Possible solution to past CM examination question

Question 5 April 2007

Visitors' Centre

by Bob Wilson

The information provided should be seen as an interpretation of the brief and a possible solution to a past question offered by an experienced engineer with knowledge of the examiners' expectations (i.e. it's an individual's interpretation of the brief leading to one of a number of possible solutions rather than the definitive "correct" or "model" answer).

Question 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/m^2
Floors	5.0kN/m^2

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/m^2
Above +2.85m	Glacial clay, internal angle of friction $\emptyset' = 28^o$, bulk density = 1950kg/m^3.

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)

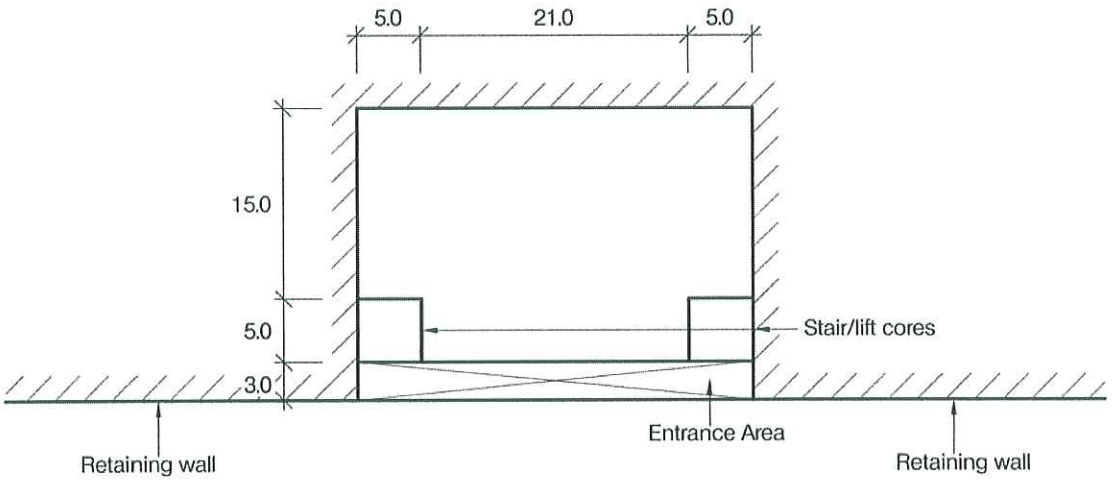
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

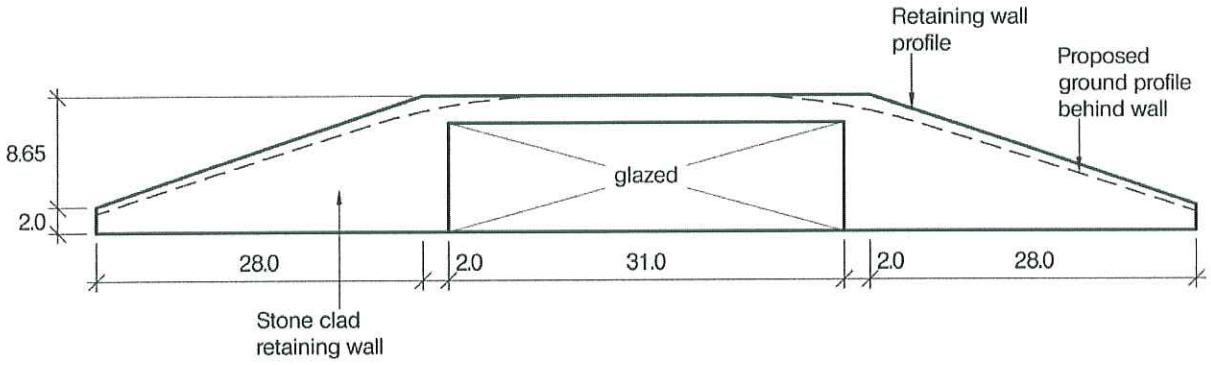
c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)

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)

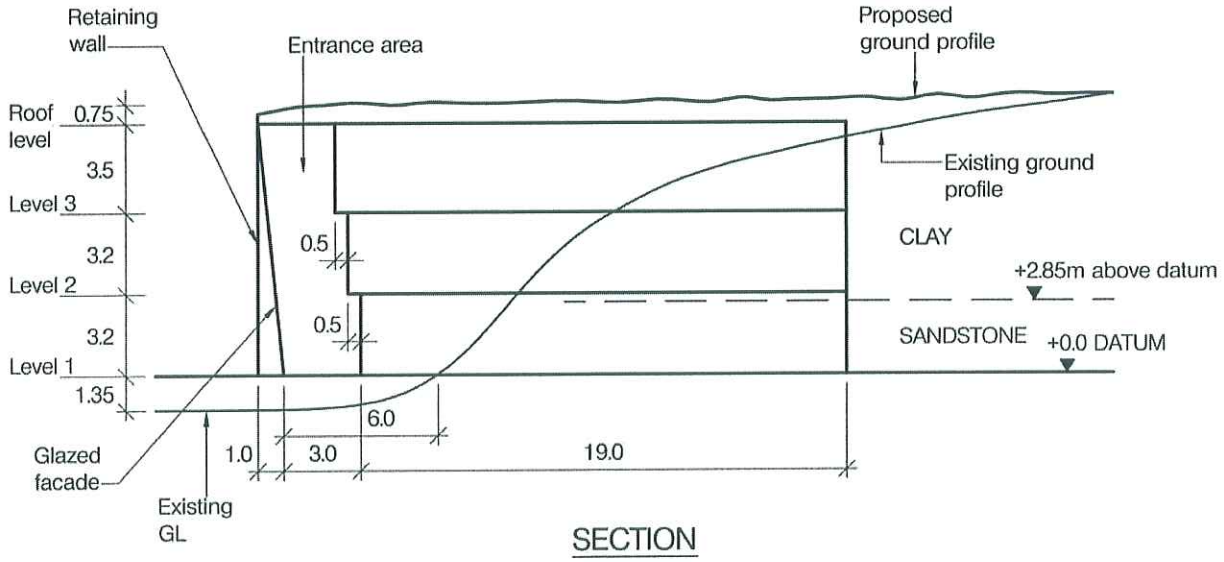
e. Prepare a detailed method statement for the safe construction of the building and an outline construction programme. (10 marks)



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.

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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.

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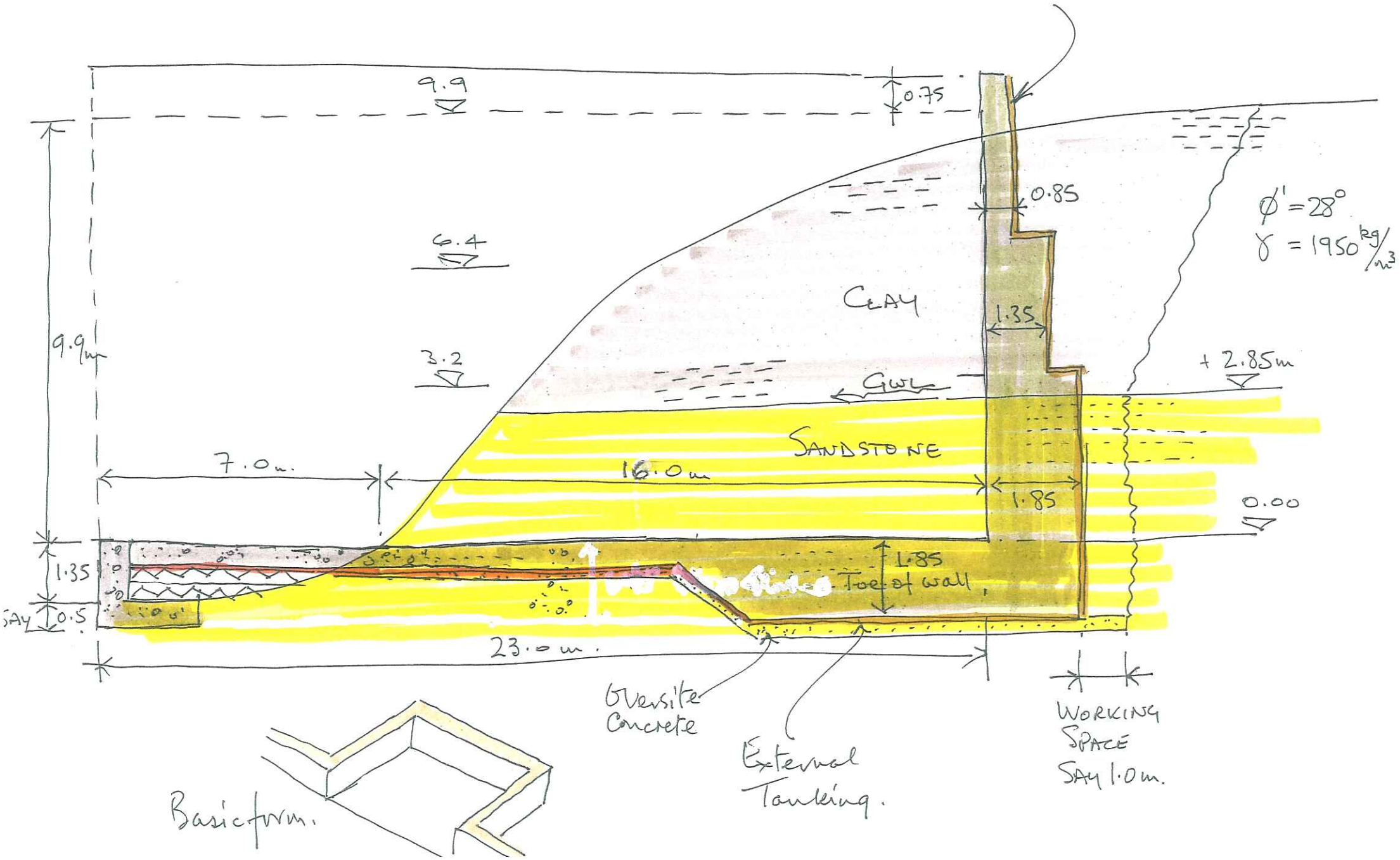
- The question is about a large, 3-level building built into the side of a hill with the roof covered with backfill. The front elevation is fully glazed.
- The main issues are:
  - the hillside excavation and groundwater control. pp. 2-3 & 4
  - the level 1 slab and perimeter walls — structure pp 9 Calcs 1-p17
  - the level 1 slabs and perimeter walls — waterproofing p10
  - Level 2 & 3 slabs and supports — stepped at entrance area. pp 11 to 14
  - Roof level slabs and support — waterproofing + soil cover.
    ? cantilevering over the glass façade? See Calculations 2 p18
  - 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 9.9m.
  - Internal columns ∉ 5m c/c each direction
    ∉ 5m from rear + side walls ? ℄ or face?
  - Structural zones Lev 2 + Lev 3 — 0.7m Imposed loads 5 kN/m²
    Roof 1.0 m — Imposed load 5 kN/m²

Hillside excavation.

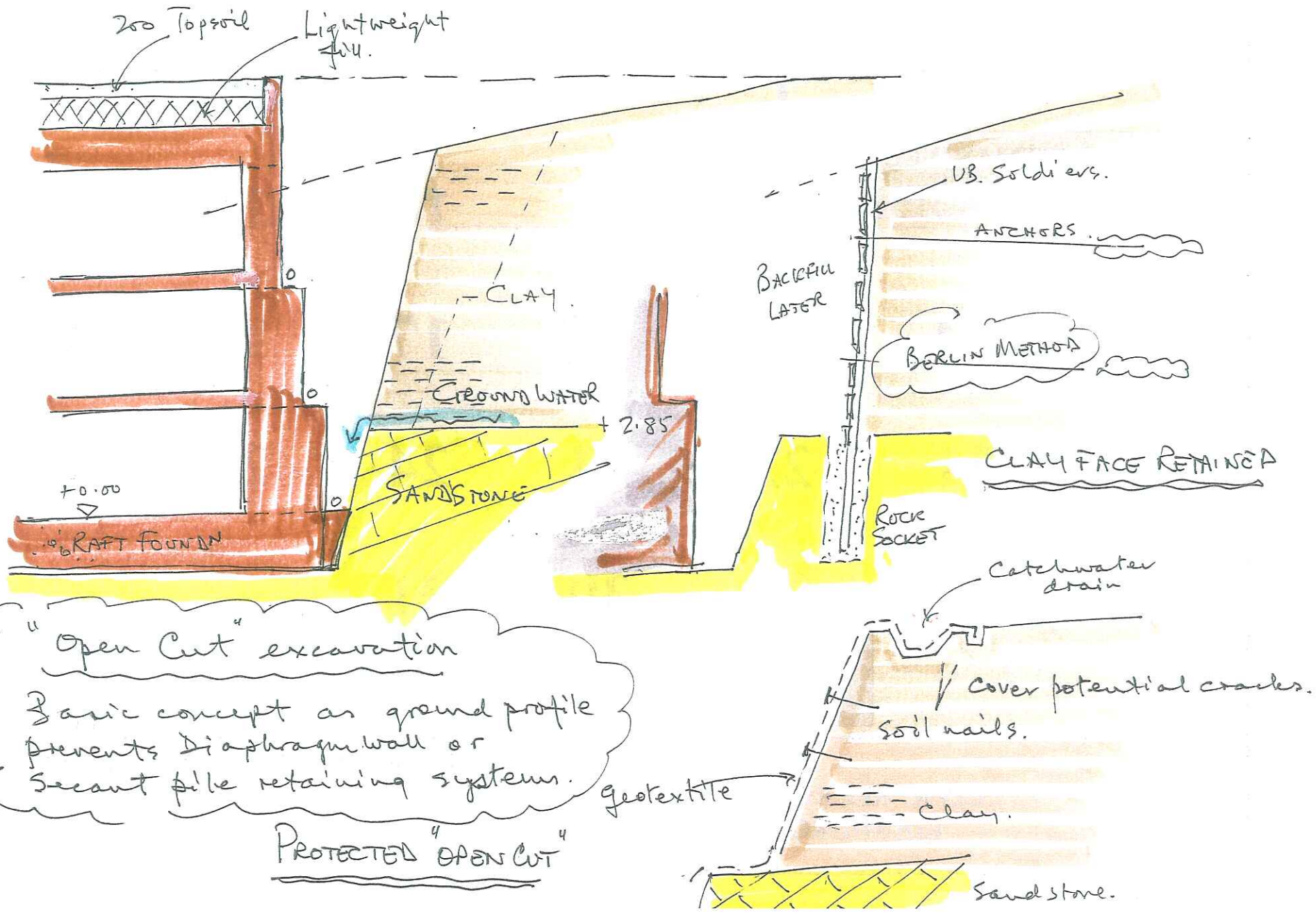
Option 1. R.C. wall constructed insitu.



$\phi' = 28°$

$\gamma = 1950\ kg/m^3$

Support Clay!

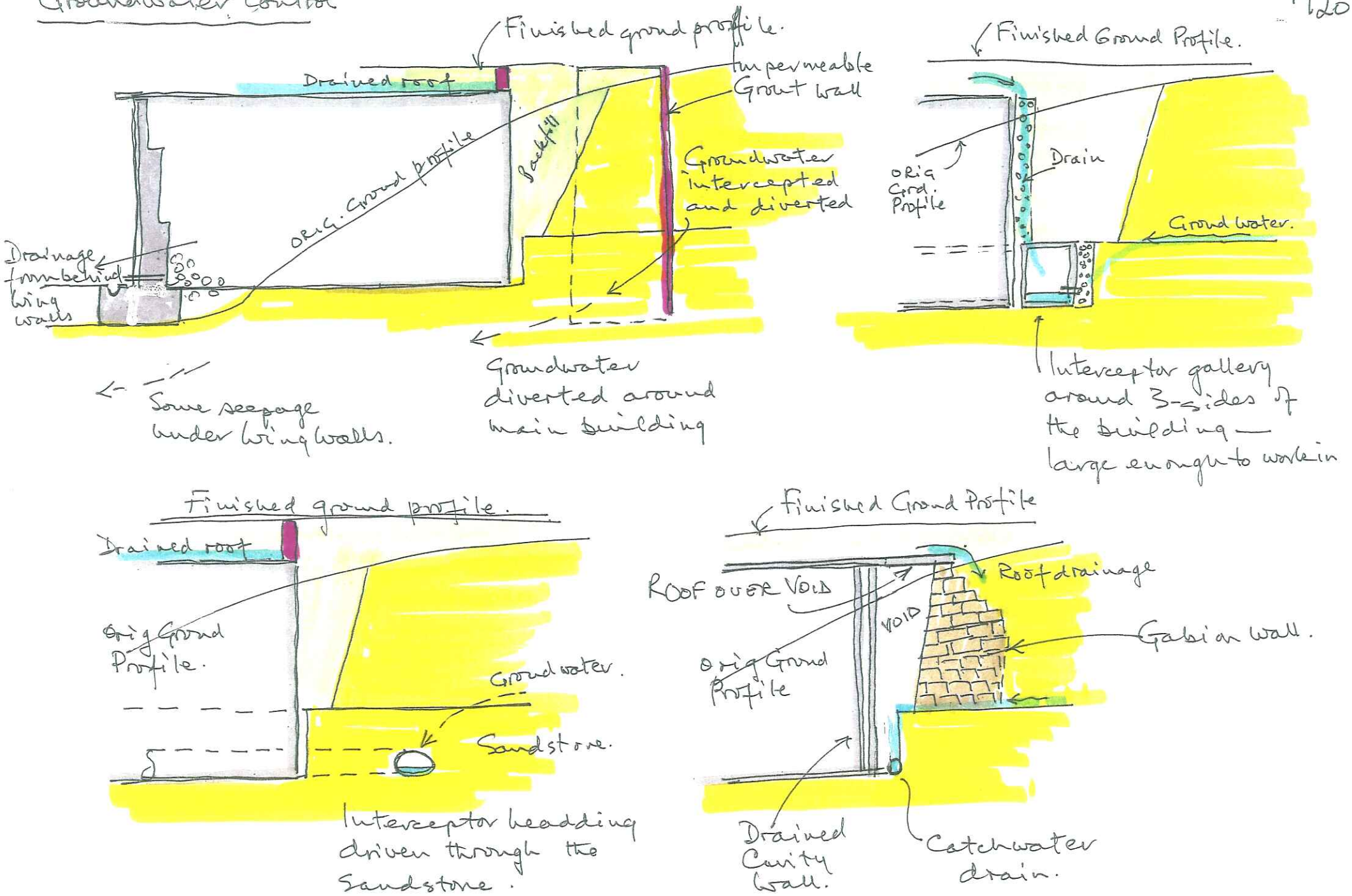


"Open Cut" excavation

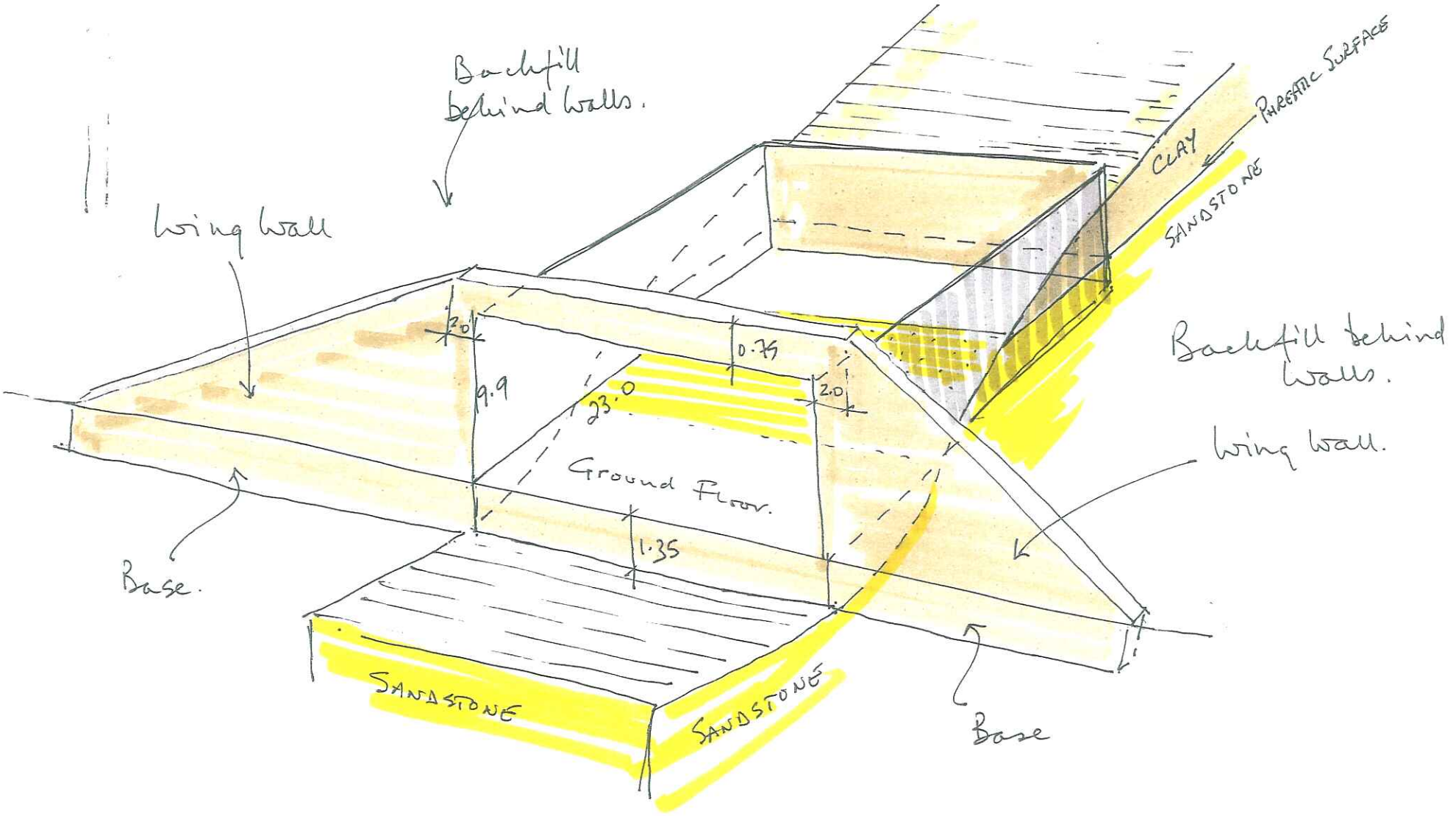
Basic concept as ground profile prevents Diaphragm wall or Secant pile retaining systems.

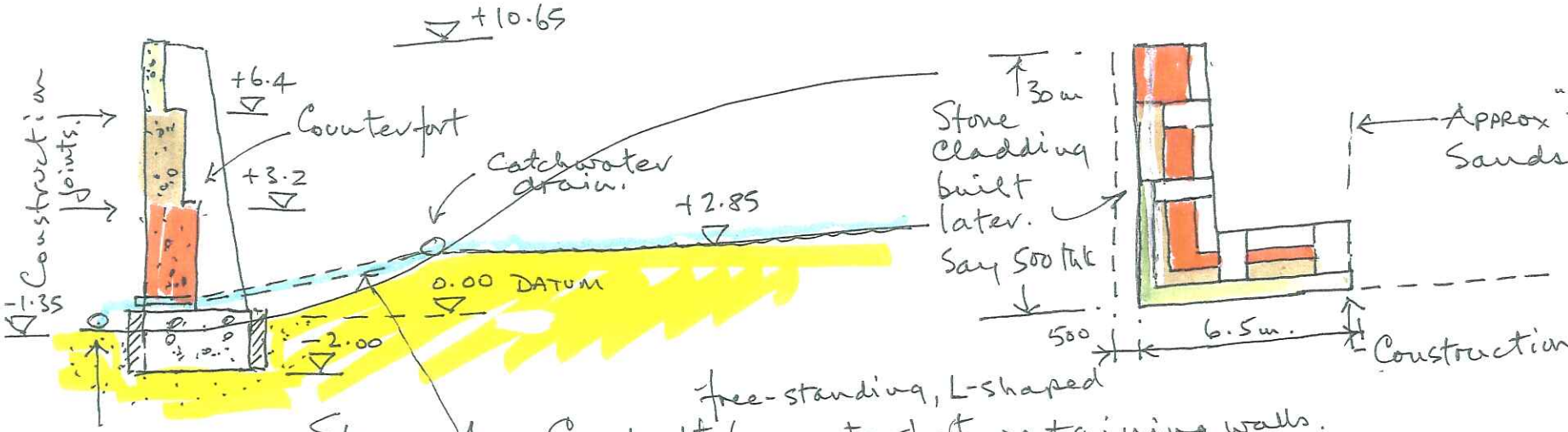
PROTECTED "OPEN CUT"

Groundwater control



Perspective View



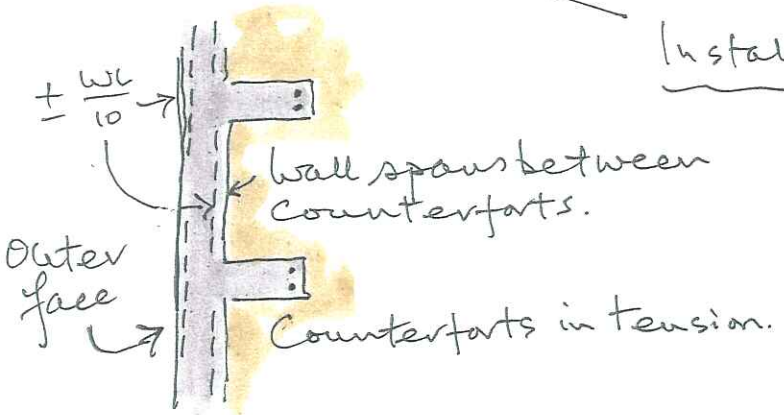


free-standing, L-shaped

Stage 1 - Construct counterfort retaining walls.

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

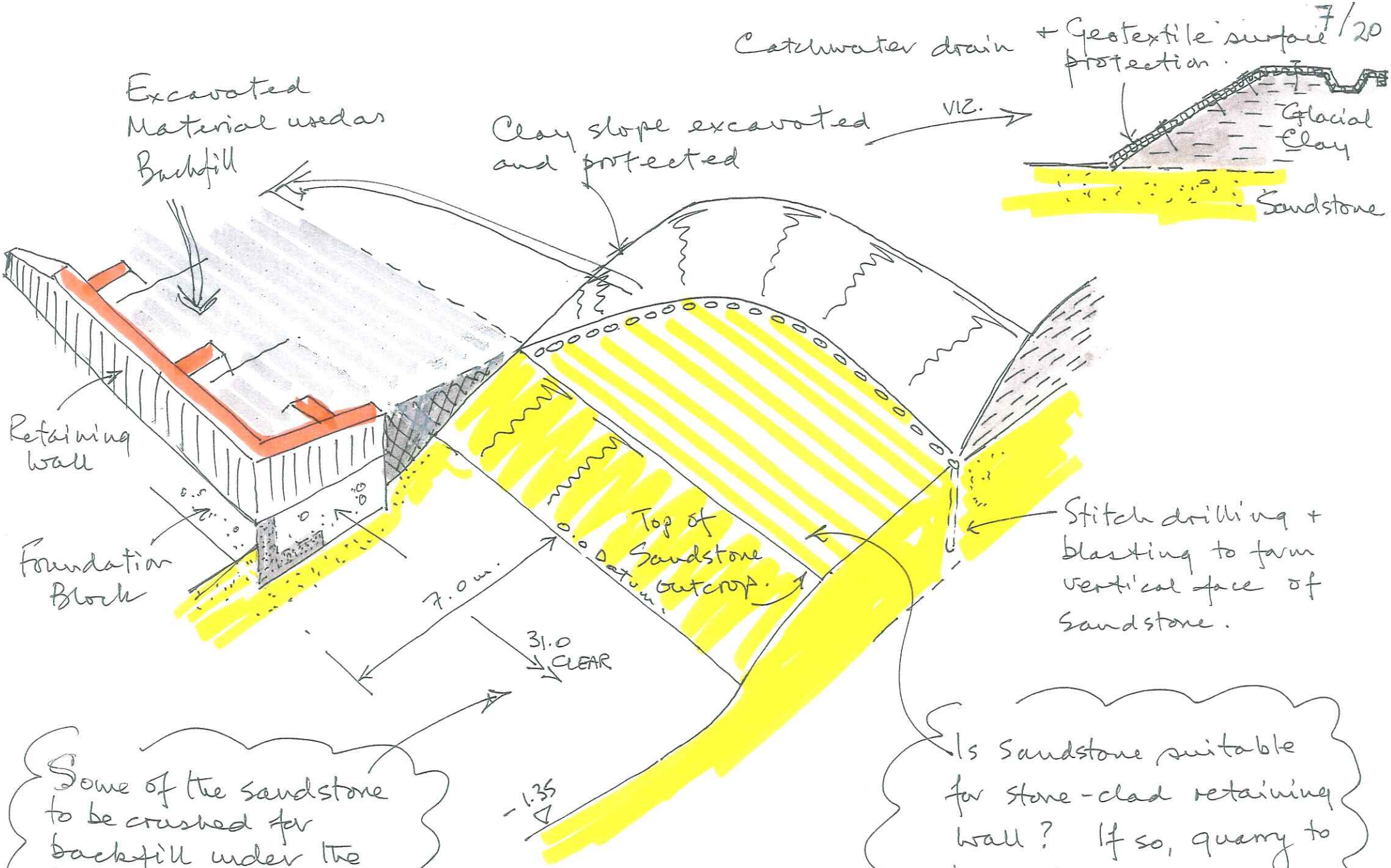
Install front-of-wall drainage — Porous pipes, trench drain to surface-water network.



* Back of wall coated with waterproof material.
* Protect with Zendrain sheets and gravel drainage layer.
* Backfill in 300 layers.
* Controlled compaction.

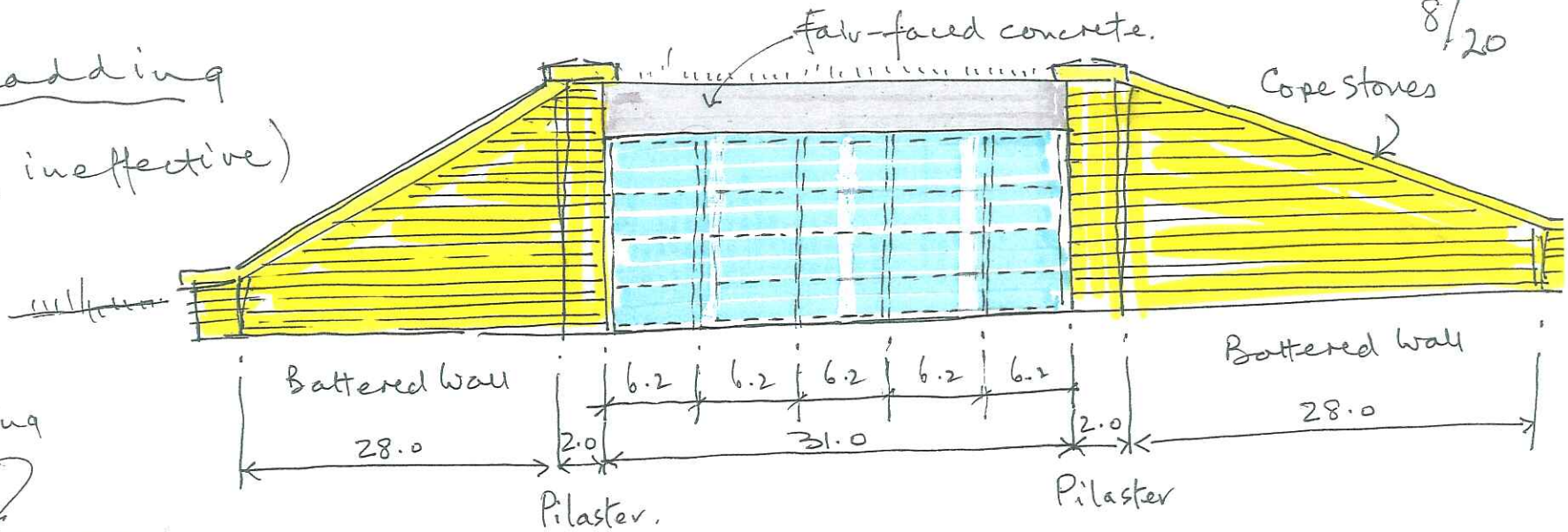
Volume behind wall backfilled with glacial clay excavated from main chamber. to +2.85m level.

Seek advice on backfilling procedure from Geotechnical Specialist!

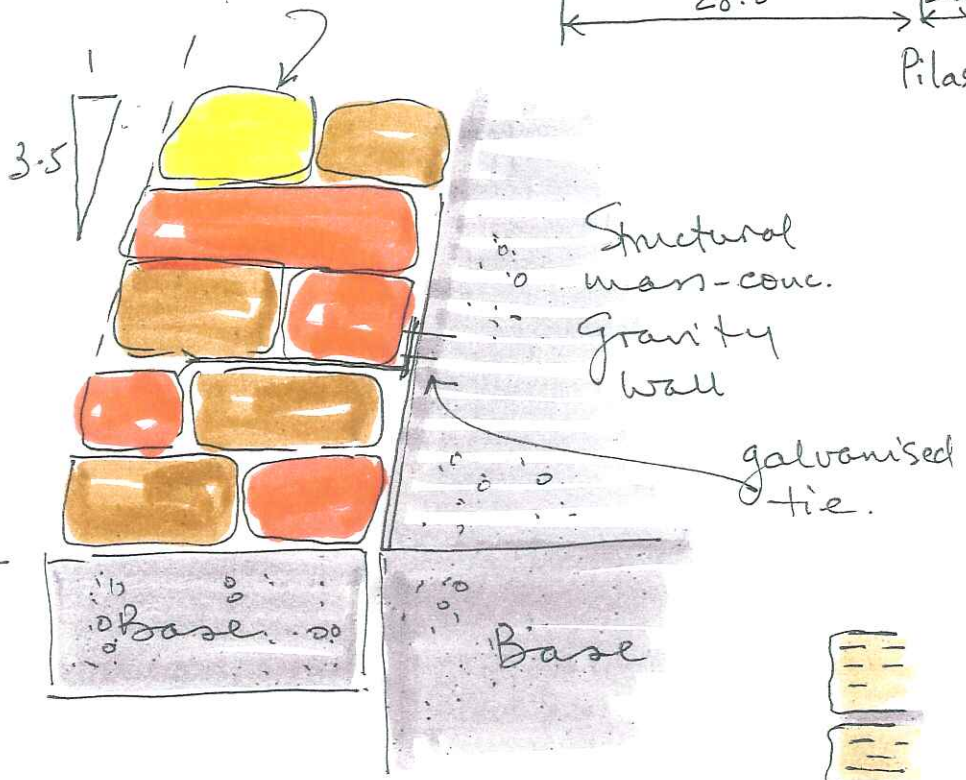

Catchwater drain + Geotextile surface protection.
viz.
Glacial Clay
Sandstone
Excavated Material used as Backfill
Clay slope excavated and protected
Retaining wall
Foundation Block
0.0
-0.5
Top of Sandstone outcrop.
0.0 Datum.
7.0 m.
31.0 CLEAR
-1.35
Stitch drilling + blasting to form vertical face of Sandstone.
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 —

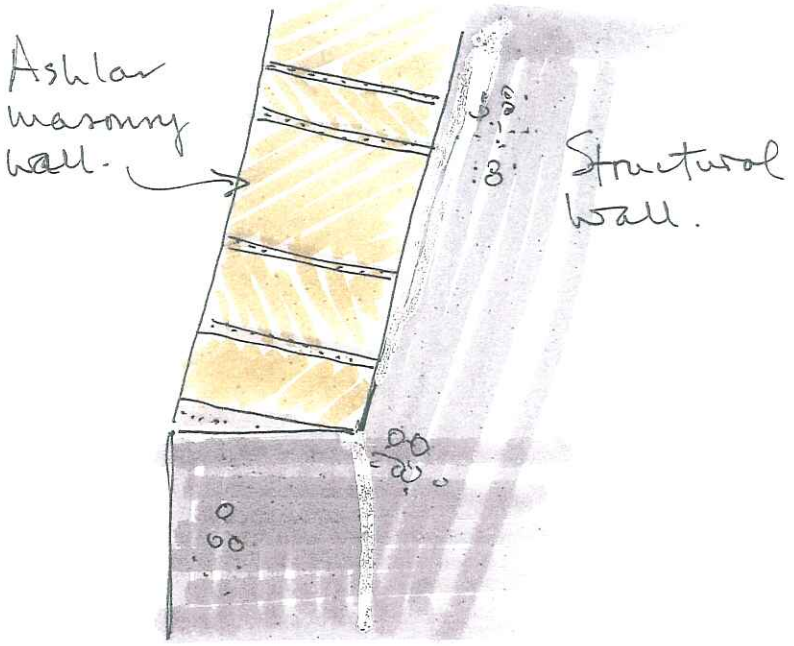
Stone cladding

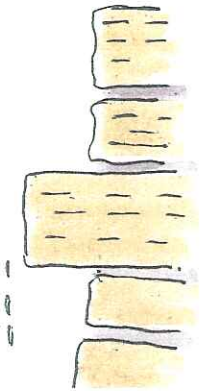
(Structurally ineffective)



Dry Stone Cladding



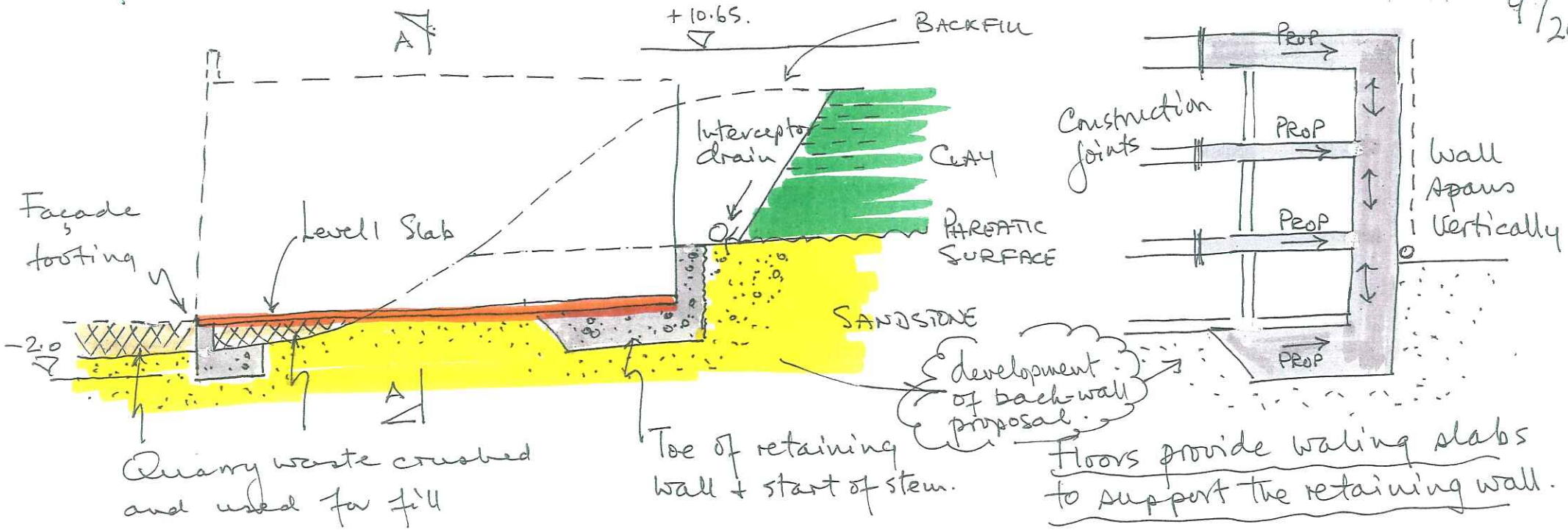




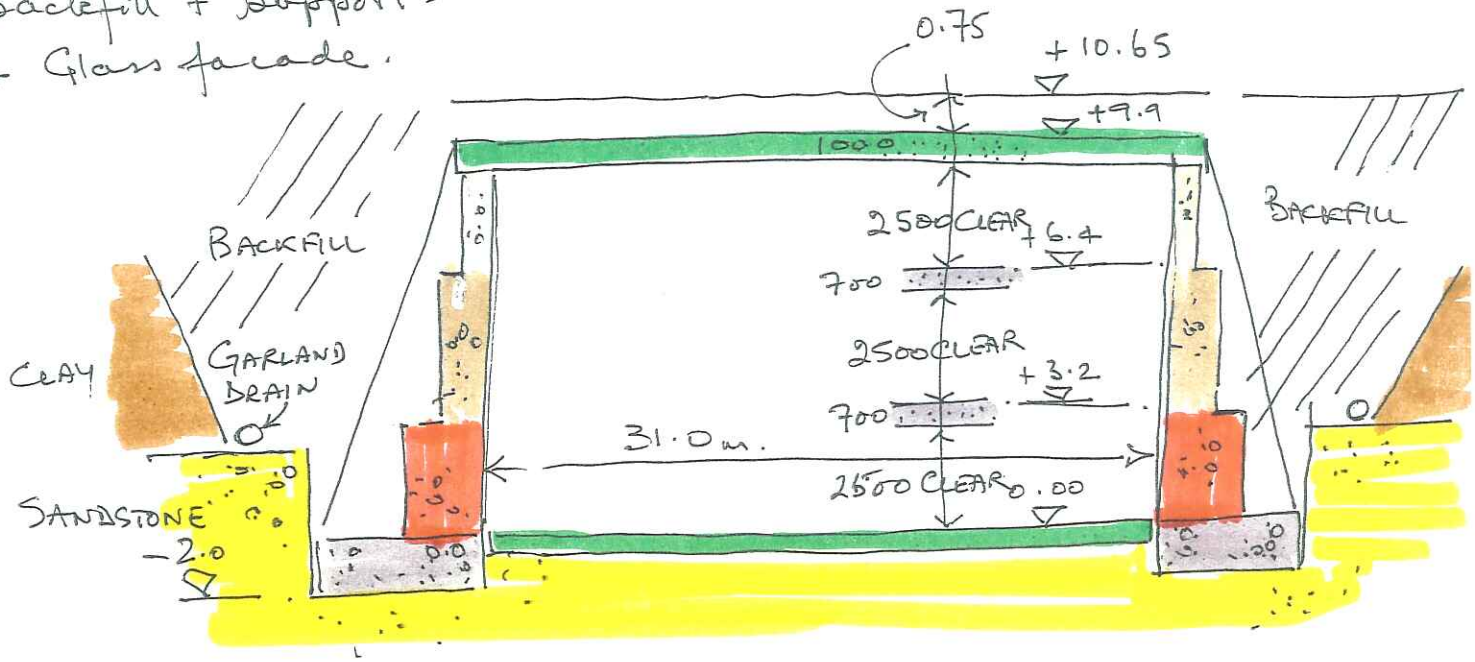
String course sheds rainwash.

Bedding in sedimentary stones to be horizontal.

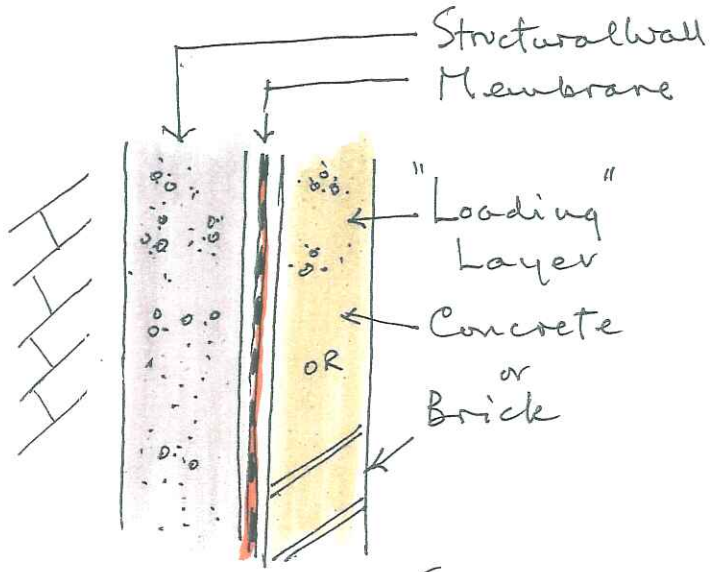
Select mortar + pointing.

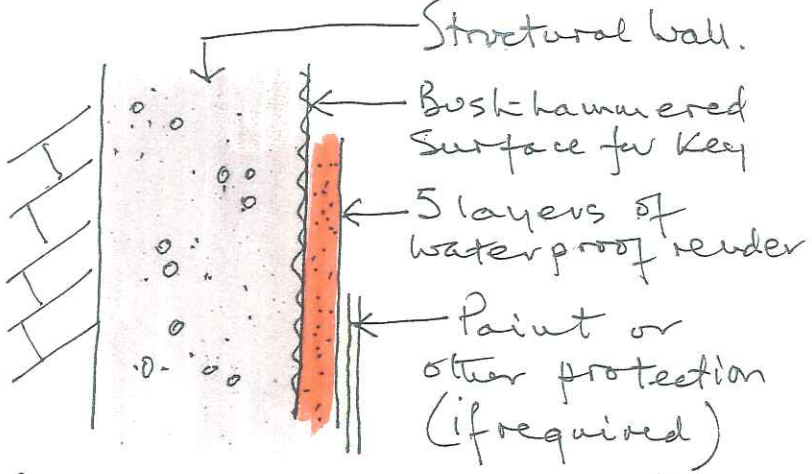


Facade footing retains backfill + supports front edge of Lev. 1 slab + Glass facade.



WATERPROOFING

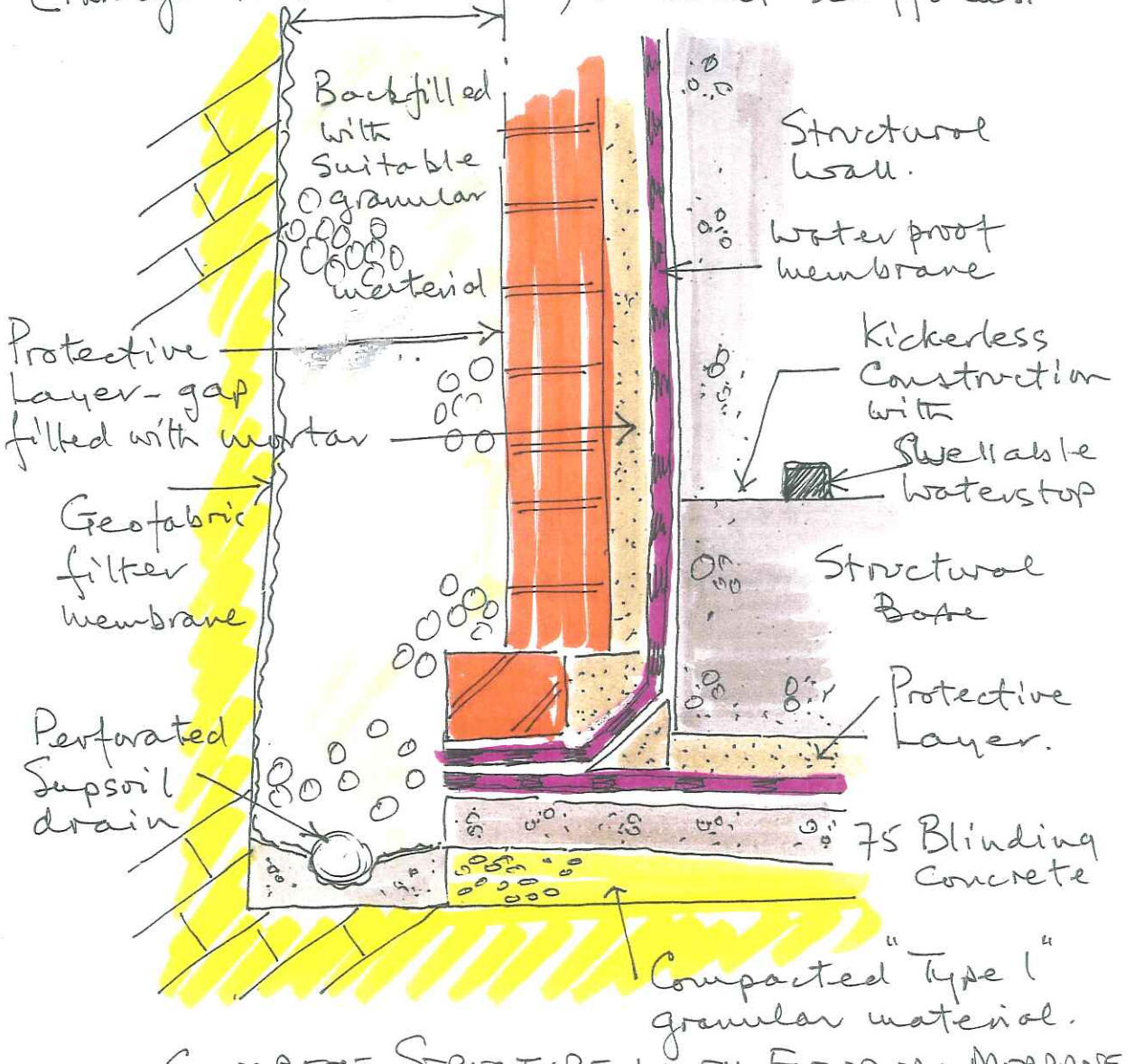




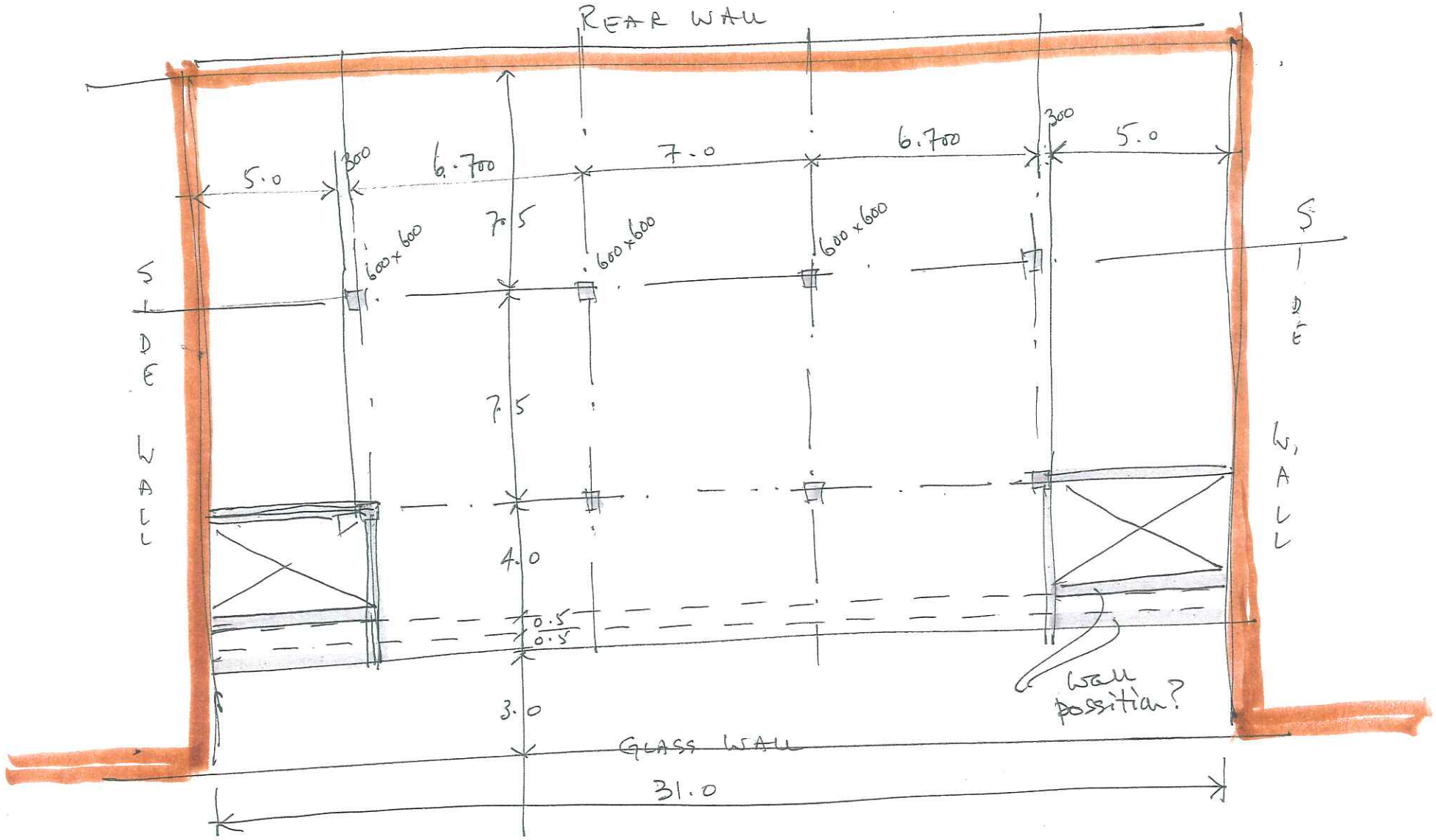
(DETAILS AT BASE NOT SHOWN)

INTERNAL TANKING PROTECTION

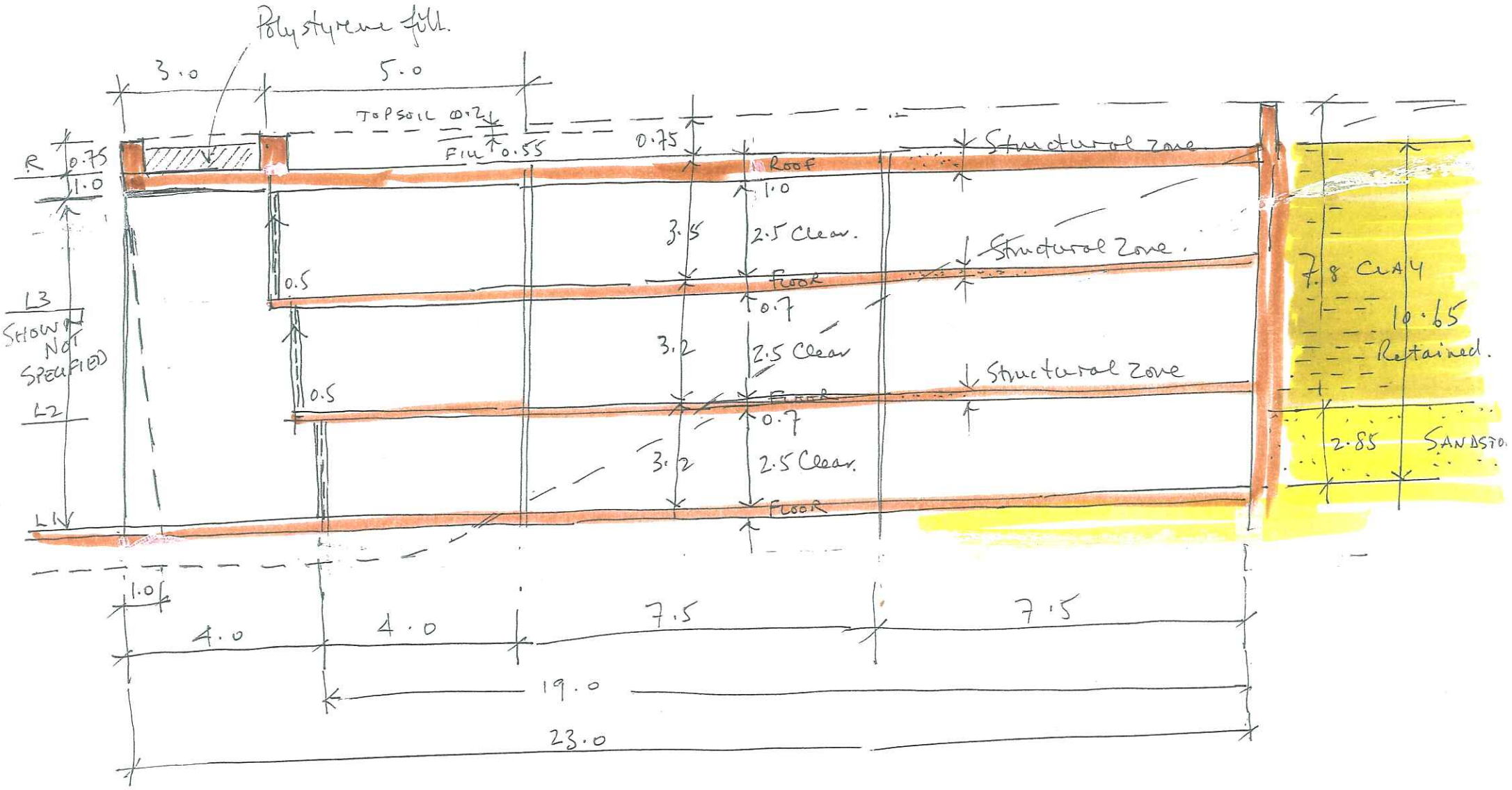
(DOES NOT REQUIRE EXTERNAL WORKING SPACE OR TEMPORARY RETENTION OF SOIL)



CONCRETE STRUCTURE WITH EXTERNAL MEMBRANE

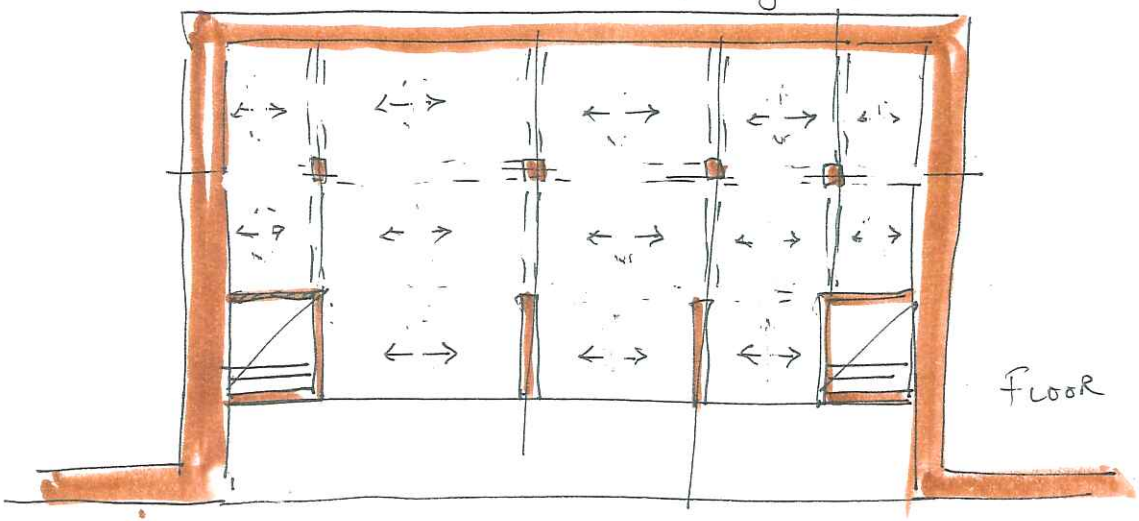


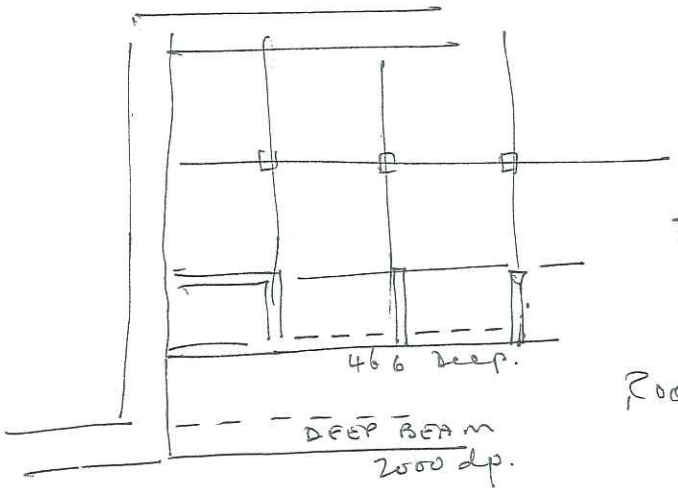
* 5.0 c/c. each way. [4]
* 5.0 from rear + side walls. [4] clear



$\frac{3000}{15} = 2066$

Beam + Longitudinal slab

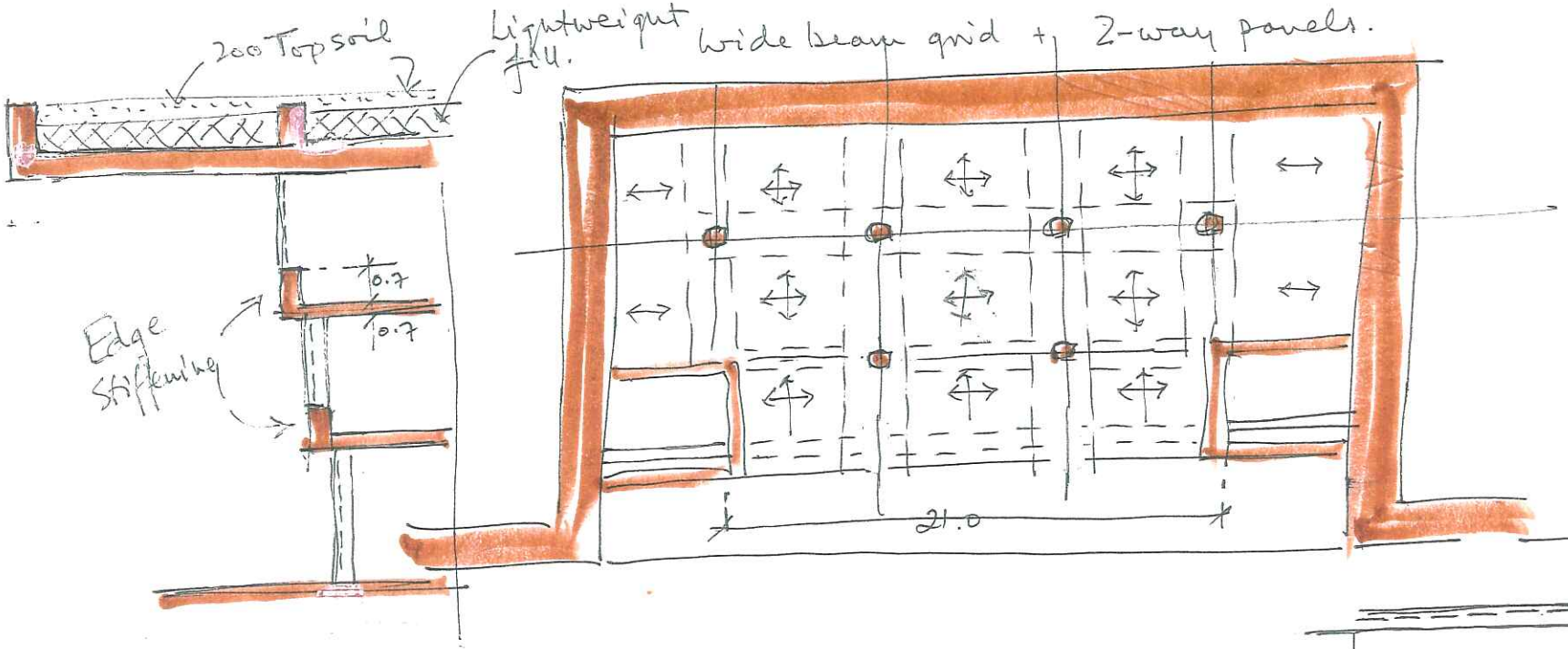




ROOF

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

Lightweight fill. Wide beam grid + 2-way panels.

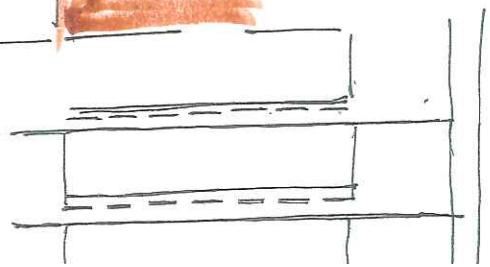


$\frac{7000}{25} = 280$

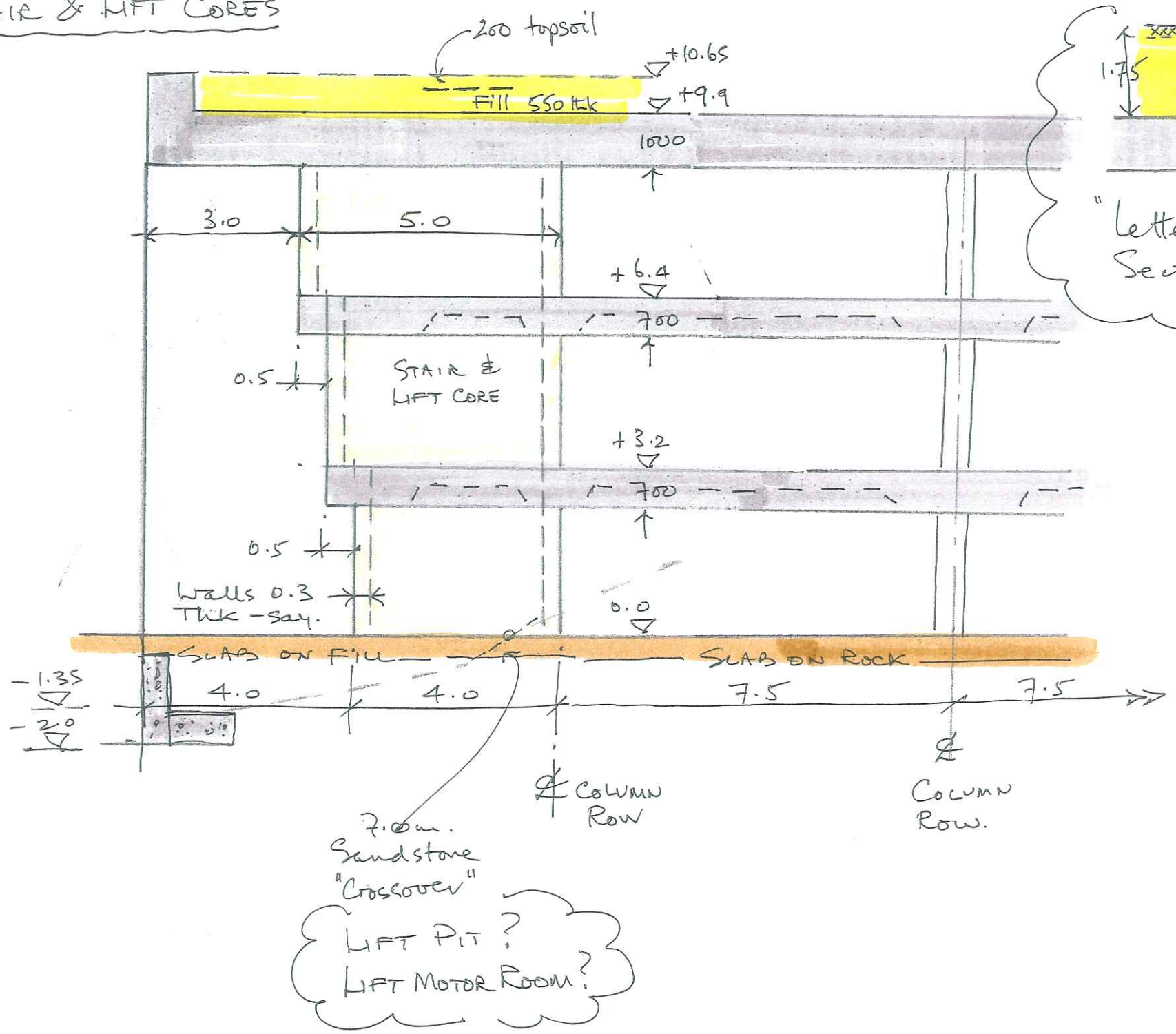
$\frac{7500}{15} = 500$

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

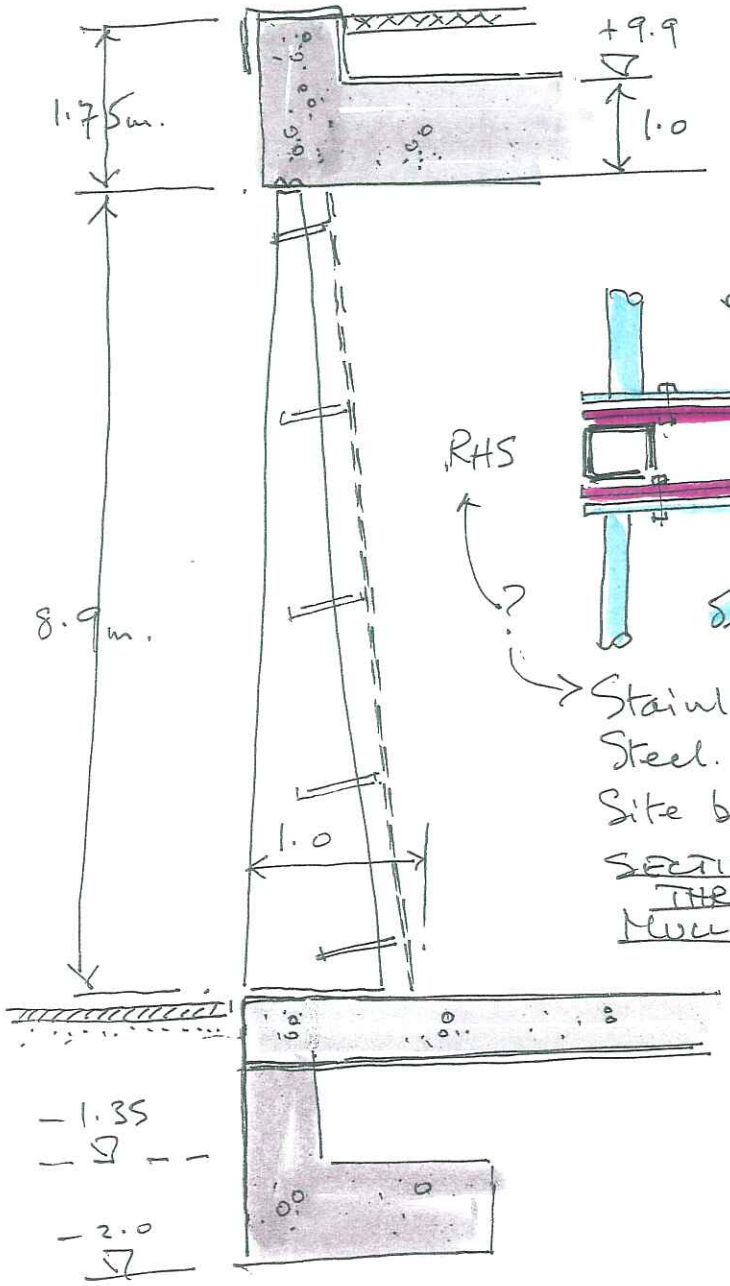
$\frac{5000}{7} = 714$

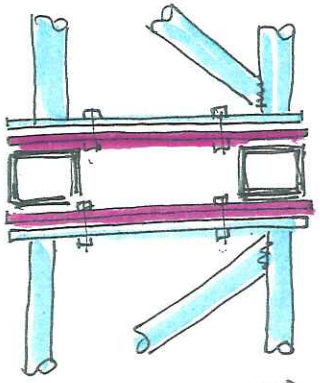


Stair & Lift Cores



GLAZED FACADE - BY SPECIALIST





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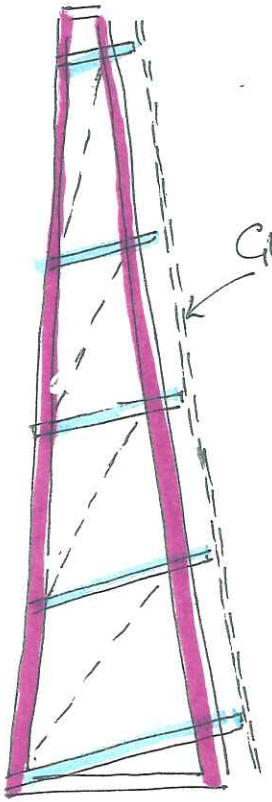
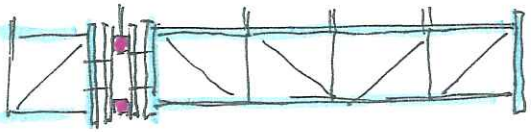
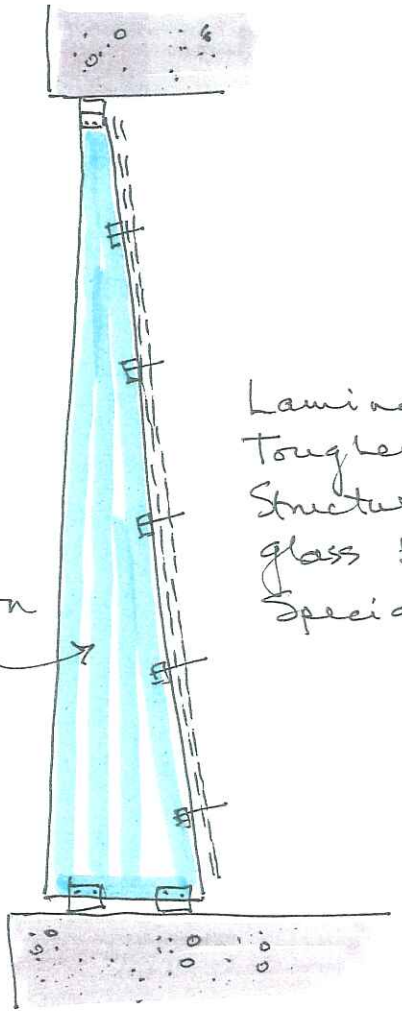


ELEVATION



PLAN.



ELEVATION

References:

(1) BS 8002:1994 - Code of Practice for Earth Retaining Structures.

(2) CIRIA C515:2000 - Groundwater control - design and practice.

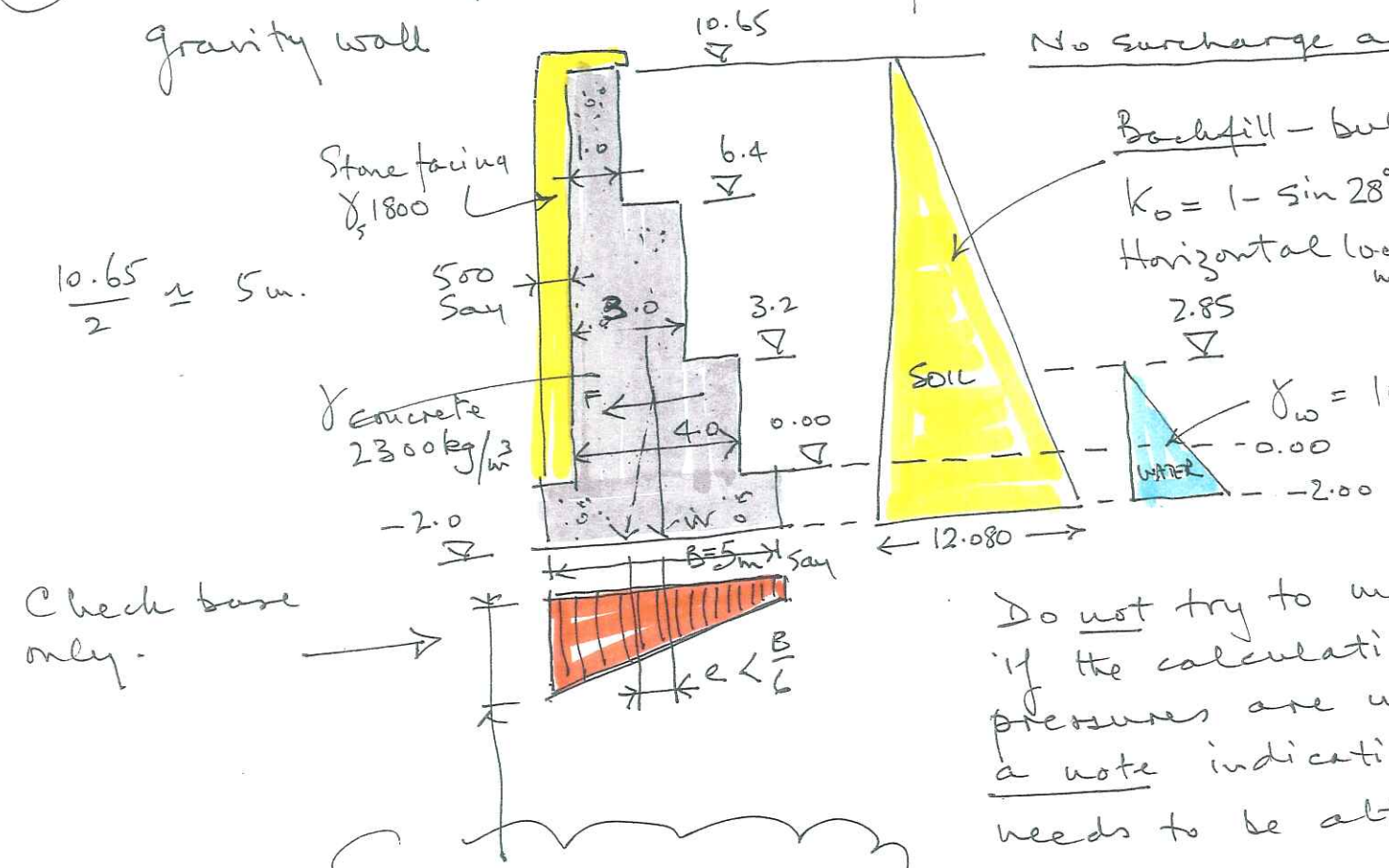
(3) CIRIA Report 139:1995 - Water-resisting basement construction - A Guide.

(4) Malcolm Puller, "Deep Excavations - a practical manual", 2nd Edition pub. Thomas Telford. 2003. ISBN$_{10}$ 0-7277-3150-5

(5) I.StructE: 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

Backfill — bulk density say 1800 kg/m³

$K_o = 1 - \sin 28^\circ = 0.53$

Horizontal load max = $1800 \times 12.65 \times 0.53 = 12080$

≡ 12.080 kN/m² (Unfactored)

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?

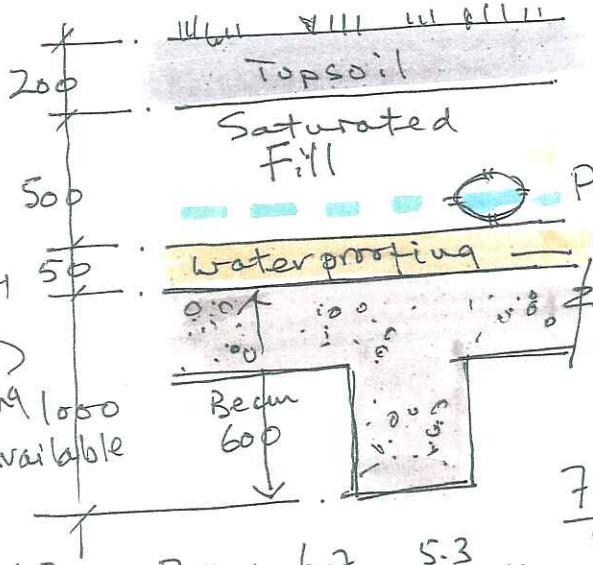
Calculations

(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:



Porous land drains laid to falls.

400 say.

Structural Zone.

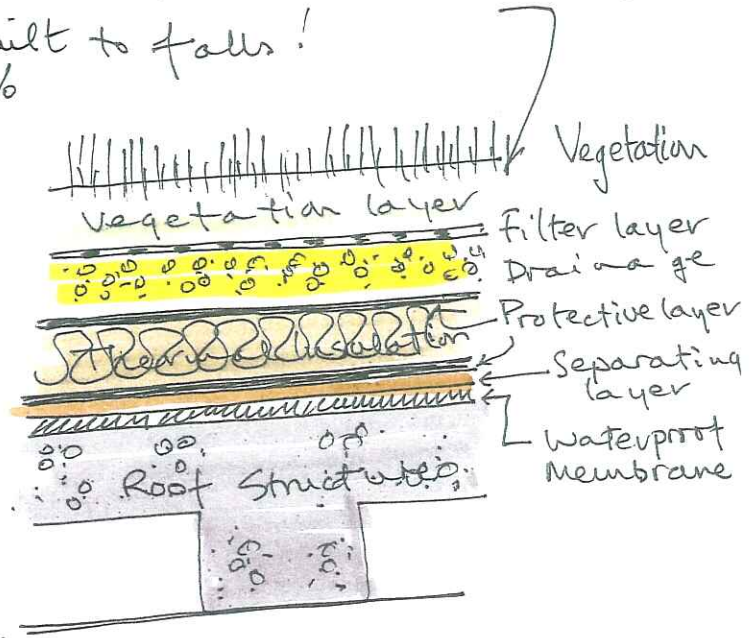
This will leave 400 for accommodating roof falls.

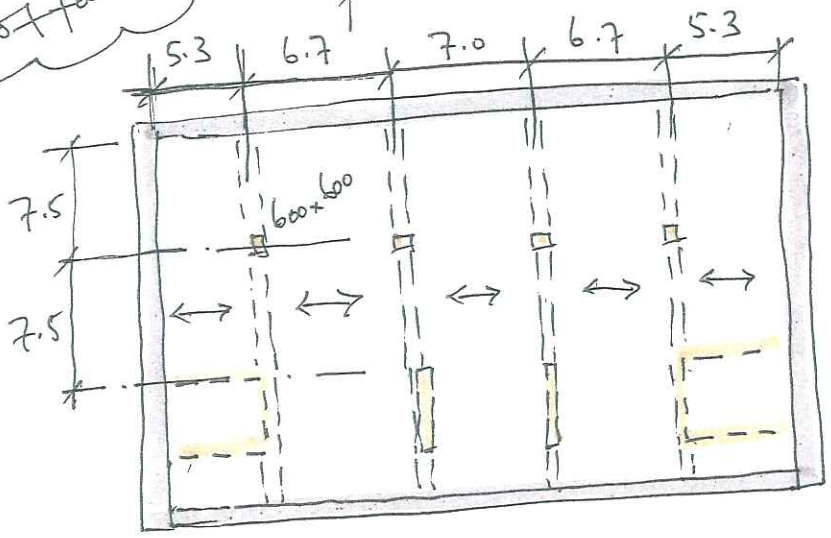
1000 Available

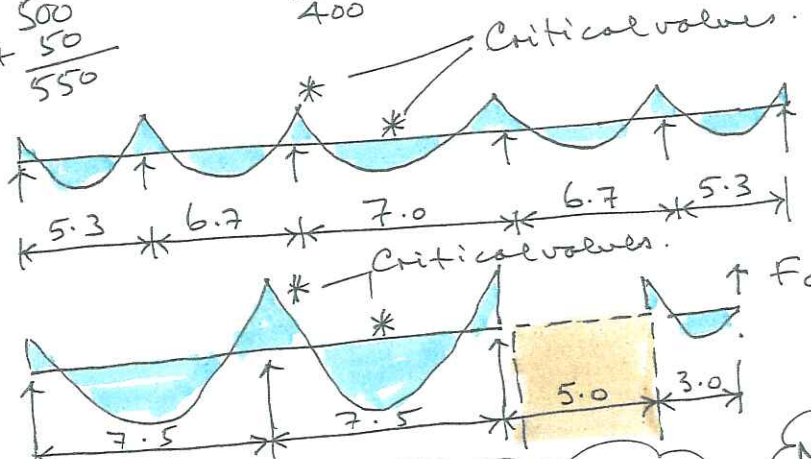
Allow 750 at 1800 kg/m³ = 1350 kg/m² ≡ 13.5 kN/m²

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

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





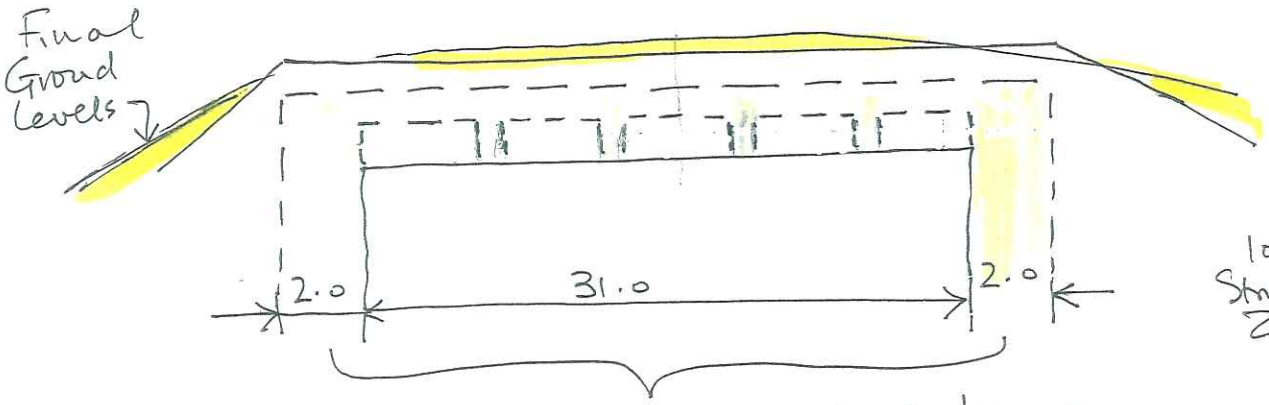


Assume all moments = $\frac{WL}{10}$

NB – See p.19 FOR CONCEPT CHANGE.

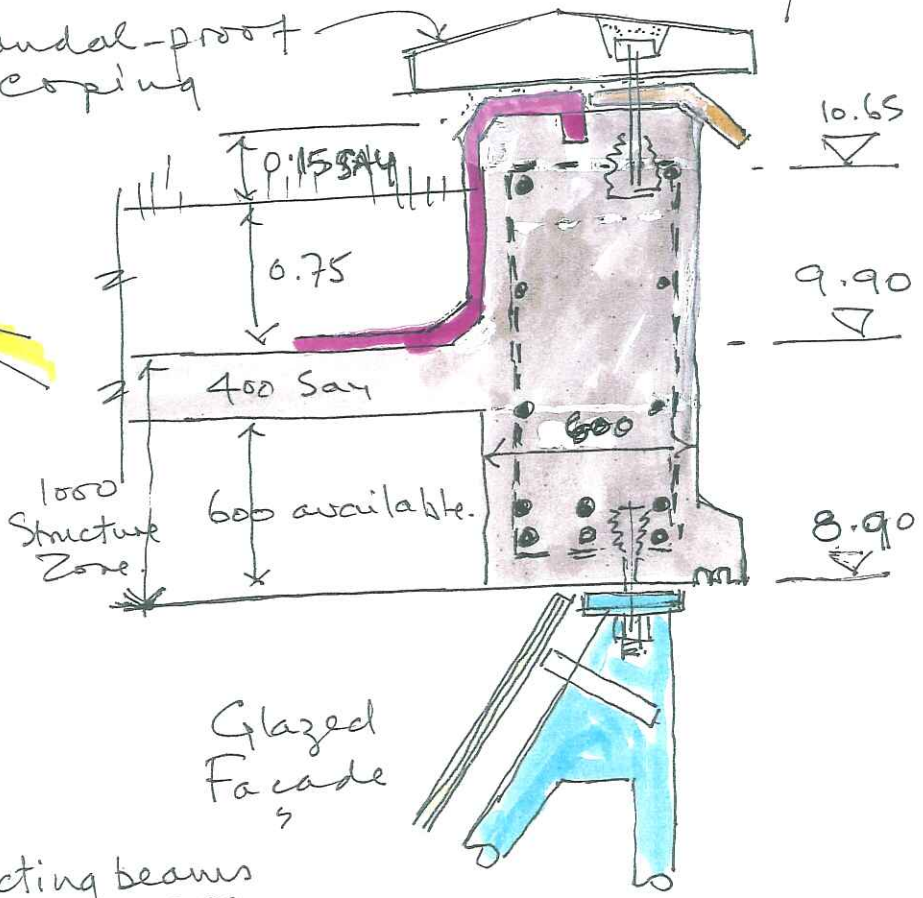
Calculations

(3) Beam over glass façades:

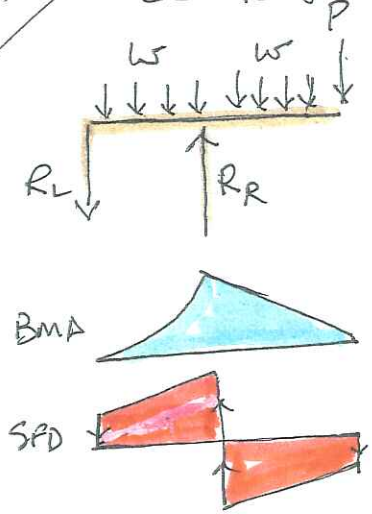


Consider acts like a portal frame.

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



* Reconsider as 5 member supported spans: on projecting beams



Rebar cage dims:

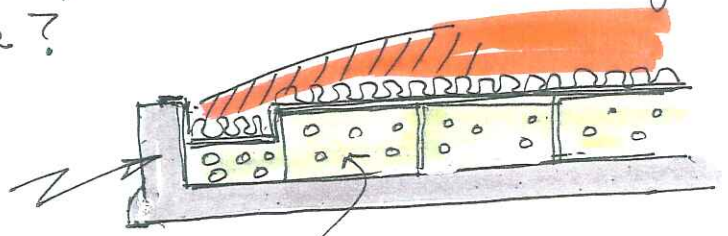
$1900 - 50 - 50 = 1800$
$600 - 50 - 50 = 500$
} Credible!

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

LETTER

Further 1.0 m. 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 1.0 m 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!