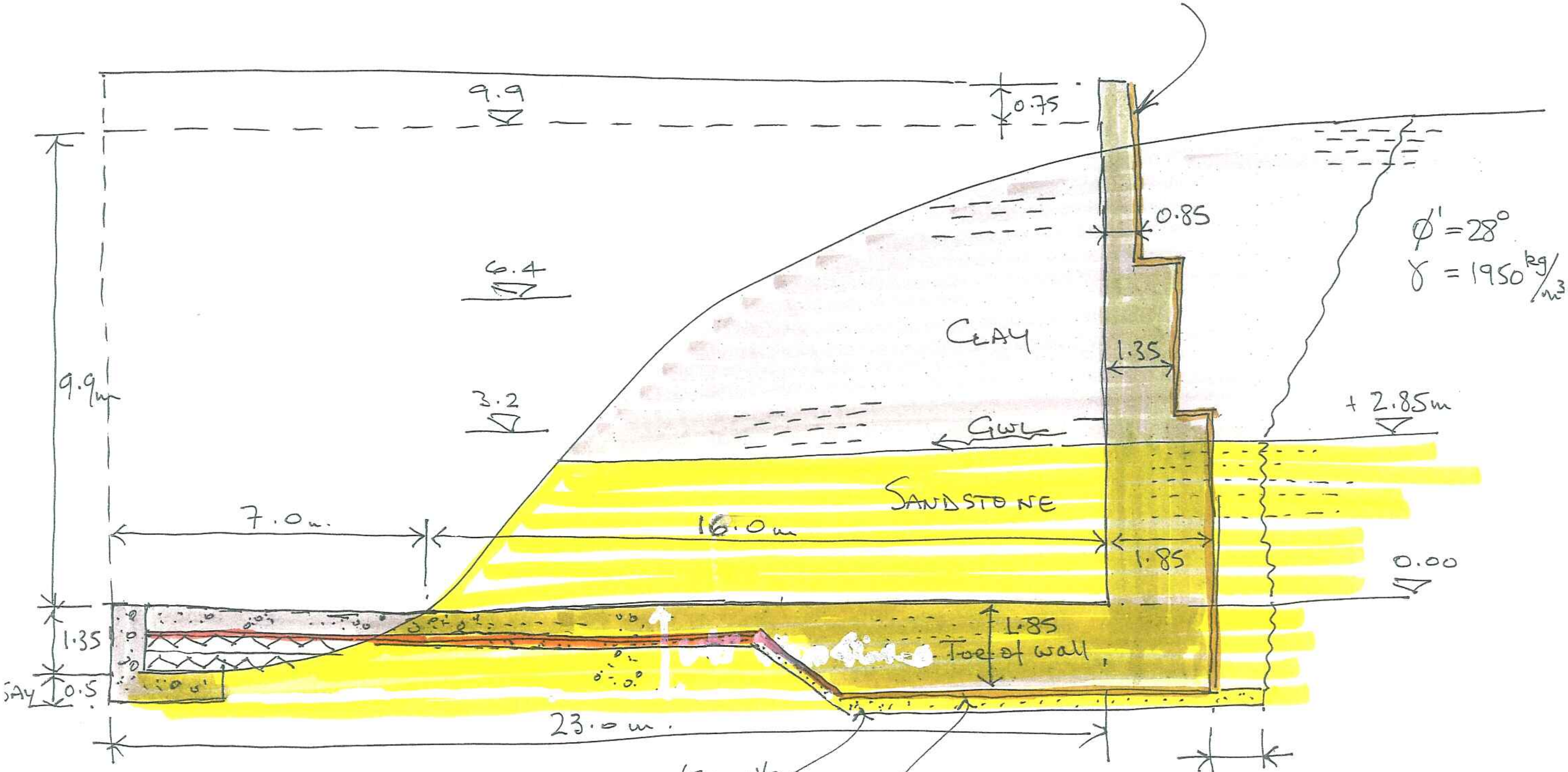
- The 'Letter' is curious – why should the ground levels be raised with more, heavy fill? But see my sheet 20. A sketch should be included.

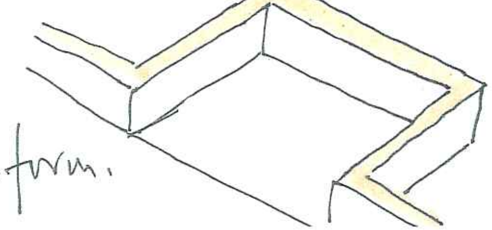
Q.5 /2007 – Visitor's Centre

- The question is about a large, 3-level building built into the side of a hill with the roof covered with backfill. The front elevation is fully glazed.
- The main issues are:
  - the hillside excavation and groundwater control. pp. 2 – 3 & 4
  - the Level 1 slab and perimeter walls — structure pp 9 Calcs 1 - p 17
  - The Level 1 slab and perimeter walls — waterproofing p10
  - Level 2 & 3 slabs and supports — stepped at entrance area. pp 11 to 14
  - Roof level slab and support — waterproofing + soil cover.
    ? cantilevering over the glass façade? See Calculations 2 p 18
  - Glass façade full-height – 9.9 m. – by specialist! p 15
  - Wing walls each side of the façade pp. 5, 6, 7 & 8
- References. p. 16.
- Calculations: pp 17, 18, 19 & 20
- Restrictions are:
  - No columns inside the entrance area – full height 9.9 m.
  - Internal columns ≮ 5 m c/c each direction
    ≮ 5 m from rear + side walls ? ℄ or face?
  - Structural zones Lev 2 + Lev 3 — 0.7 m Imposed loads $5 \, kN/m^2$
    Roof 1.0 m — Imposed load $5 \, kN/m^2$

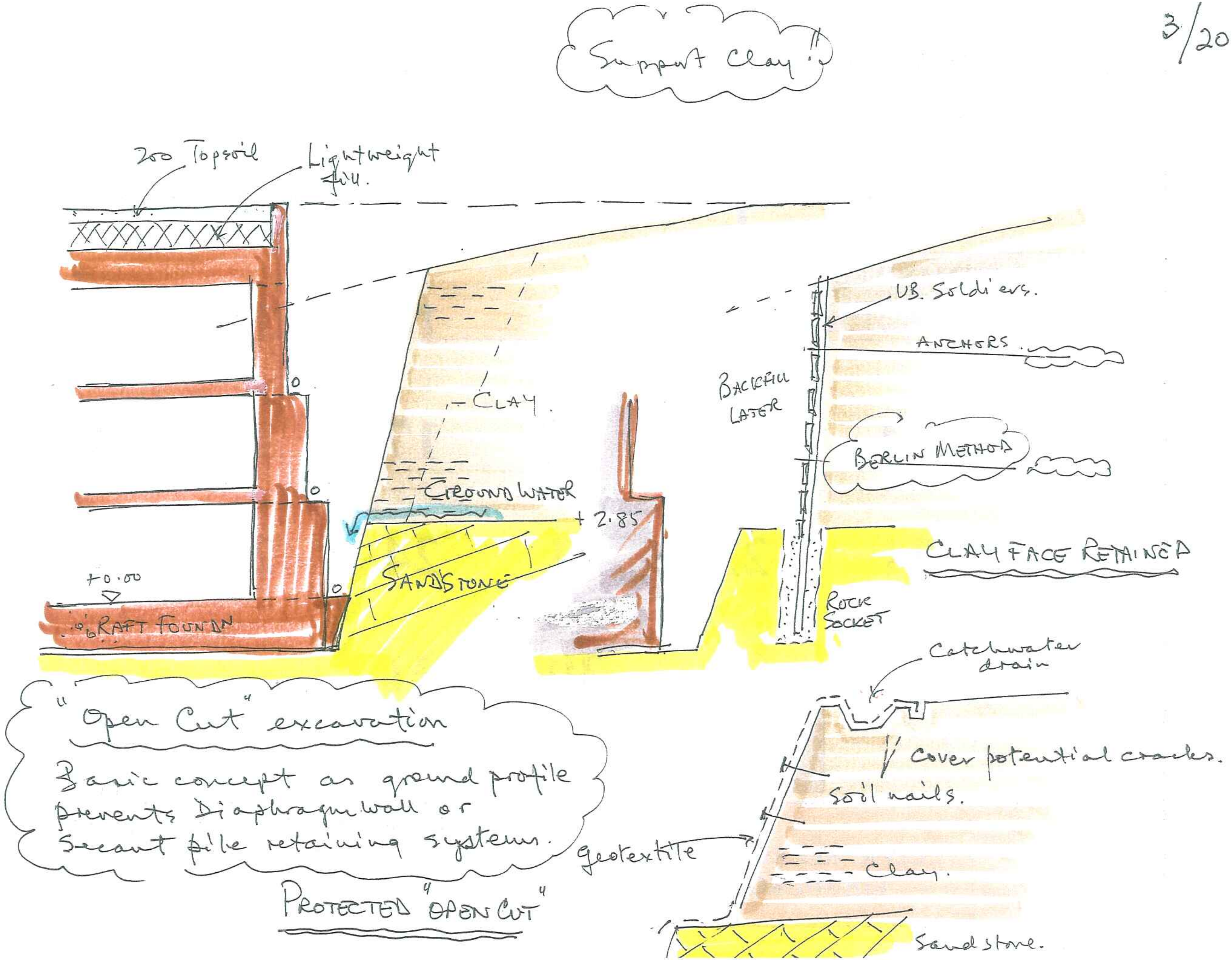
Hillside excavation.

Option 1. R.C. wall constructed insitu.

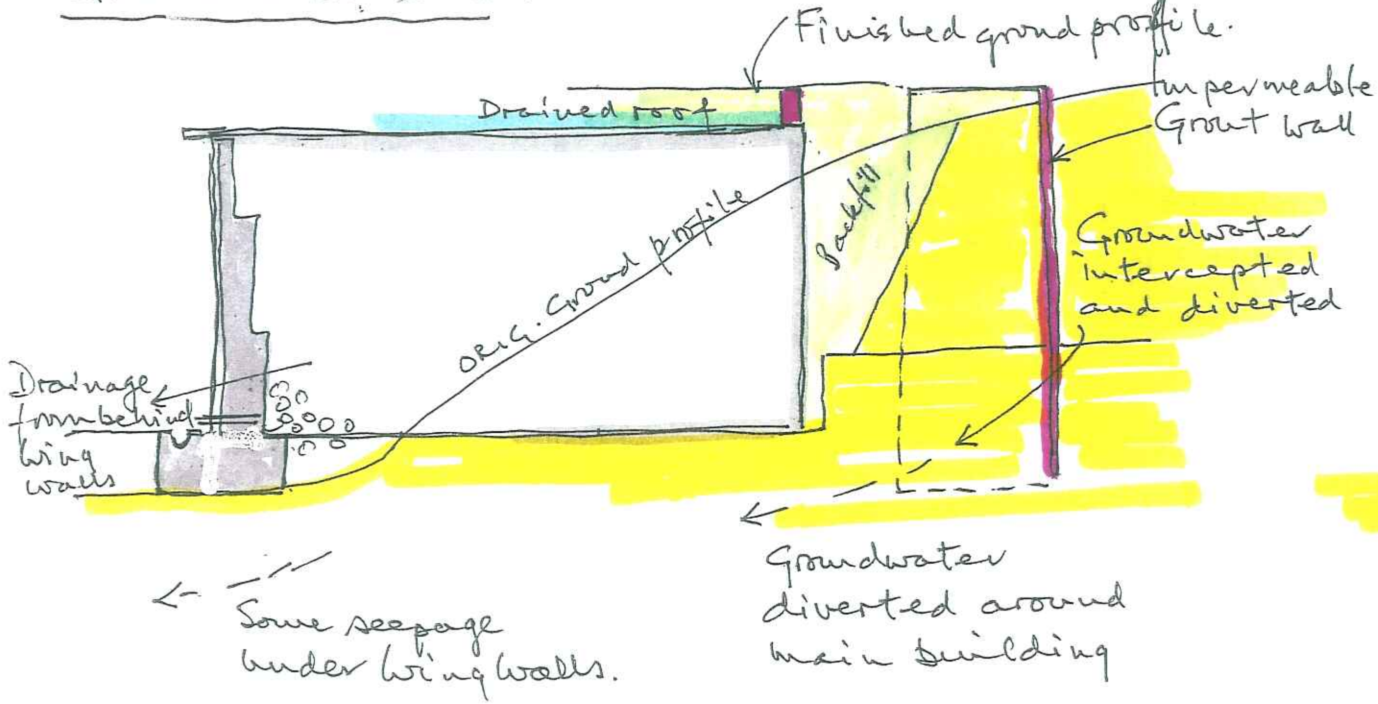


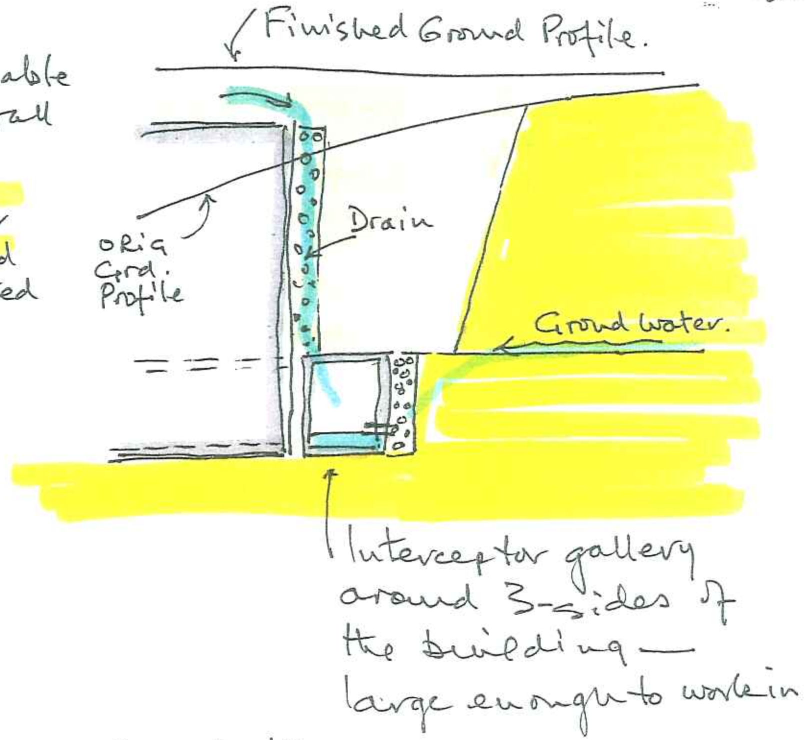


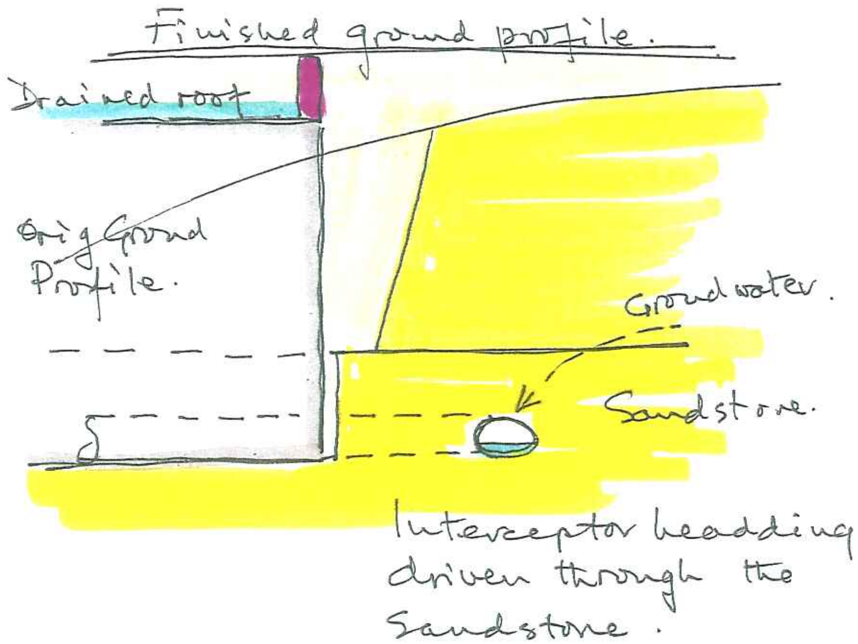
Basicform.

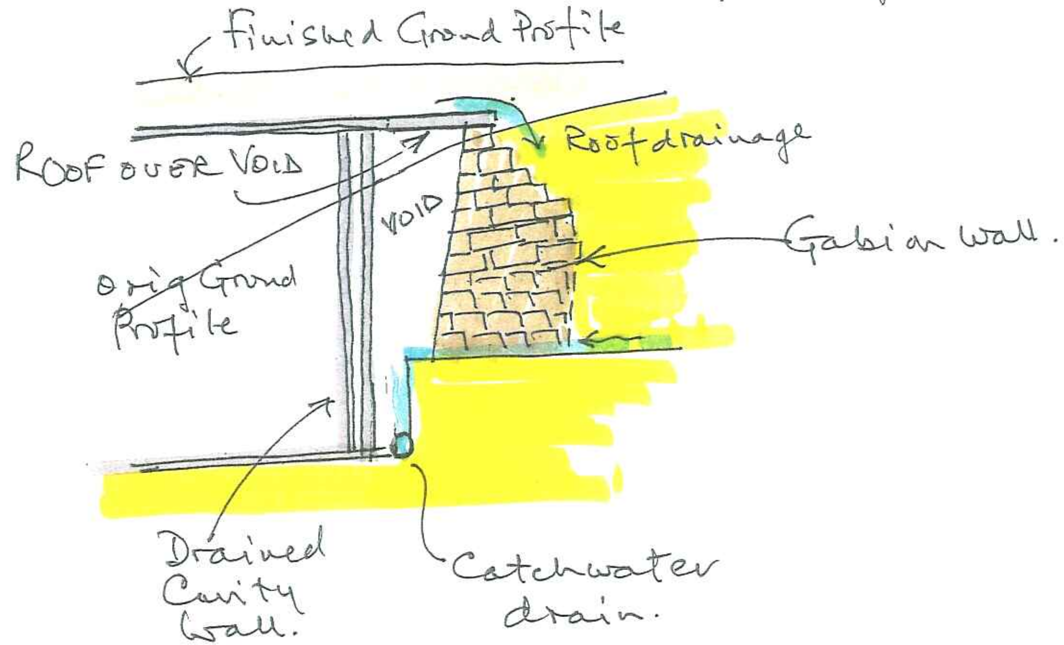

Support Clay!!
200 Topsoil
Lightweight fill.
Clay.
Ground Water
+2.85
Sandstone
+0.00
Raft Found'n
Backfill Later
U.B. Soldiers.
Anchors.
Berlin Method
Clay Face Retained
Rock Socket
Catchwater drain
Cover potential cracks.
Soil nails.
Geotextile
Clay.
Sandstone.
"Open Cut" excavation
Basic concept as ground profile prevents Diaphragm wall or Secant pile retaining systems.
Protected "Open Cut"

Groundwater control

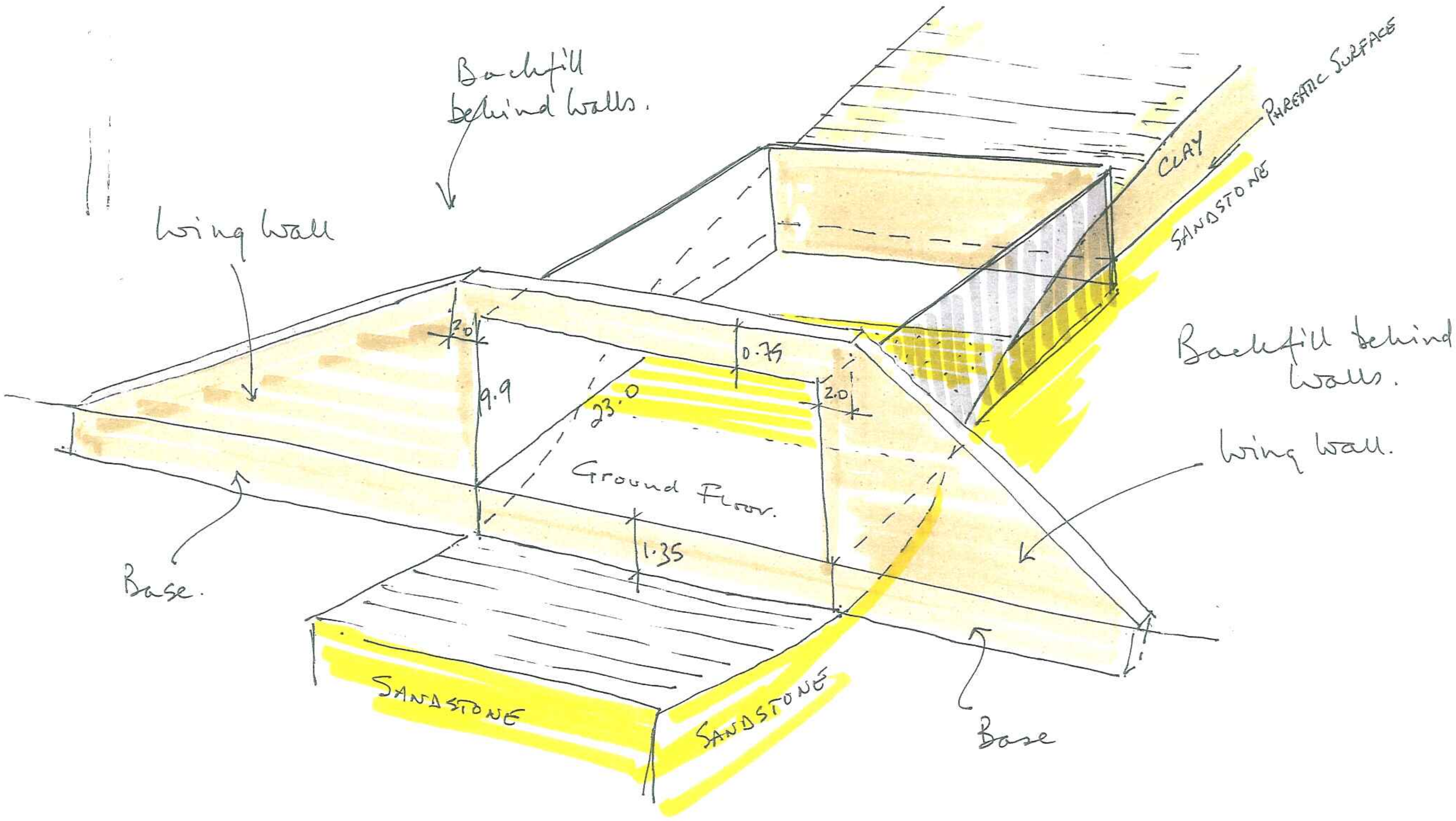


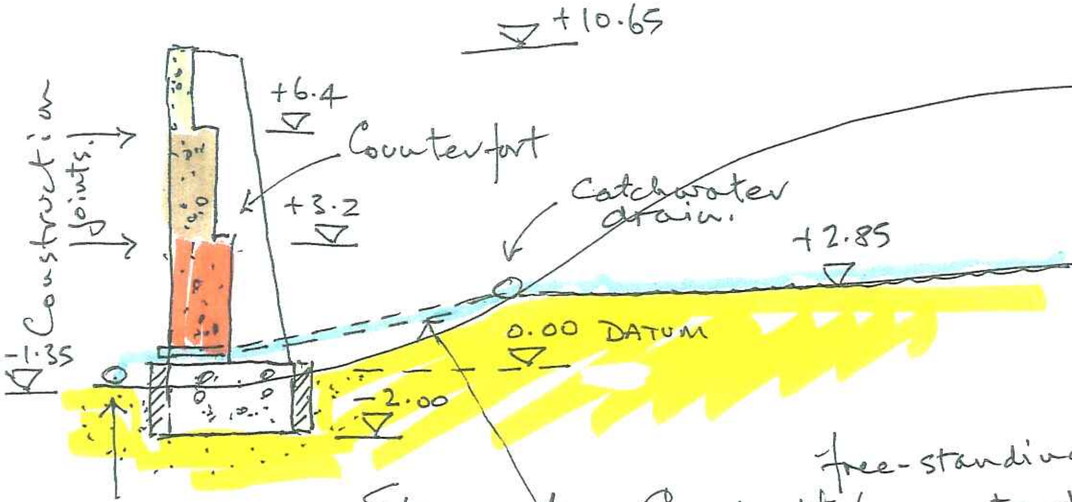


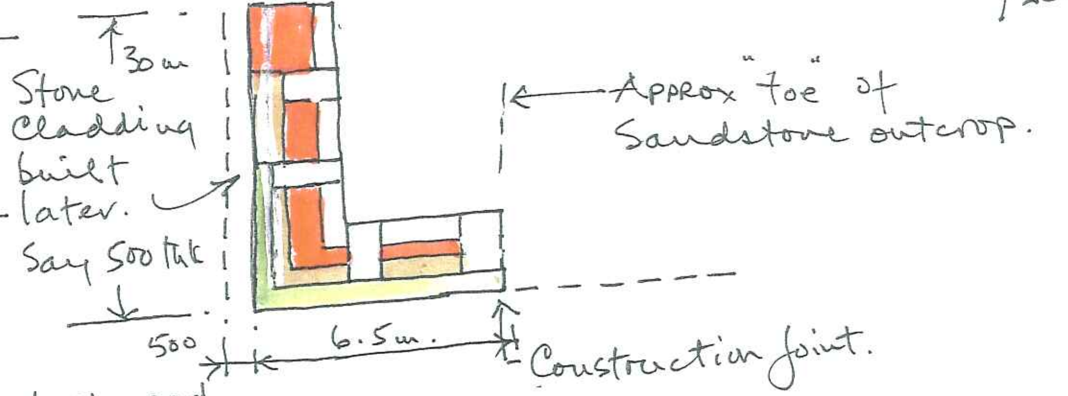




Perspective View



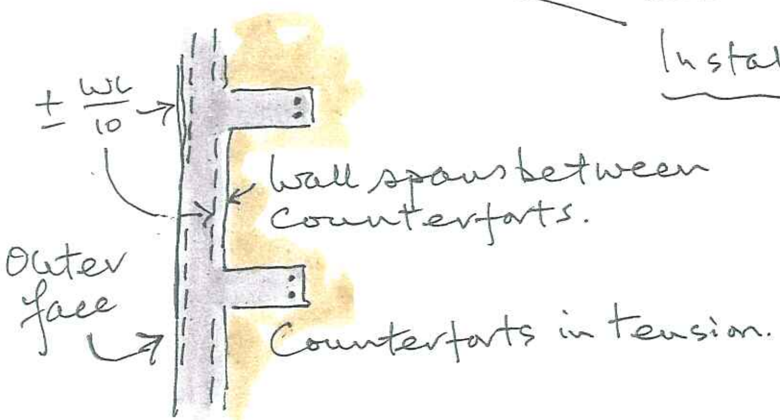




Stage A - Construct free-standing, L-shaped / counterfort retaining walls.

Install back-of-wall drainage. — Herring-bone land drains + weepholes through wall.

Install front-of-wall drainage — Porous pipes, french drain to surface-water network.



* Back of wall coated with waterproof material.

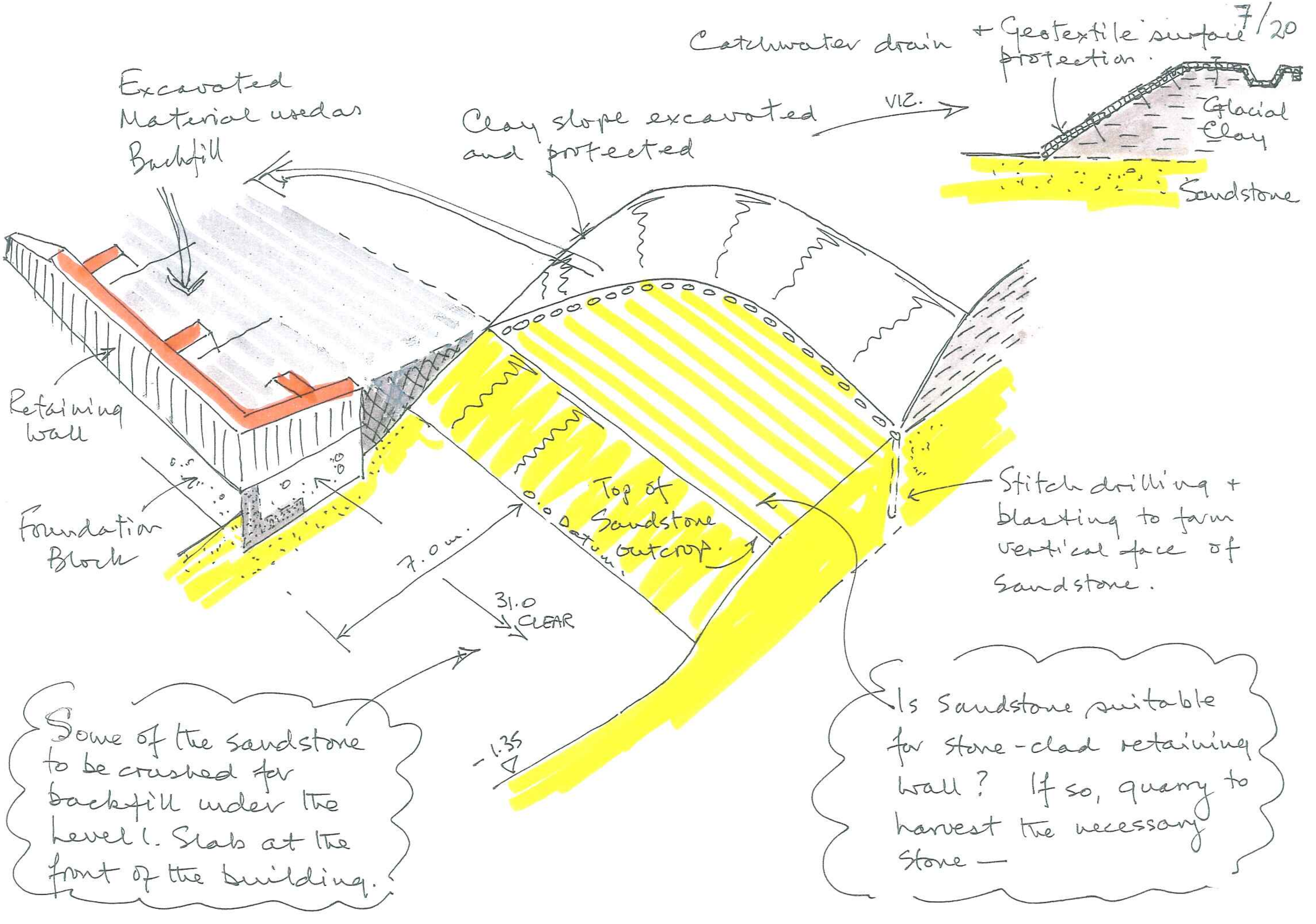
* Protect with Zemdrain sheets and gravel drainage layer.

* Backfill in 300 layers.

* Controlled compaction.

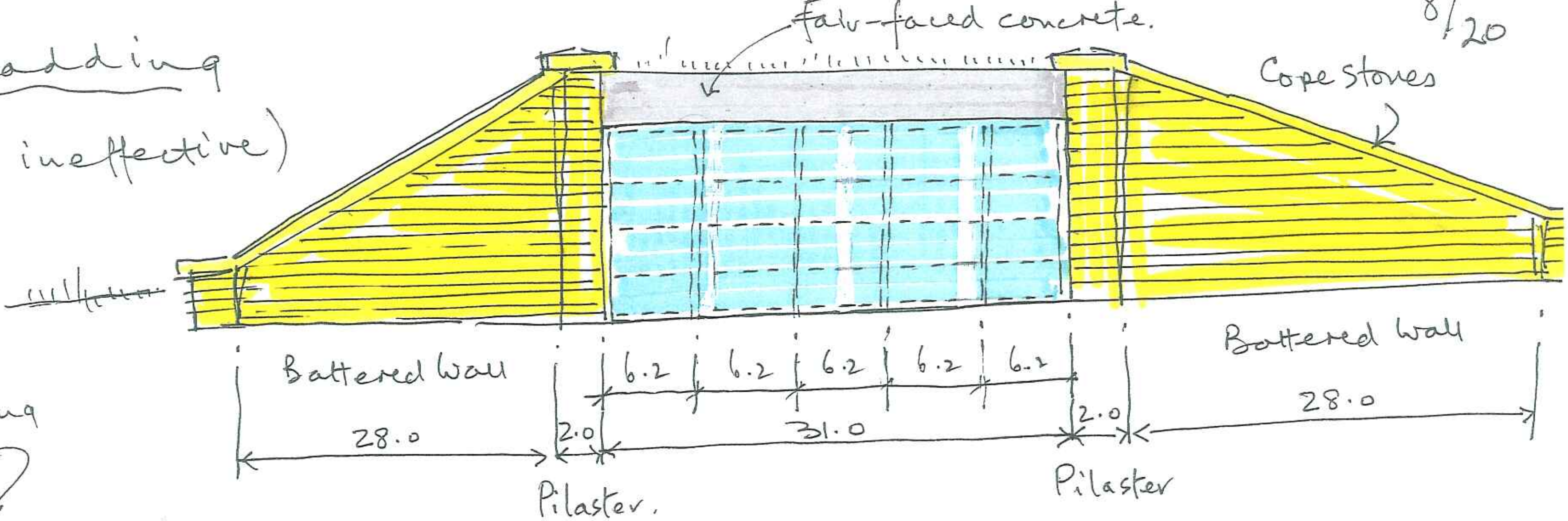
Volume behind wall backfilled with glacial clay excavated from main chamber. to + 2.85m level.

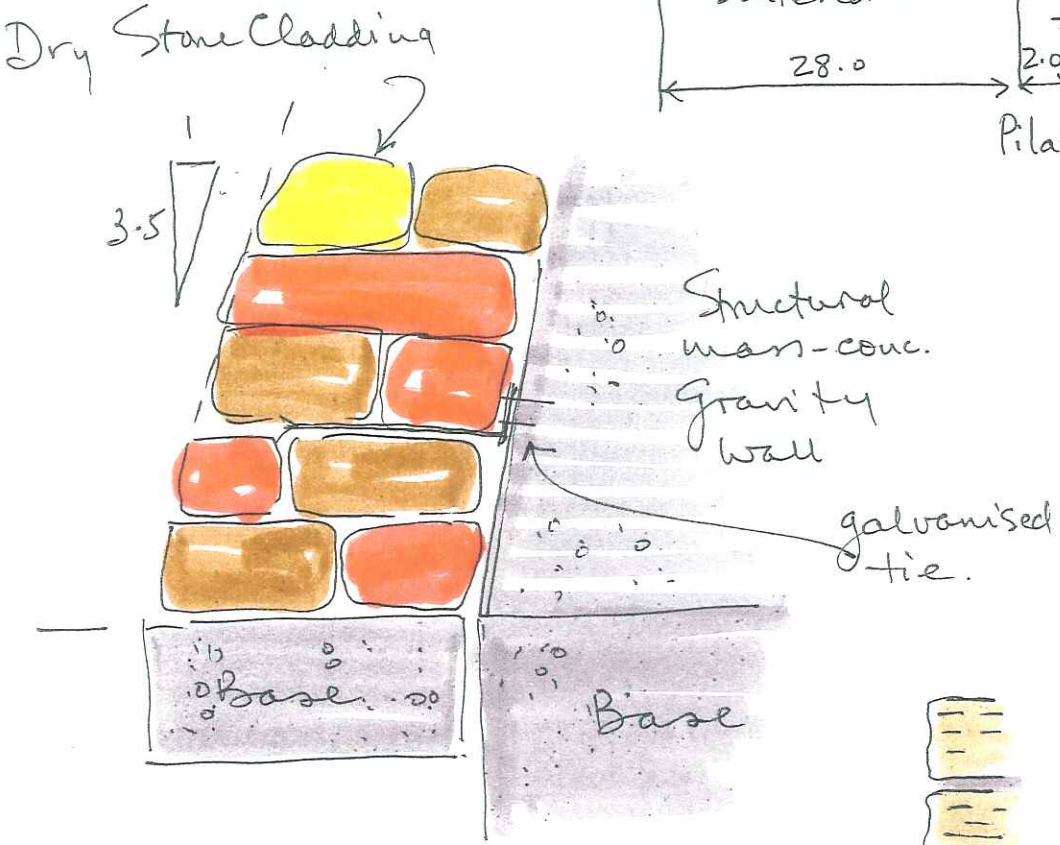
Seek advice on backfilling procedure from Geotechnical ~~Spec~~ Specialist!

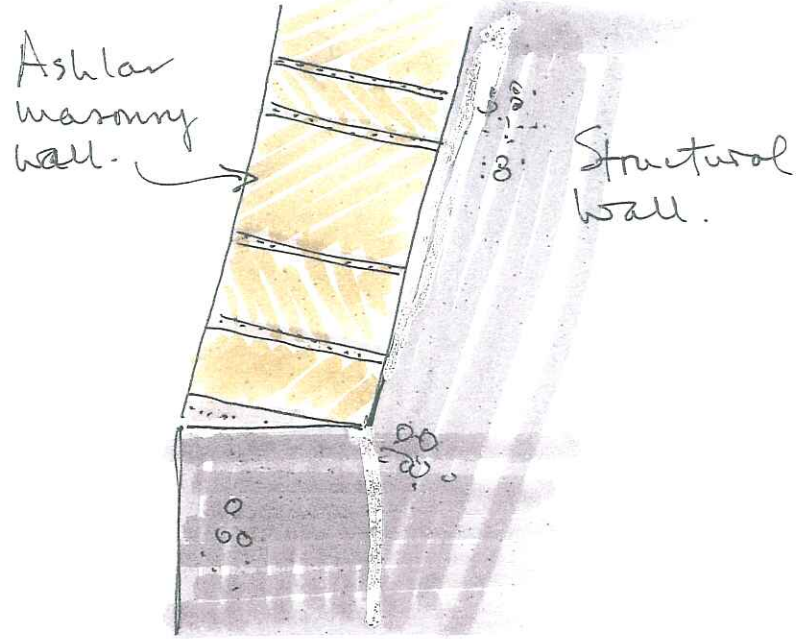

Catchwater drain + Geotextile surface protection.
VIZ.
Glacial Clay
Sandstone
Excavated Material used as Backfill
Clay slope excavated and protected
Retaining wall
Foundation Block
7.0 m.
31.0 CLEAR
Top of Sandstone outcrop.
Datum
Stitch drilling + blasting to form vertical face of Sandstone.
-1.35
Some of the sandstone to be crushed for backfill under the Level 1. Slab at the front of the building.
Is Sandstone suitable for stone-clad retaining wall? If so, quarry to harvest the necessary stone —

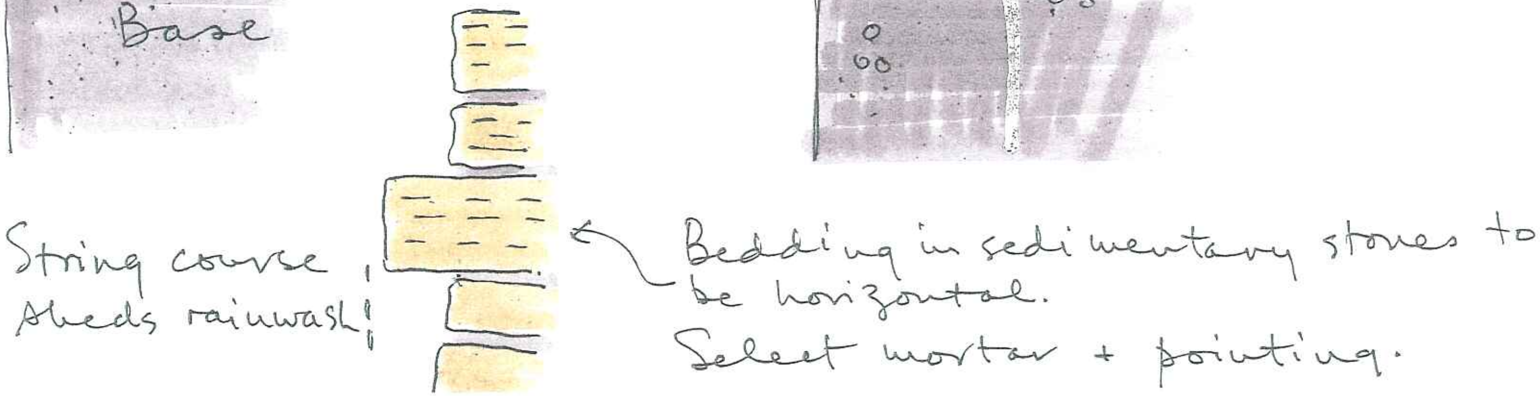
Stone cladding

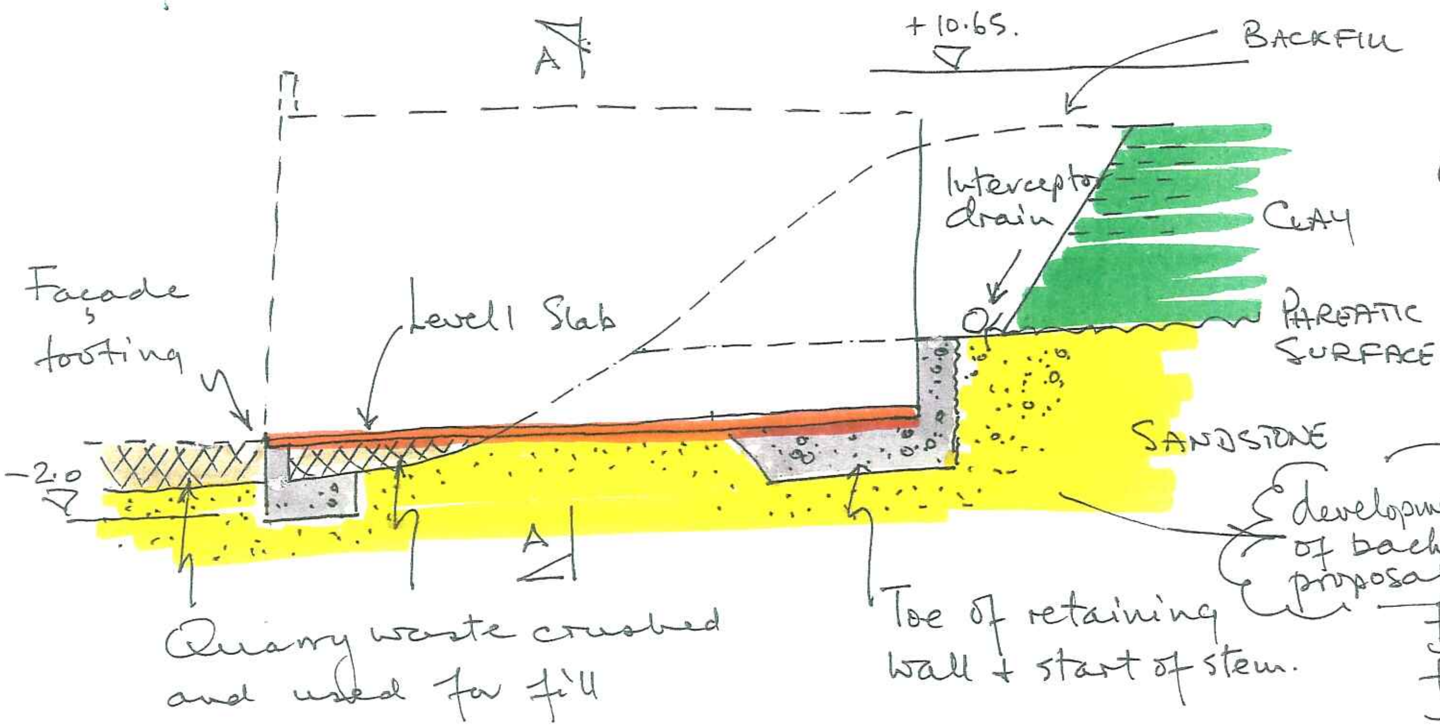
(Structurally ineffective)

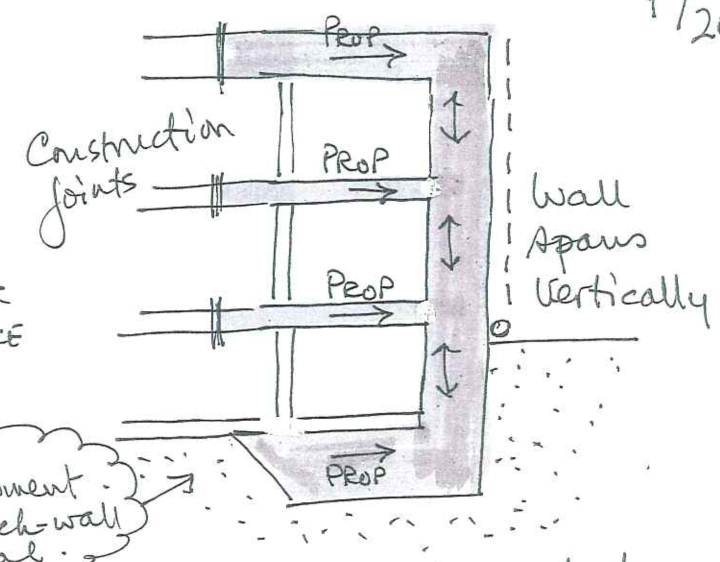






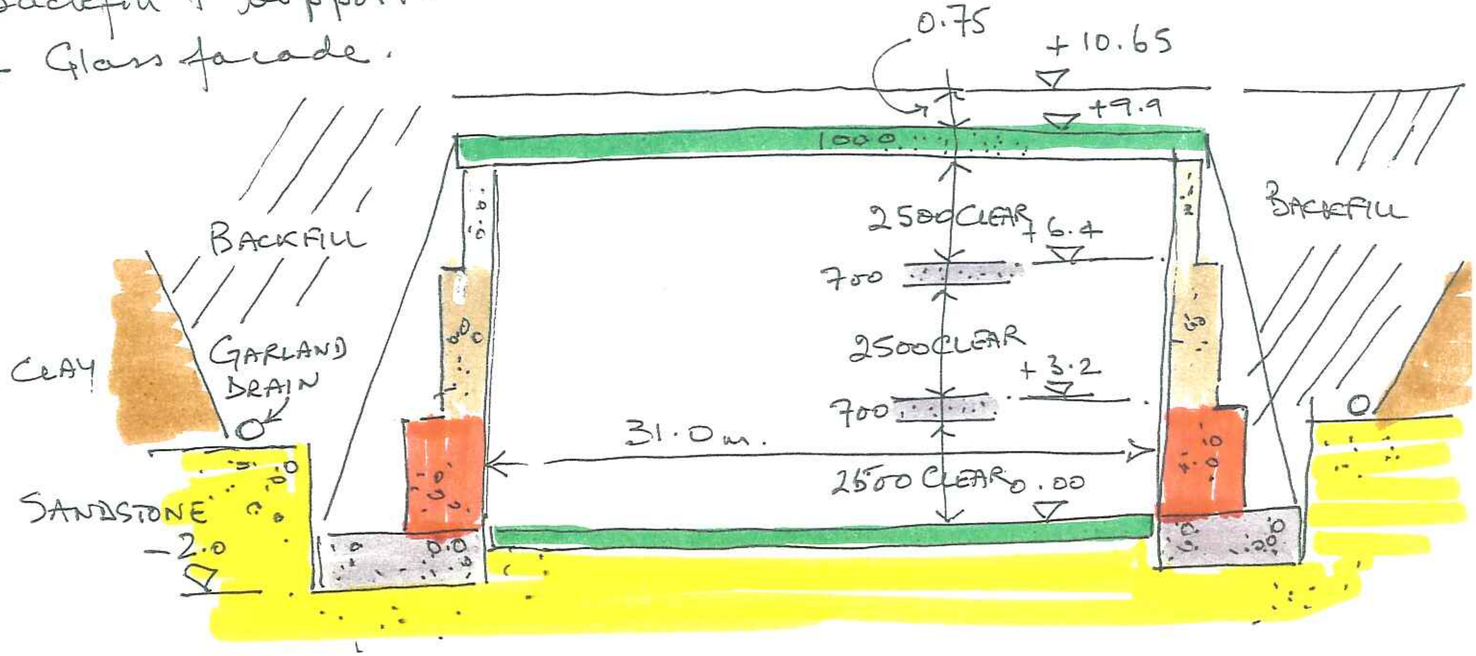




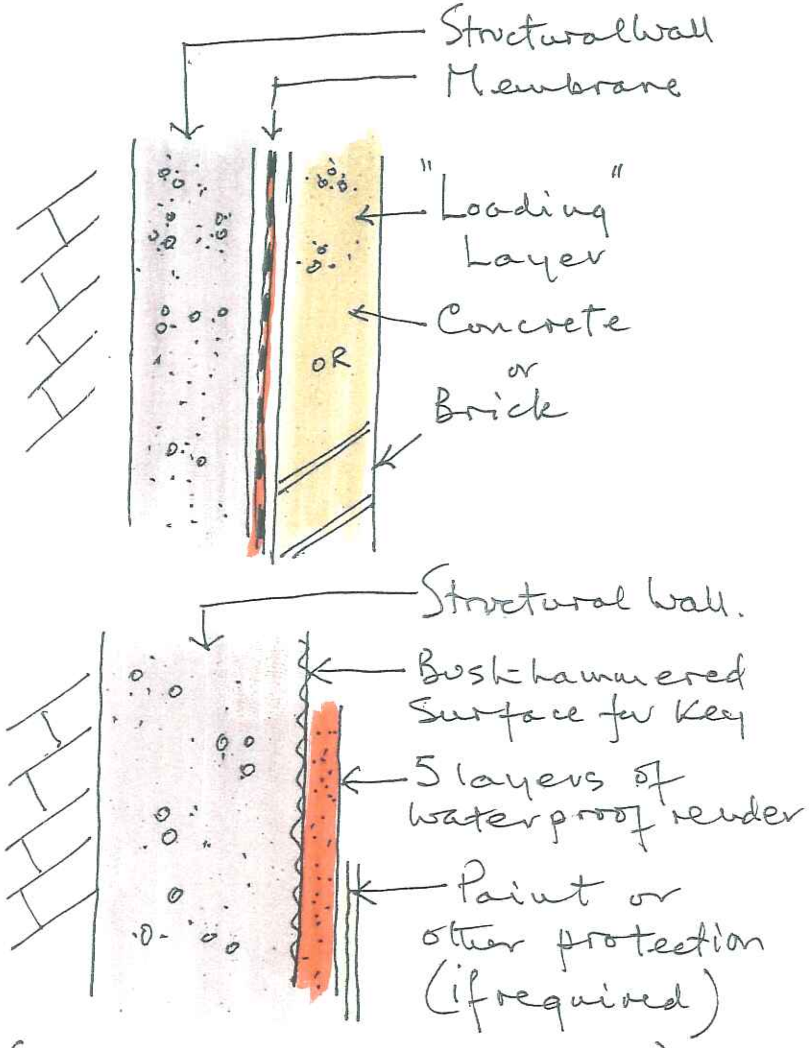


Floors provide waling slabs to support the retaining wall.

Facade footing retains backfill + supports front edge of Lev. 1 slab + Glass facade.

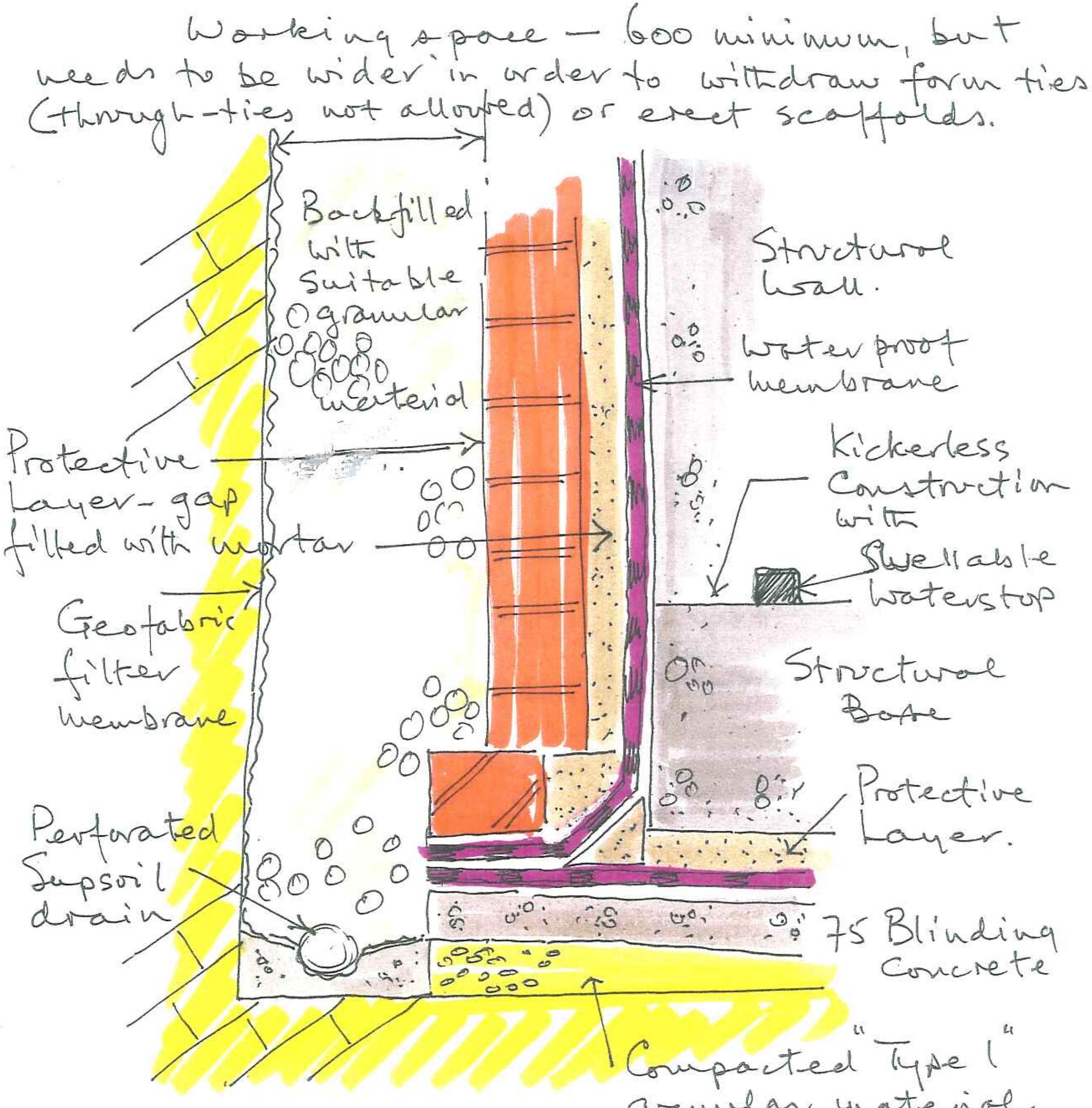


WATERPROOFING

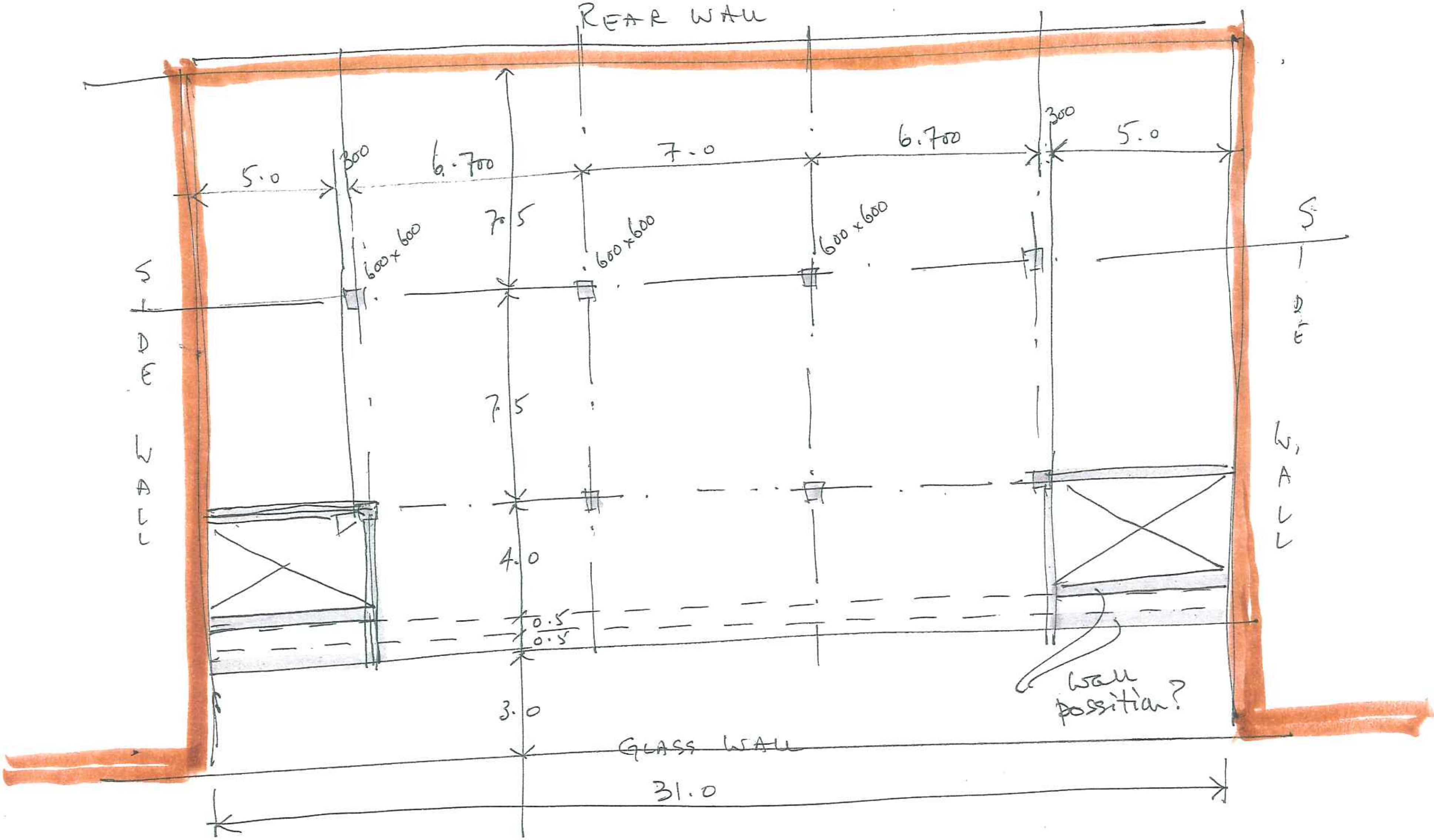


(DETAILS AT BASE NOT SHOWN)

INTERNAL TANKING PROTECTION
(DOES NOT REQUIRE EXTERNAL WORKING SPACE OR TEMPORARY RETENTION OF SOIL)

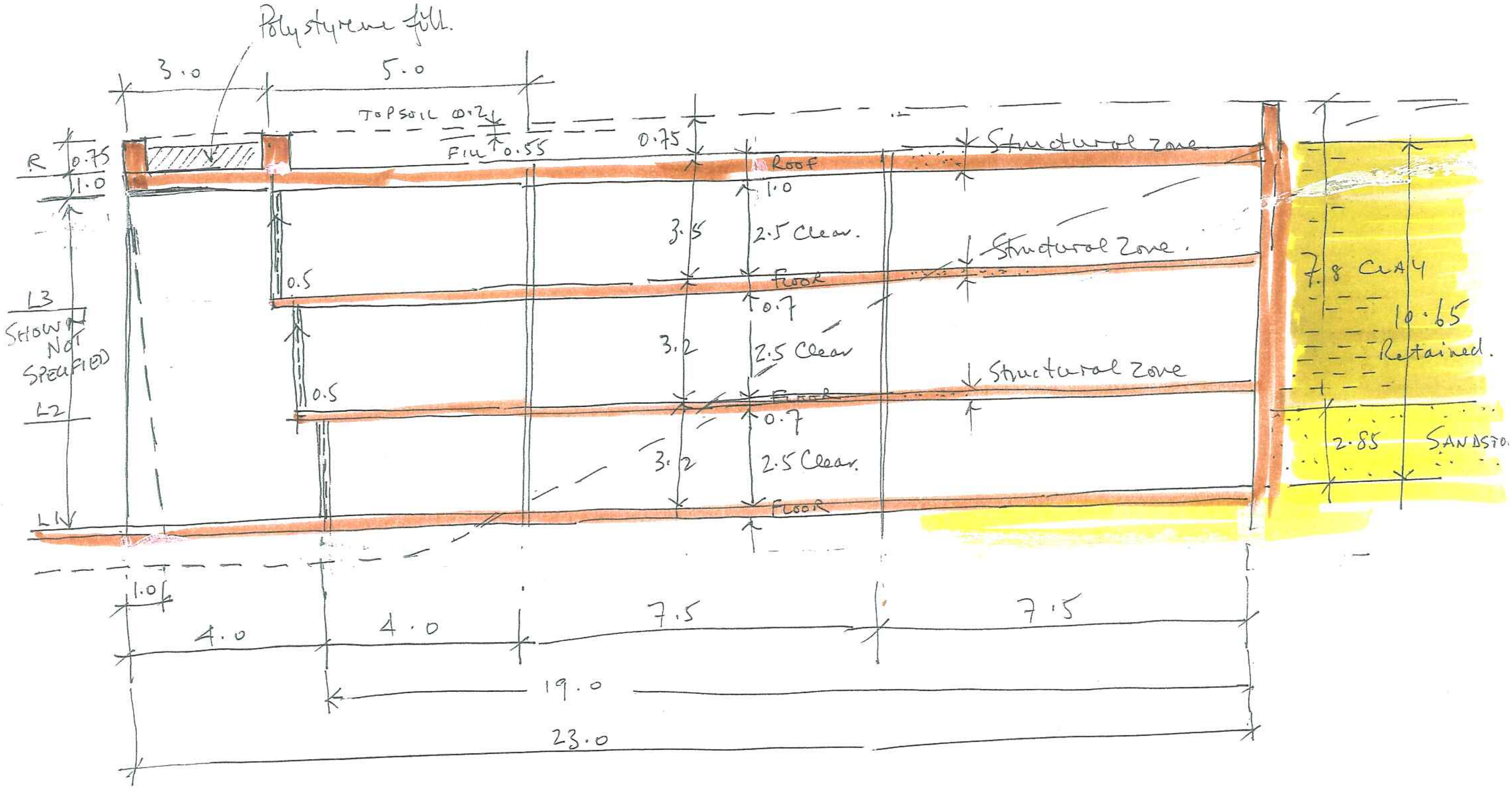


CONCRETE STRUCTURE WITH EXTERNAL MEBRANE



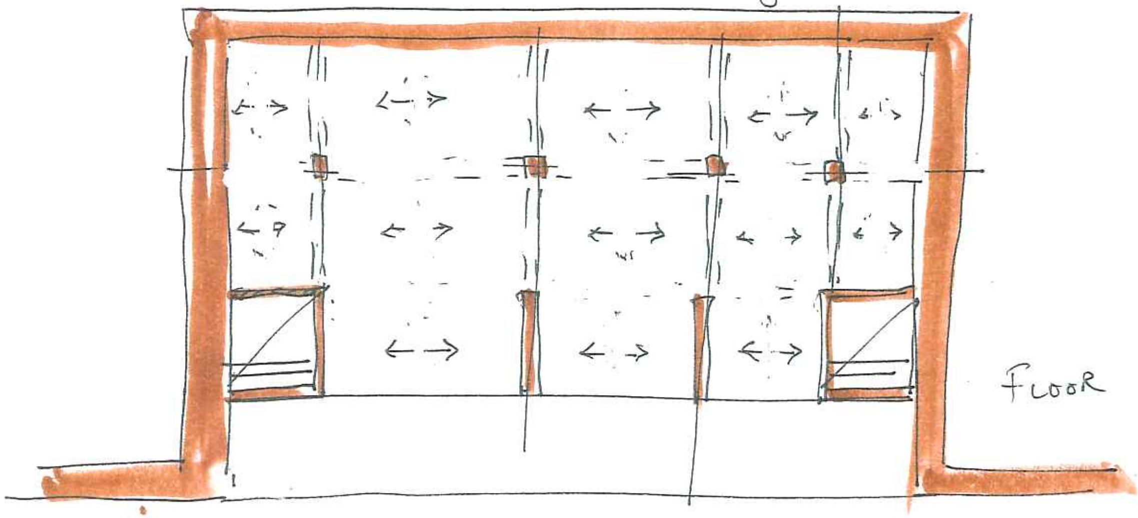
℄ 5.0 c/c. each way. ☑

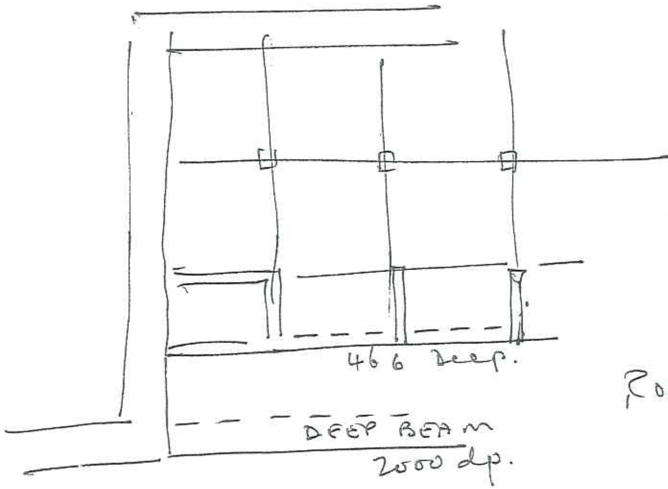
℄ 5.0 from rear + side walls. ☑
Clear



$\frac{31000}{15} = 2066$

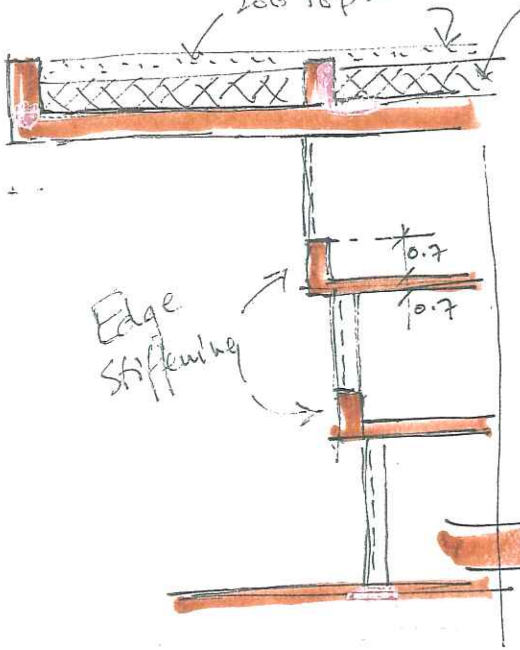
Beam + Longitudinal slab



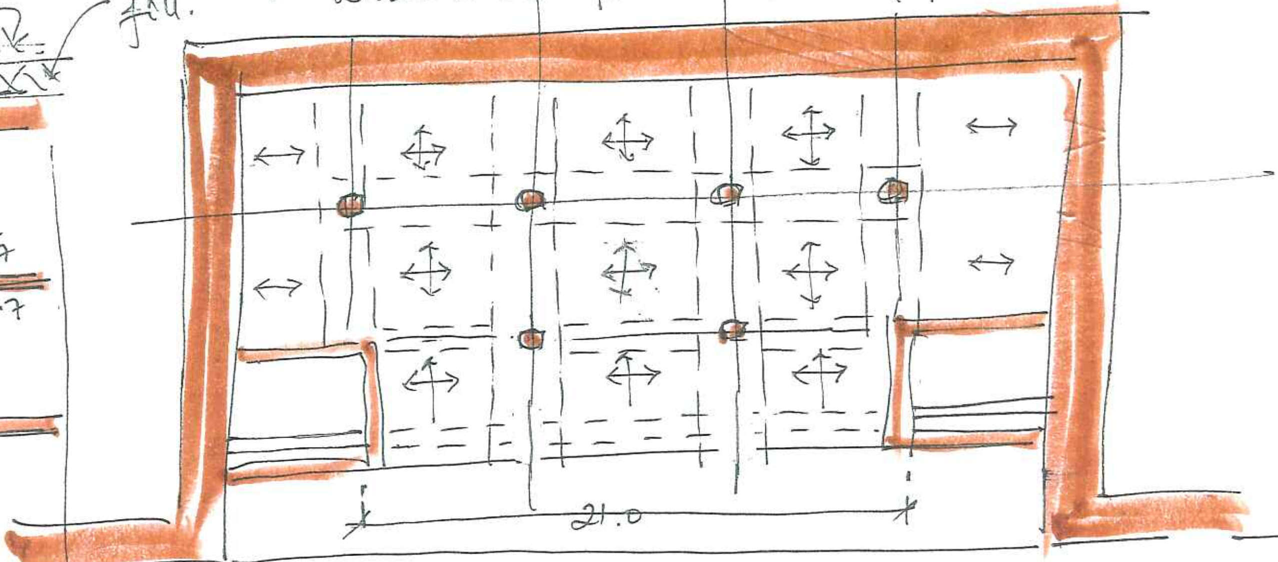


ROOF

$$\frac{7000}{15} = 466.$$



Wide beam grid + 2-way panels.

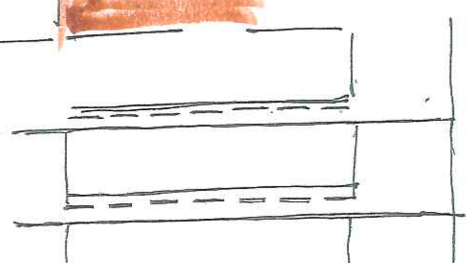


$$\frac{7000}{25} = 280$$

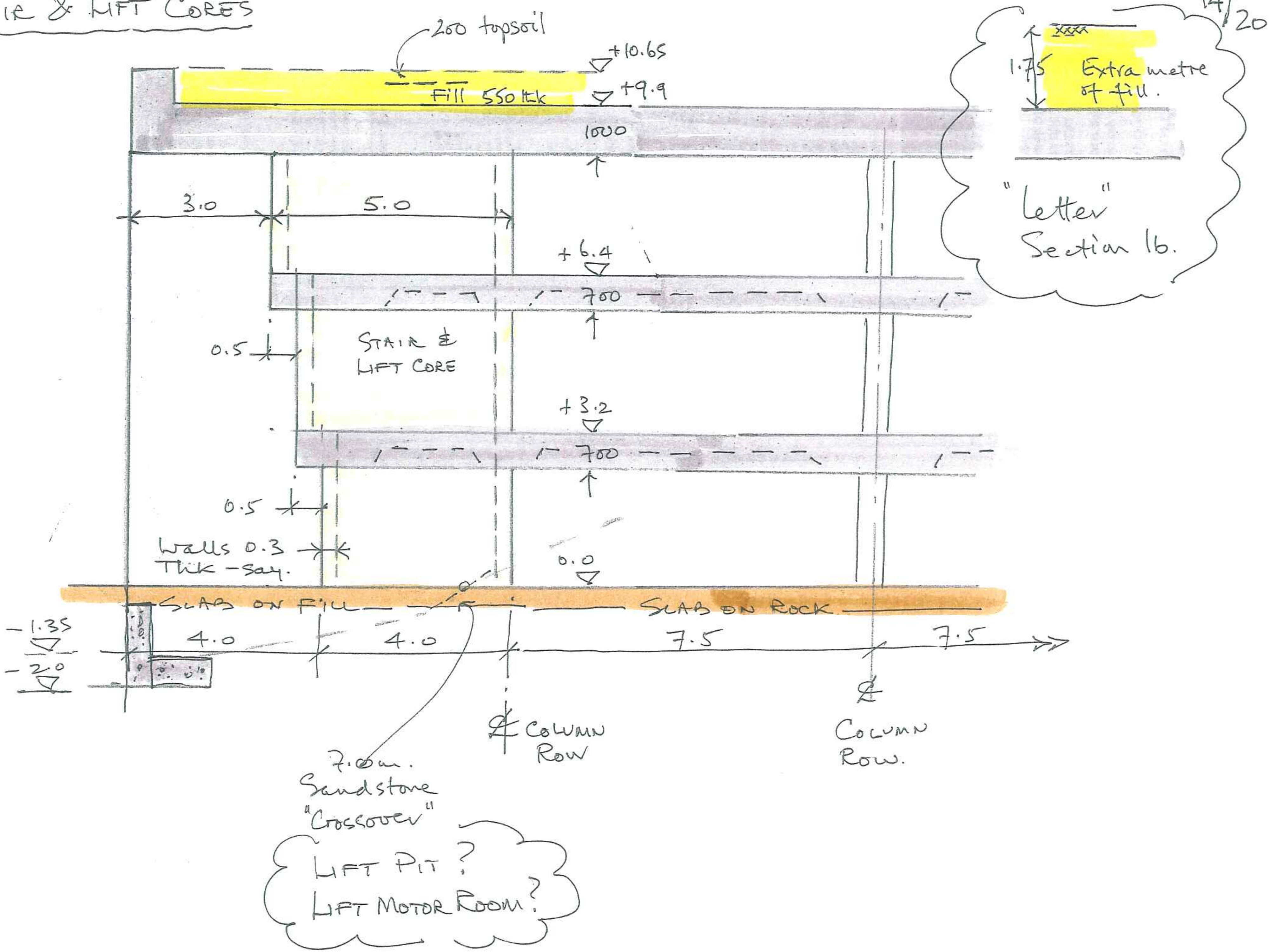
$$\frac{7500}{15} = 500$$

$$\frac{21000}{15} = 1400$$

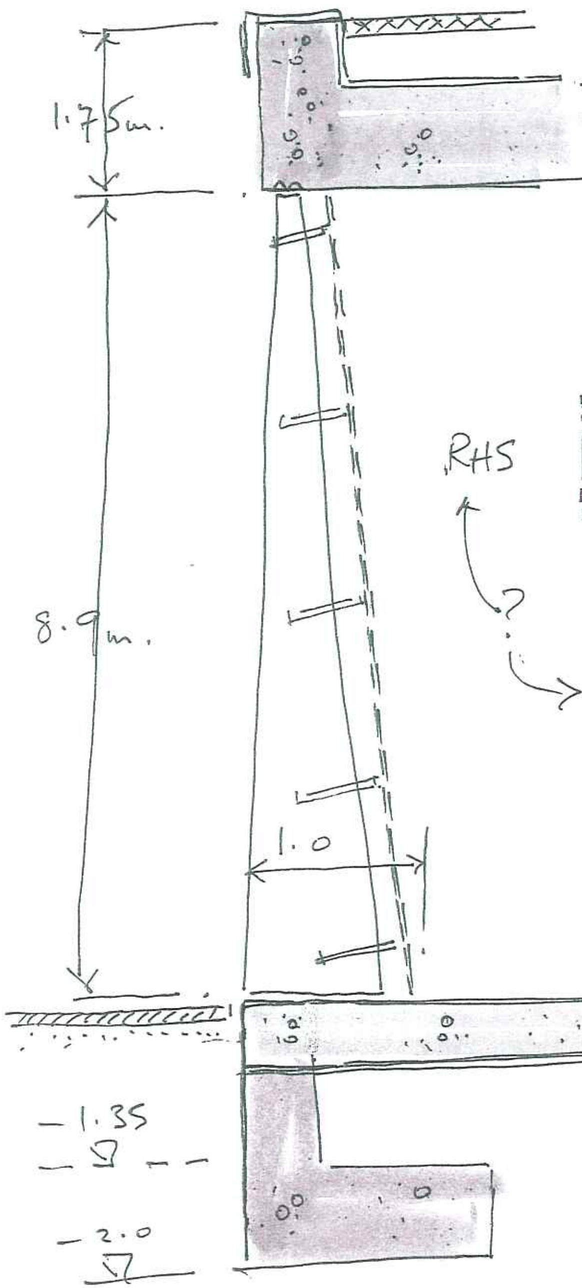
$$\frac{5000}{7} = 714$$

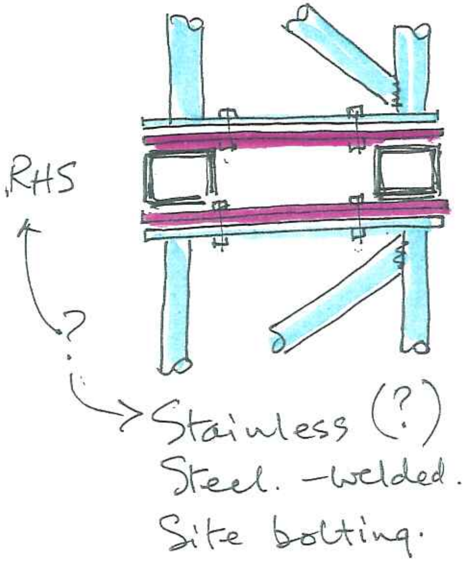


Stair & Lift Cores

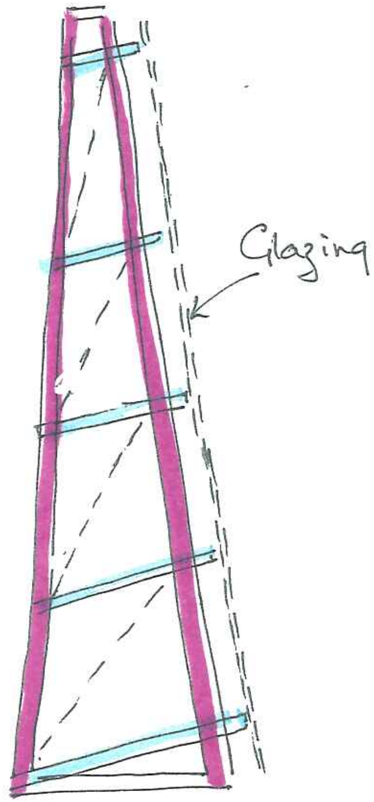


GLAZED FAÇADE – BY SPECIALIST

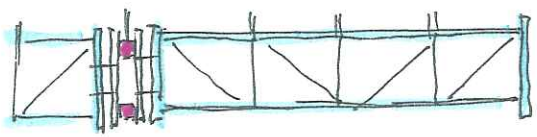




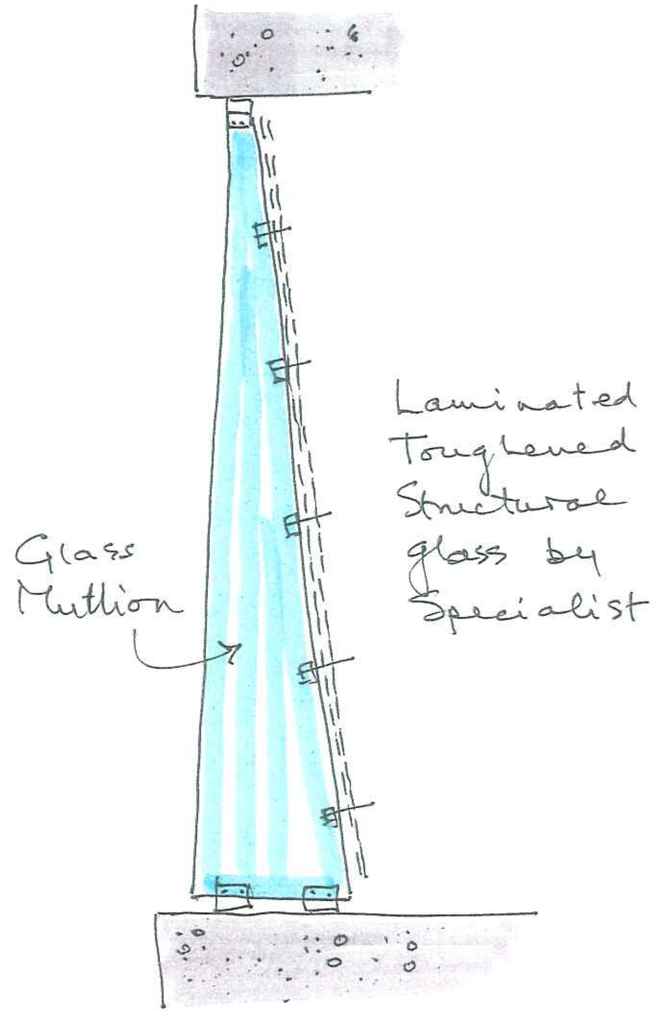
SECTION THRO MULLION



ELEVATION



PLAN.



ELEVATION

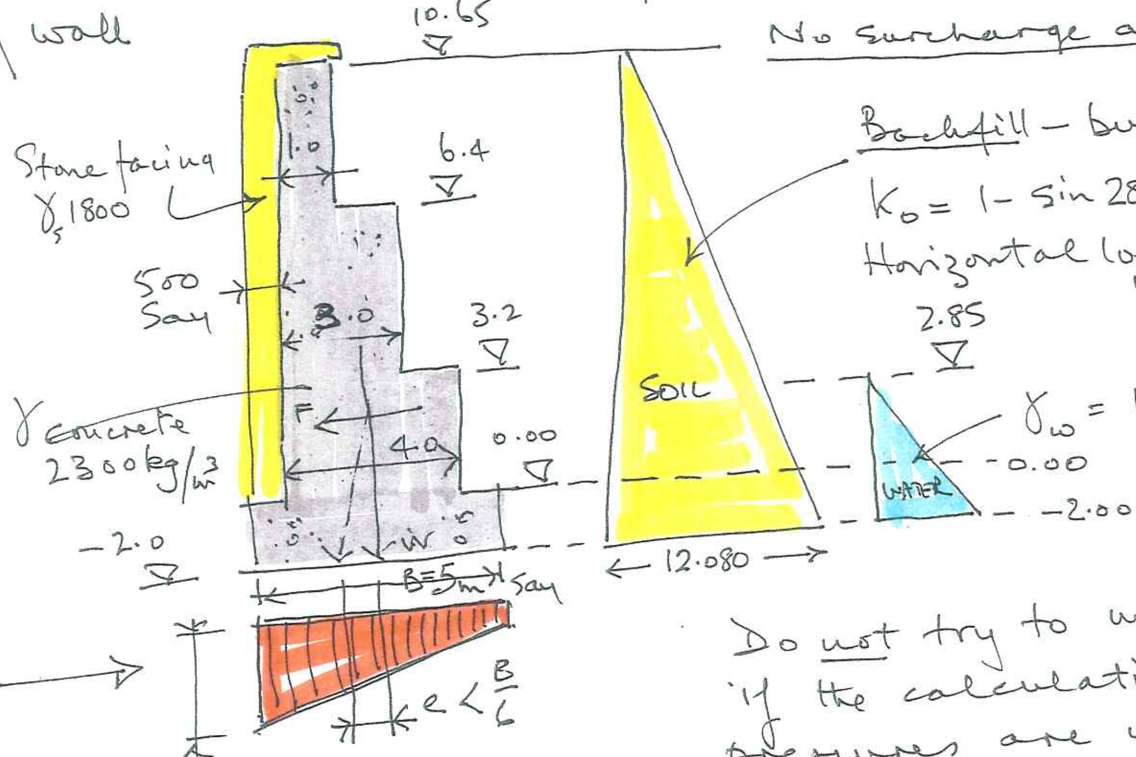
References:

1. BS 8002:1994 - Code of Practice for Earth Retaining Structures.
2. CIRIA C515: 2000 - Groundwater control - design and practice.
3. CIRIA Report 139: 1995 - Water-resisting basement construction - A Guide.
4. Malcolm Puller, "Deep Excavations - a practical manual", 2nd Edition pub. Thomas Telford. 2003. ISBN$_{10}$ 0-7277-3150-5
5. I.Struct E: Dec. 1999 - Structural use of glass in buildings.

Calculations

(1.) Free-standing wing wall. — probably idealised as a mass-concrete gravity wall

No surcharge assumed



$\frac{10.65}{2} \simeq 5$ m.

Backfill — bulk density say 1800 kg/m³

$K_o = 1 - \sin 28° = 0.53$

Horizontal load$_{max}$ = 1800 × 12.65 × 0.53 = 12080

≡ 12.080 kN/m²

(Unfactored)

γ_w = 1000 kg/m³

Check base only.

Do not try to modify the wall section if the calculation shows that the base pressures are unsatisfactory — write a note indicating that this element needs to be altered

Check safe bearing on Sandstone ≯ 3000 kN/m²

For appearance the face of the wall should be "battered" back and should include string courses (drip courses) to shed rainwash.
Pilasters each side of opening to "square up"
Presumably beam is also stone faced?

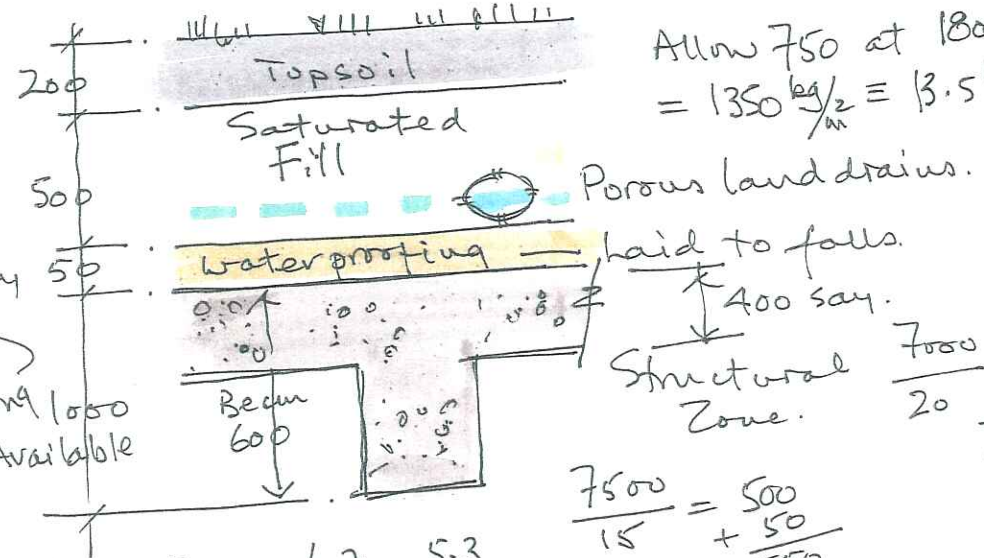
Calculations

(2) Roof slab — • allowable structural zone 1.000m thick.

• imposed loading 5.0 kN/m² – Surface loading ≃ 1.2 kN/m²

• No roof sagging! Roof slab built to falls! 2–3%

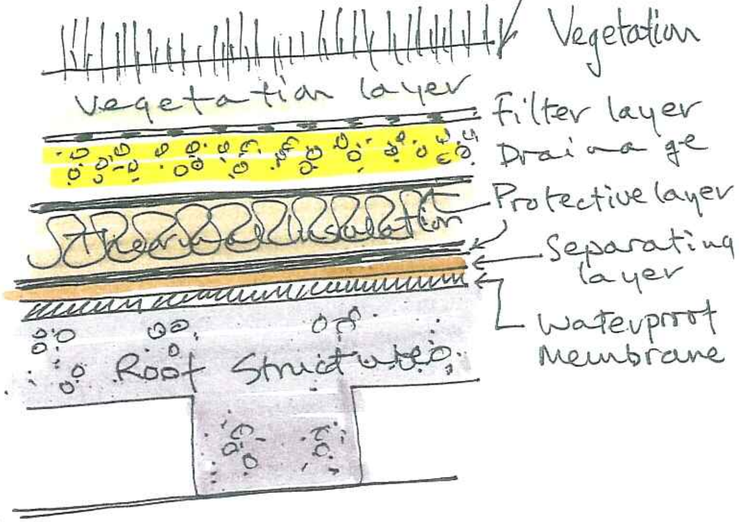
"Basic" Section:



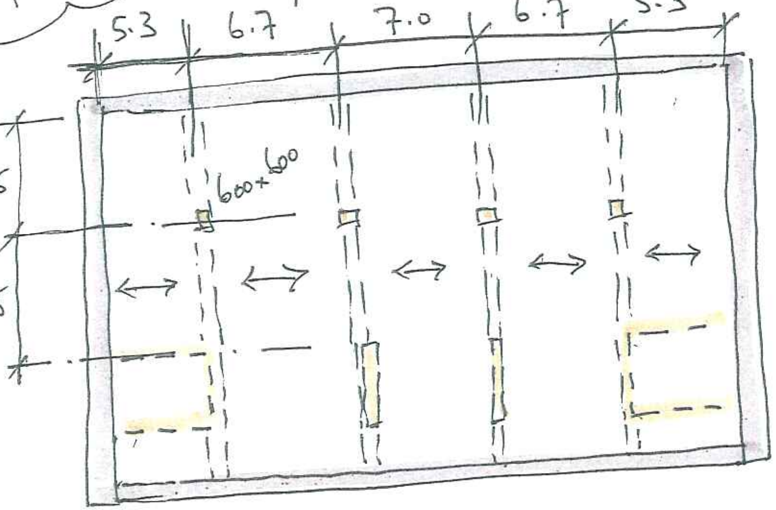
Allow 750 at 1800 kg/m³ = 1350 kg/m² ≡ 13.5 kN/m²

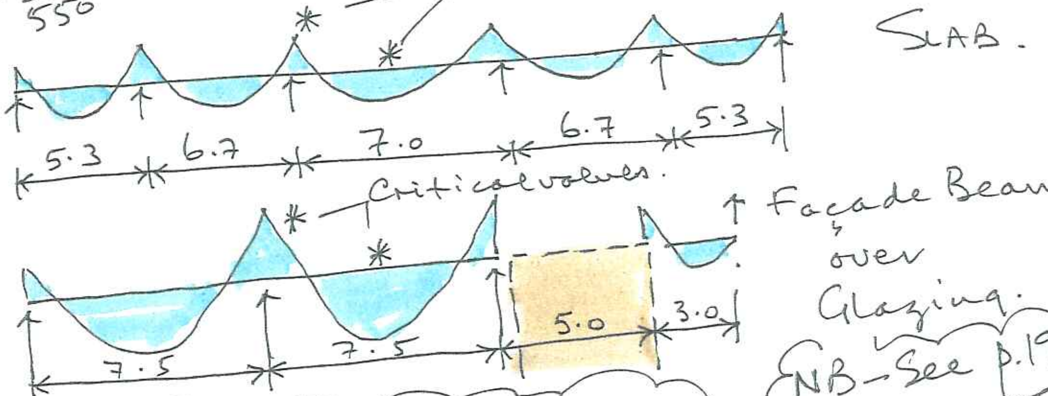
$\frac{7000}{20} = 350 + 10 + 40 = 400$

$\frac{7500}{15} = 500 + 50 = 550$



This will leave 400 for accommodating roof falls.



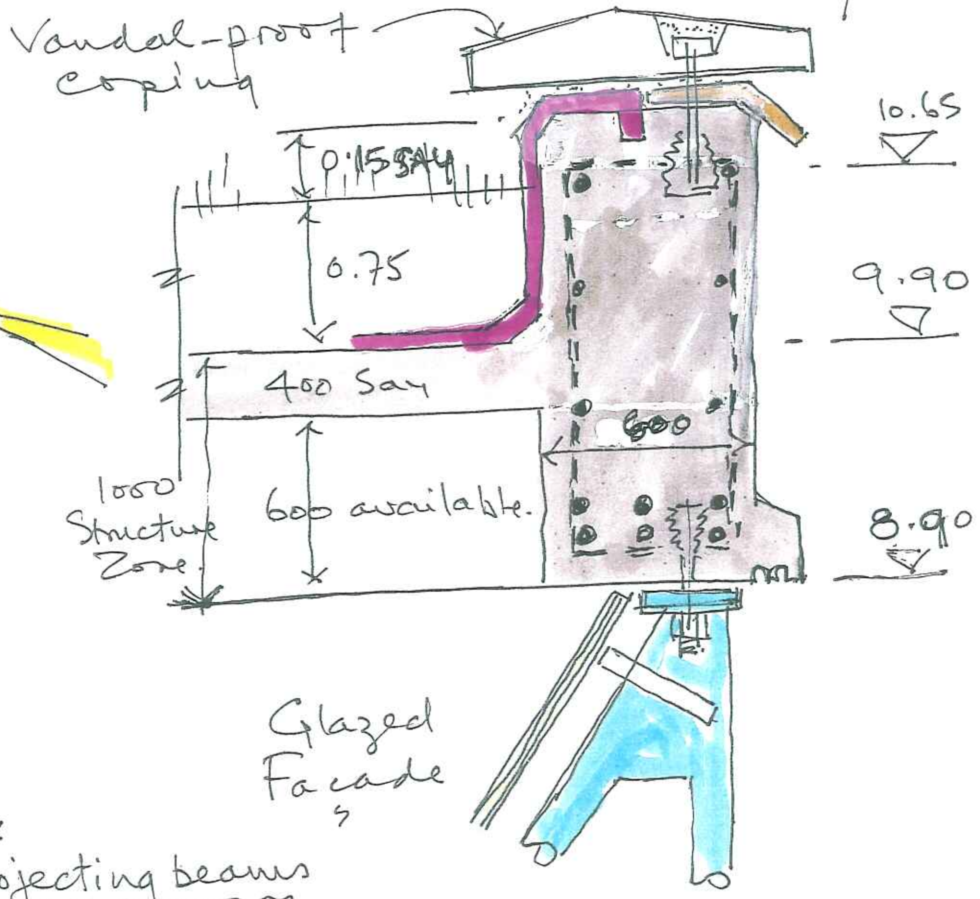


Assume all moments = $\frac{wL}{10}$

NB – See p.19 FOR CONCEPT CHANGE.

Calculations

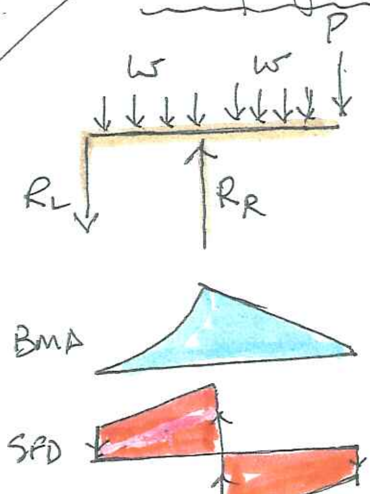
③ Beam over glass façade:



Consider acts like a portal frame.

$L/d = 31000/20 = 1550 \quad b = d/3 = 517$

* Reconsider as 5 member supported spans: on projecting beams



Rebar cage dims:

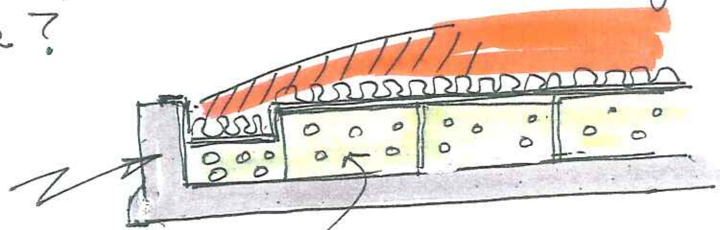
$1900 - 50 - 50 = 1800$
$600 - 50 - 50 = 500$ } Credible!

But critical there should be no sag — glazed façade and roof drainage. Also appearance!

LETTER

Further 1.0m. depth of fill — yes, possible but would require re-design of roof slab + roof beams — possibly requiring closer column centres. But if new ground levels are necessary why not add 1.0m of lightweight insulation-type material e.g. polystyrene?

Keep edge detail and limit fill over Entrance area — OR Raise edge detail.



METHOD STATEMENT & PROGRAMME.

Break the "General Rule" that answers should be "stand-alone" and not refer back to other answers. In this case — FOR THE DIAGRAMS ONLY — refer back to pages 3, 4 and 7 (say) and then explain the sequence (and the reasons for the sequence) in more detail.

The programme must emphasize how long the initial excavation and retaining walls will take. Time to be shown for waterproofing walls and later for waterproofing roof + installing the roof drainage. Backfill over roof using low-weight machinery after a reliable strength has be demonstrated. In-situ measurements BEFORE fabrication of glazed façade. Do not show times for fitting services and finishing the habitable areas!