Possible solution to past CM examination question

Question 2 - April 2013

Sports Hall

by Dr Peter Gardner

Question 2. Sports hall

Client's requirements

1. A new sports hall is required in the shape of a 90 degree circular sector. See Figure Q2.
2. The playing area is to be 40m radius and 8m high.No structural elements are allowed inside this space.
3. The sloping seating area is to be 10m wide and extend from ground level to 5m high.No columns or other structural members are permitted to obstruct the view of the playing area.
4. There are no restrictions to the structure outside the building envelope.
5. An existing reinforced concrete basement slab 0.2m thick has been discovered at 2m depth covering the whole site.
6. The playing area is to be covered in top soil so no ground floor slab is required. A minimum of 30 per cent of the roof area must be glazed to allow the growth of grass turf on the playing surface.

Imposed Loading

7. Roof loading 0.5kN/m²
8. Seating loading 5.0kN/m²

Site conditions

9. The site is located in a coastal location. Basic wind speed is 46m/s based on a 3 second gust; the equivalent mean hourly wind speed is 23m/s.
10. Borehole for proposed sports hall

0m – 0.5m	Top soil
0.5m – 2.0m	Sand N=10
2.0m – 2.2m	Concrete slab
Below 2.2m	Dense Gravel N=30

Borehole for second sports hall

0.0m – 4.0m	Loose clayey sand
4.0m – 7.0m	Sand N=10
Below 7.0m	Gravel N=20

No water was found in either borehole

Omit from consideration

11. Detailed design of seating including access stairs

SECTION 1 (50 marks)

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure.Indicate clearly the functional framing, load transfer and stability aspects of each scheme.Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After the completion of the Sports Hall the client decides to construct a second hall in another location where the ground conditions are given by a second borehole.Write a letter to your client advising him of the implications of this information. (10 marks)

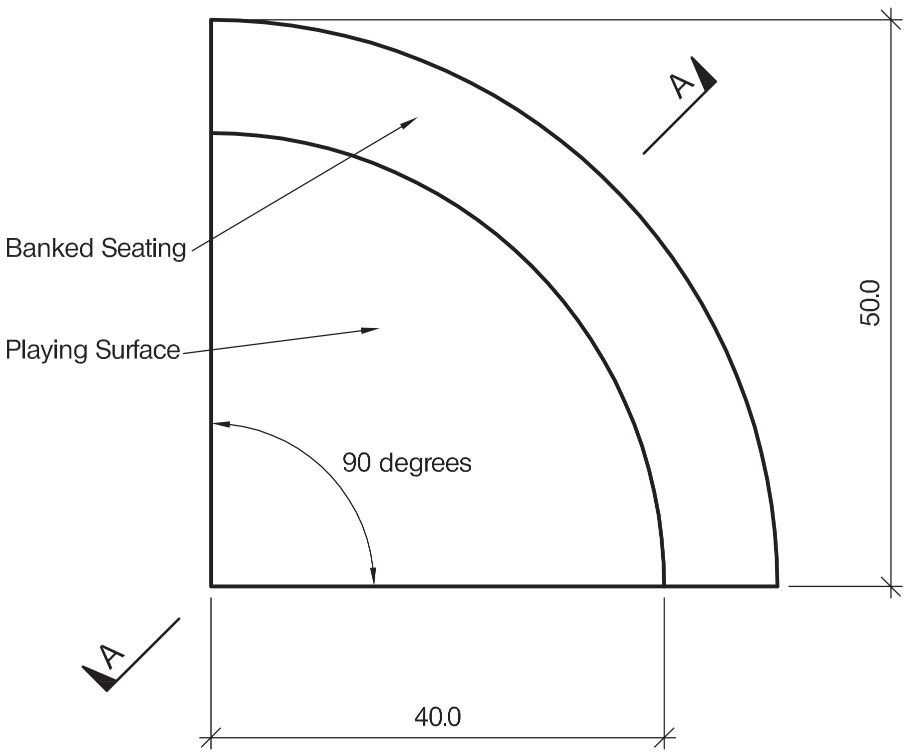
SECTION 2 (50 marks)

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)



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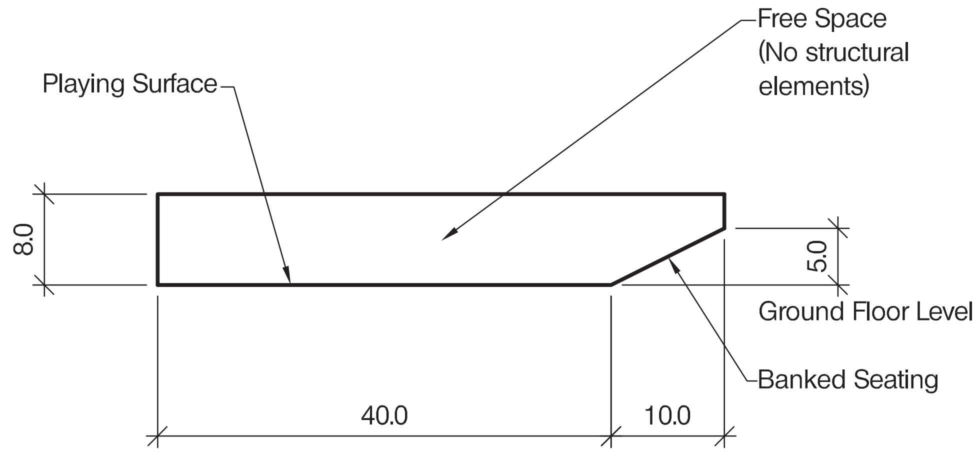


SECTION A - A

NOTE: All dimensions are in metres

FIGURE Q2

Sports Hall

Introduction

This question requires the design of a new sports hall with an unusual shape. It forms one quarter of a circle and contains a playing area of 40m radius with a further area of banked seating that borders the playing surface. The playing area and the seating are to be completely free of structural elements but there is no further restriction on the structure. There is an unusual feature in the ground. The playing area is grassed which necessitates a third of the roof to be glazed. This should provide a relatively straightforward framework around which to develop suitable structural arrangements.

The brief

- Clear span building with an unusual shape (quarter of a circle).
- No structural elements are allowed inside the building's open space, but there are no restrictions outside the described envelope.
- Sloping seating to be 10m deep in plan, and 5m high at the rear.
- There is half a metre of topsoil and a further 1.5m of sand below which is a 200mm thick concrete slab which sits on top of dense gravel.
- The playing area is to be covered with topsoil. (ie no ground floor slab required).
- A minimum of 30% of the roof area is to be glazed to facilitate light reaching the grassed playing surface.

Development of structural schemes

As no internal columns are allowed, it is obvious that there are going to be some long span roof beams required for the structure. There are various options available ranging from radial beams to a 3-D grid (see figure 1). The majority of candidates who attempt this question proposed the roof arrangement shown in figure 1(a). Although this is structurally sound and thus perfectly satisfactory, it doesn't show any particular imagination and doesn't reflect the geometry of the structure.

The arrangement shown in figure 1(e) has the disadvantage that all the large roof members meet at a point, the arrangements shown in figure 1(f) or (g) overcome this problem. Figure 1(j) represents a three-dimensional roof which would provide a structurally efficient roof but would be too complex to design in the time allowed in the examination.

Other possibilities would be supporting the long span roof beams with cable stays strung from a tower (see figure 2(a)) or portalised lattice frameworks.

The brief specifically mentions a requirement for 30% glazing in the roof to allow-in light to facilitate growth of the turf. Although this doesn't affect the layout of supporting elements it does mean that excessive deflection/flexibility could cause a problem and therefore providing a relatively stiff structural framework would be an important consideration.

Stability could be provided by bracing positioned around each of the perimeter faces; by fixed based columns acting as vertical cantilevers; by portal action or a combination of these. The raked seating support provides a triangle which could be used to aid stability.

Any of the above main framing options, combined with variation in the stability system could be developed into "two distinct and viable schemes".

Ground conditions and foundations

It seems fairly obvious that a building of this size will need substantial foundations on good soil and therefore founding on the dense gravel seems the only practical option. There is no better soil with increasing depth so assuming sufficient capacity can be gained by pad footings at 2.2m this would seem to be the ideal solution.

The issue of the existing concrete slab needs to be investigated/discussed. If the concrete is in reasonable condition and the site investigations don't question the quality of the concrete and the consistency of the gravel beneath can be assured, there is no particular reason why the foundations shouldn't be placed on top of the concrete slab (although my natural tendency is to dig out the slab and found on virgin gravel). However there may well be substantial lateral loads which would need to be resisted entirely by friction between the slab and the concrete (unless a key is constructed).

It would be unwise to be tempted to found in the sand, partly because this is a substantial building and the sand is relatively weak, but also by definition the sand must have been imported at some stage as it sits on top of the concrete slab.

If one wished to propose an alternative foundation solution (which probably isn't necessary as long as sufficient variation has been provided in the superstructure), piles into the gravel would be an option.

Section 1b

The scenario presented in section 1b revolves around the client wishing to build an identical structure in a different location where there are substantially different ground conditions. This should lead one to concentrate on the problems in the ground, but a comprehensive answer could include checking for factors that might impinge on the superstructure’s design, particularly the wind speed and other environmental factors connected with the location.

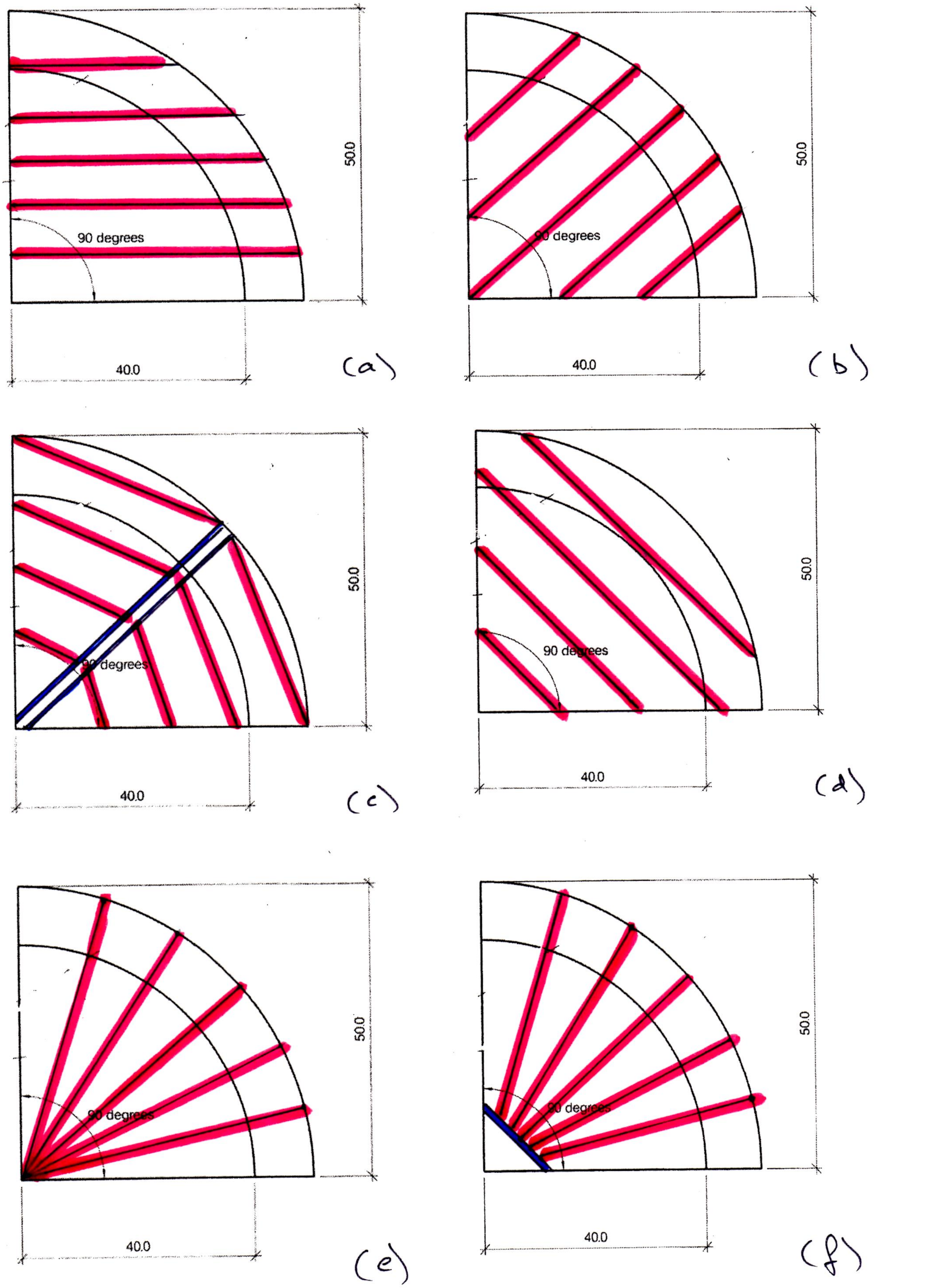
There are very different ground conditions at the second site with gravel being found at 7m, with 4m of loose clayey sand and an additional 3m of weak sand on top of the gravel. The depth would suggest a piled solution with due note being made of the necessity to ensure that lateral loads can be properly dealt with.

The other factor that could be brought to the client's attention is that the first site had half a metre of topsoil whereas the second site has clayey-sand at the surface which would necessitate a layer of imported topsoil for the grassed playing surface. Both sites would need temporary ground works to support construction vehicles, particularly cranes for steelwork erection and additionally piling rigs for the second site.

All these factors combined would provide a complete and detailed letter.

Summary

Overall this seems to be a relatively straightforward question involving long span roof beams configured in an unusual geometrical layout. It provides an ideal vehicle to provide two distinct and viable alternatives and is not clouded by any issues that could cause difficulty. Therefore, as long as one has sufficient experience to tackle large clear span buildings this question shouldn't present any particular difficulties.



Q2 - Figure 1 a - f.

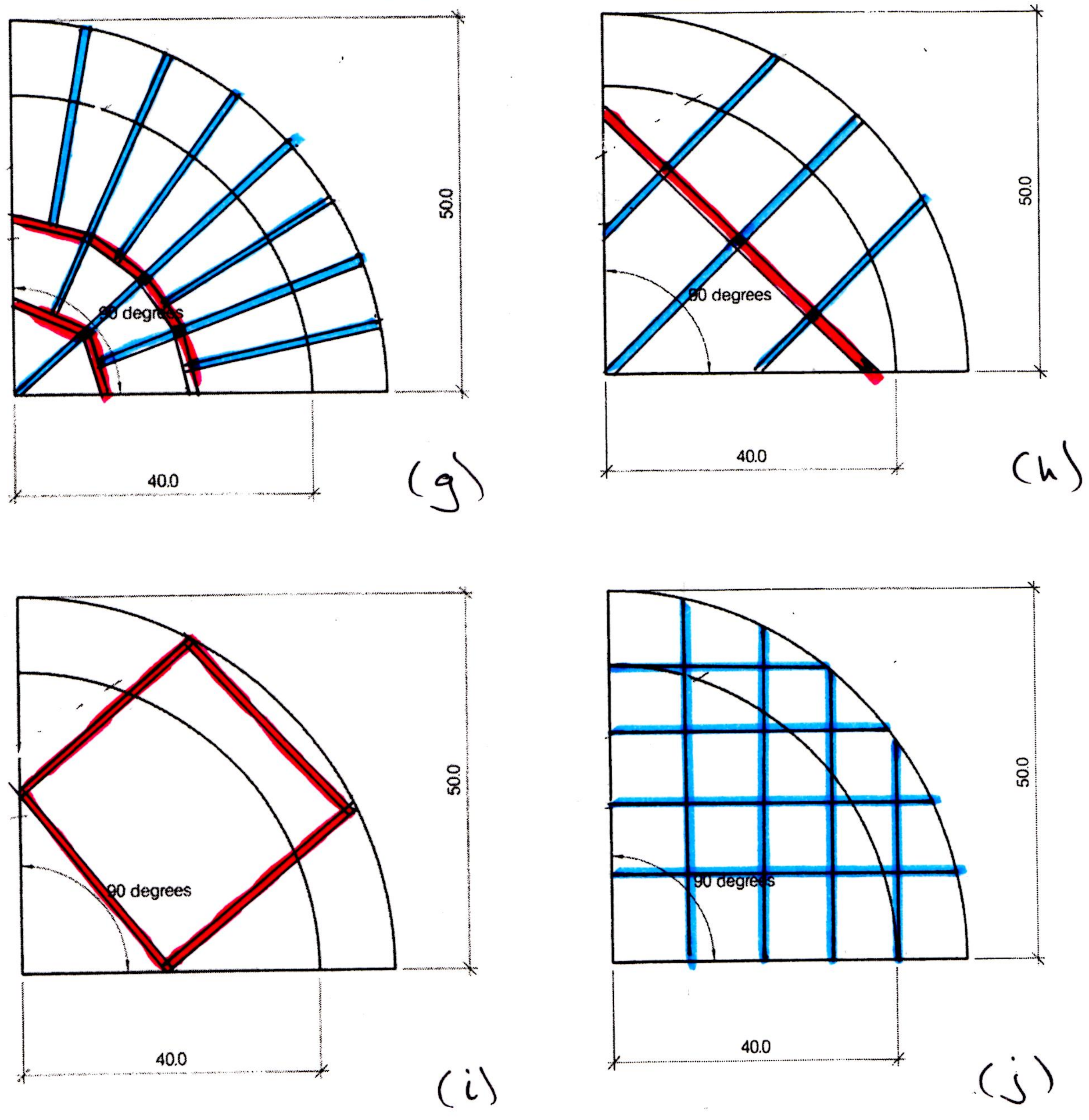
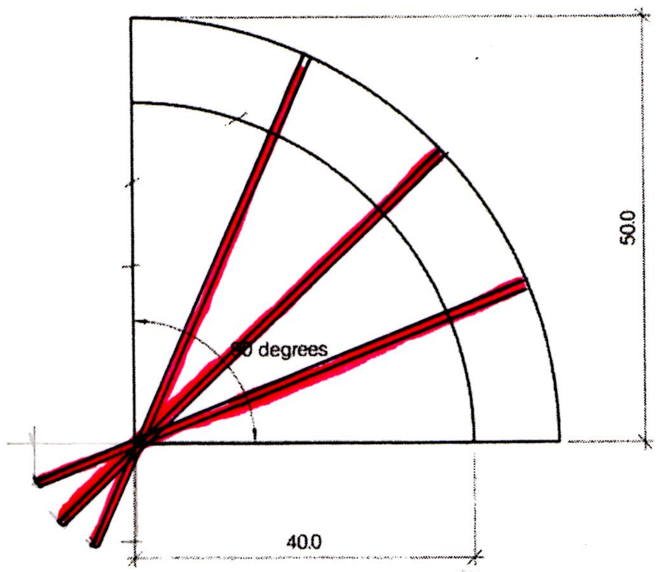

90 degrees
50.0
40.0
(g)
90 degrees
50.0
40.0
(h)
90 degrees
50.0
40.0
(i)
90 degrees
50.0
40.0
(j)

Figure 1 (g-j).



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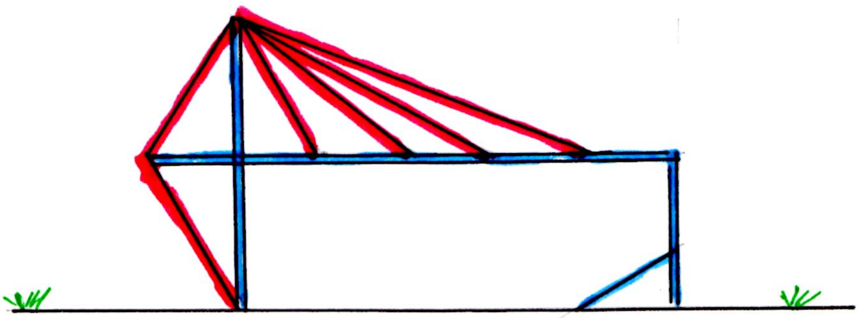


ELEVATION / SECTION.

FIGURE 2

Possible solution to past CM examination question

Question 3 - April 2013

Footbridge over a waterfall

by Saprava Bhattacharya

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).

Question3. Footbridge over a waterfall

Client's requirements

1. A 2.5m wide footbridge across a waterfall approximately 50.0m high. Bridge should be aesthetically pleasing and should provide dramatic views over the edge of the fall. See Fig 3.
2. A rocky outcrop at mid-span with a plan area of approximately 3.0m x 3.0m may be used for vertical support. No other foundations are permitted within 5.0m of the edge of the fall.
3. For safety reasons, the river upstream of the bridge cannot be navigated and cannot be used for any construction activity.

Imposed loading

4. Uniformly distributed load 5.0kN/m_2

Site conditions

5. The site is located in open countryside. Basic wind speed is 46m/s based on a 3 second gust; the equivalent mean hourly wind speed is 23m/s.
6. Ground conditions: Granite Allowable bearing capacity 2000kN/m^2. Rocky outcrop Maximum un-factored vertical load 250kN

Omit from consideration

7. Longitudinal imposed loading.

SECTION 1 (50 marks)

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After the design has been completed, investigation shows that the rocky outcrop is not able to be used for support. Write a letter to your client explaining the implications on your design. (10 marks)

SECTION 2 (50 marks)

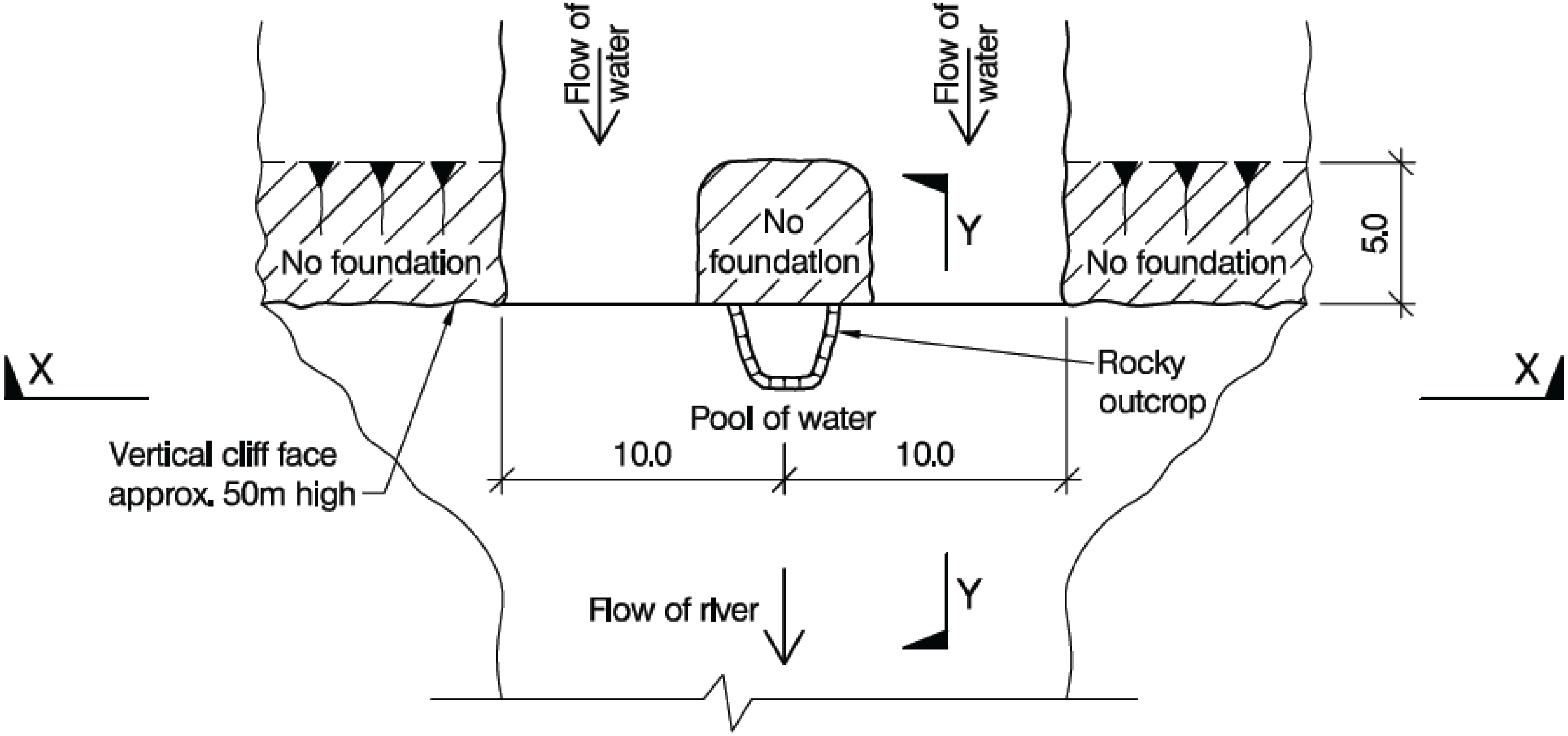
For the solution recommended in Section 1(a):

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

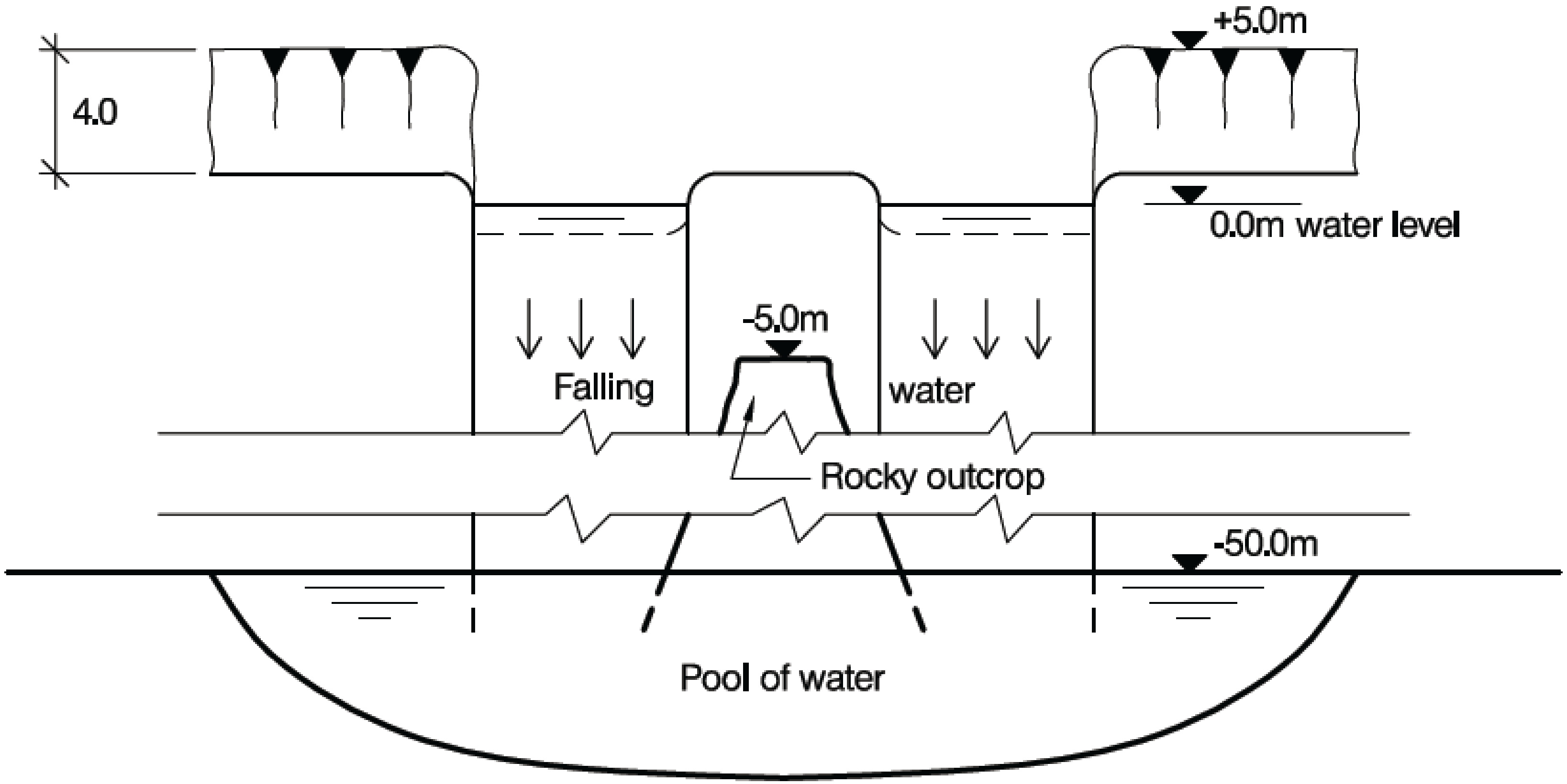
d. Prepare general arrangement plans, sections & elevations to show the dimensions, layout & disposition of the structural elements & critical details for estimation. (20 marks)

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

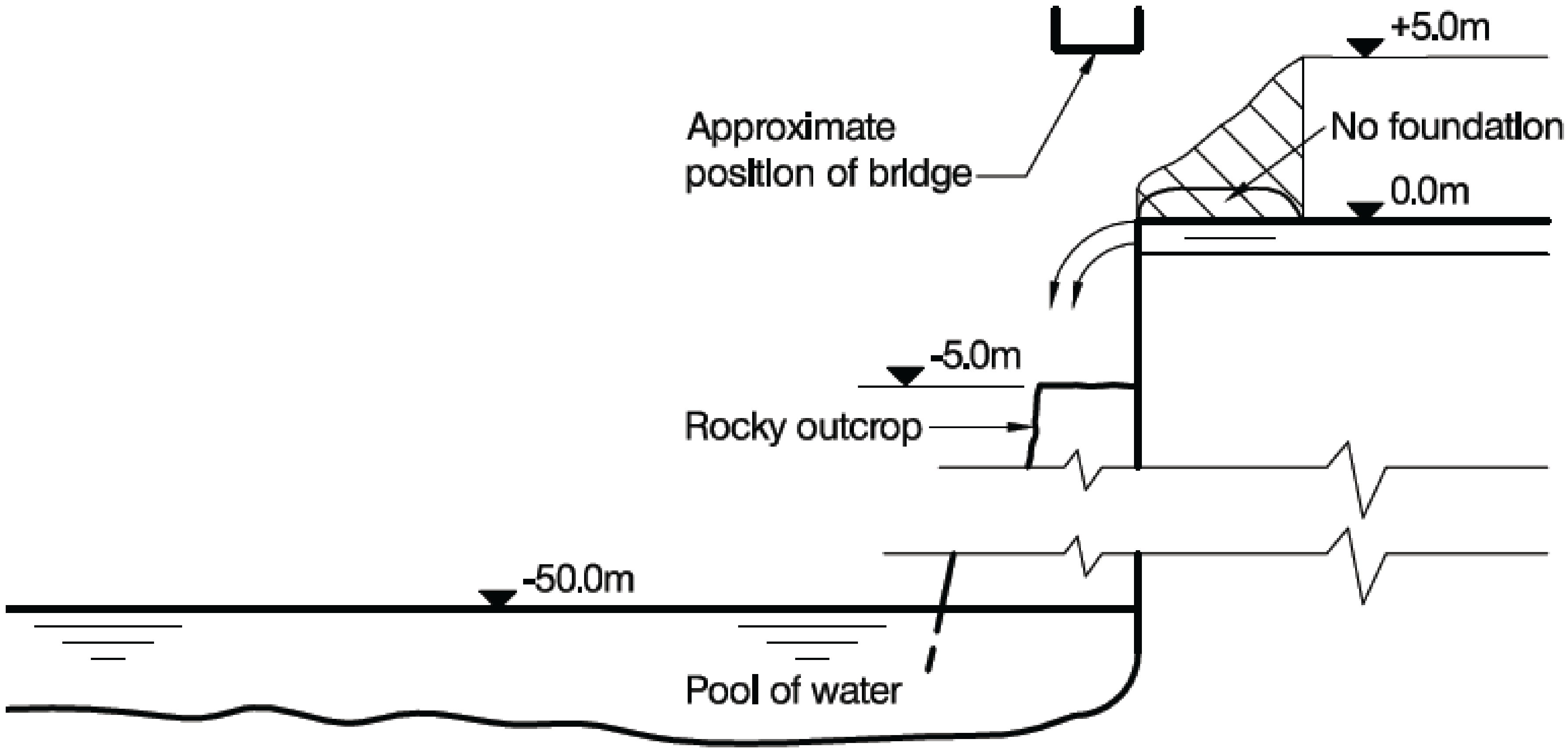
Footbridge / Viewing Gallery over a Waterfall Figure 3



PLAN ON WATERFALL


+5.0m
4.0
0.0m water level
-5.0m
Falling
water
Rocky outcrop
-50.0m
Pool of water

VIEW X - X


+5.0m
Approximate
position of bridge
No foundation
0.0m
-5.0m
Rocky outcrop
-50.0m
Pool of water

SECTION Y -Y

Introduction:

The main idea of this bridge came from the bird's eye view of Niagara waterfall – the thought was "if there could be a curved bridge that could facilitate people to view the waterfall very closely from the top?" One day in future, bridge engineers might be able to make a transparent bridge / viewing gallery, keeping the natural beauty intact.

Figure A: Bird's eye view of Niagara waterfall.

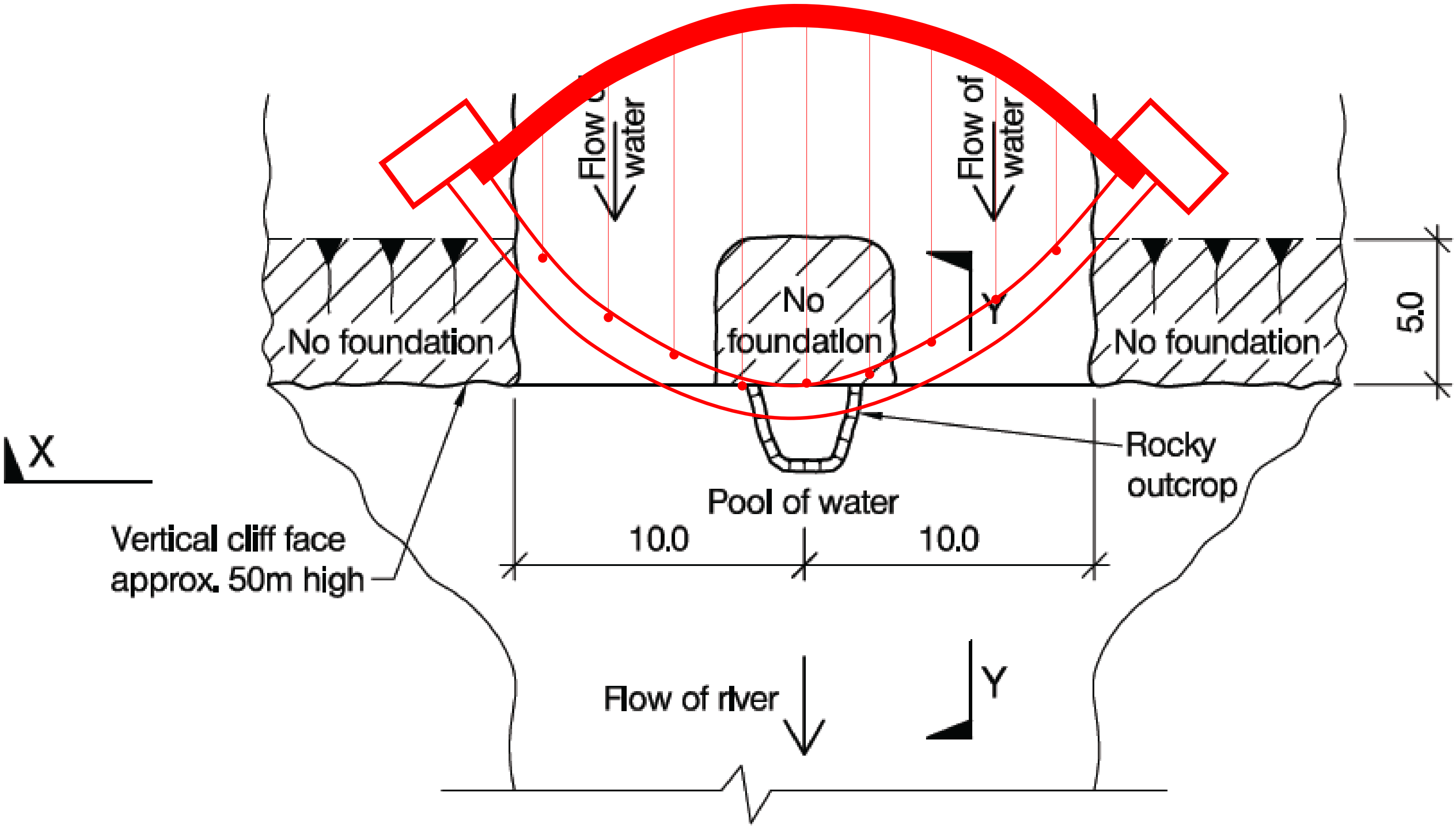
Figure B: Smaller waterfall

It reminded another small waterfall with a rocky outcrop in the middle where the above dream can be fulfilled hence this question was set for future chartered engineers.

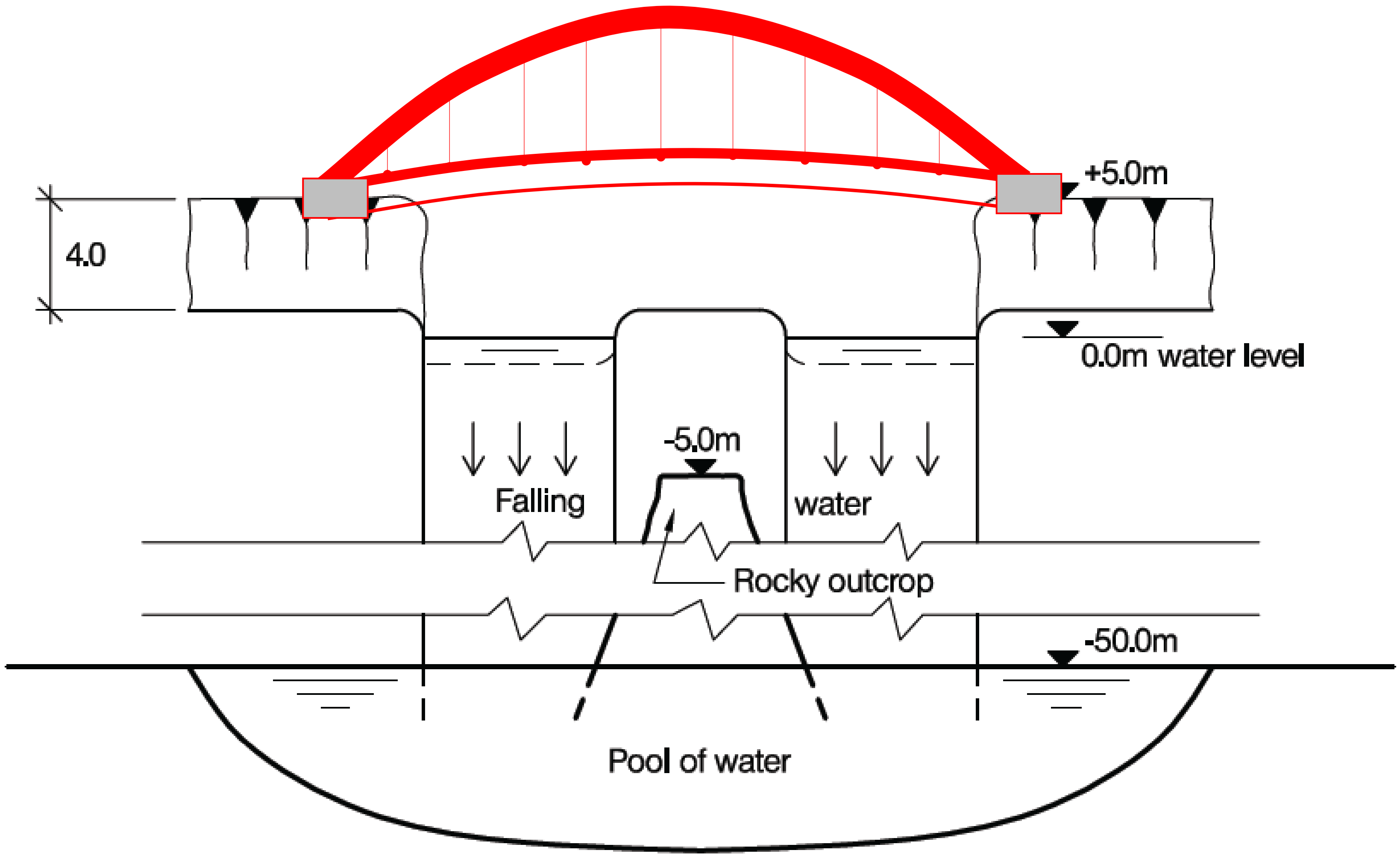
Understanding the question and visualisation of the site in three dimensions is the most important step to solve the problem. At the same time structural engineer's ability to analyse beams curved in plan is equally important for this particular question. The most important and challenging aspect of this particular problem is how the structure to be built safely.

However following figures shows the various different possible options as the solution to this particular problem but only three of them fully complies with client requirements and that is what expected from candidates.

1. **<u>First option may be a Non-moving Gateshead millennium bridge</u> – an appropriate solution to maintain beauty but can't be a chosen option as it may not be the most appropriate solution for any candidate to manage in seven hours examination situation.**

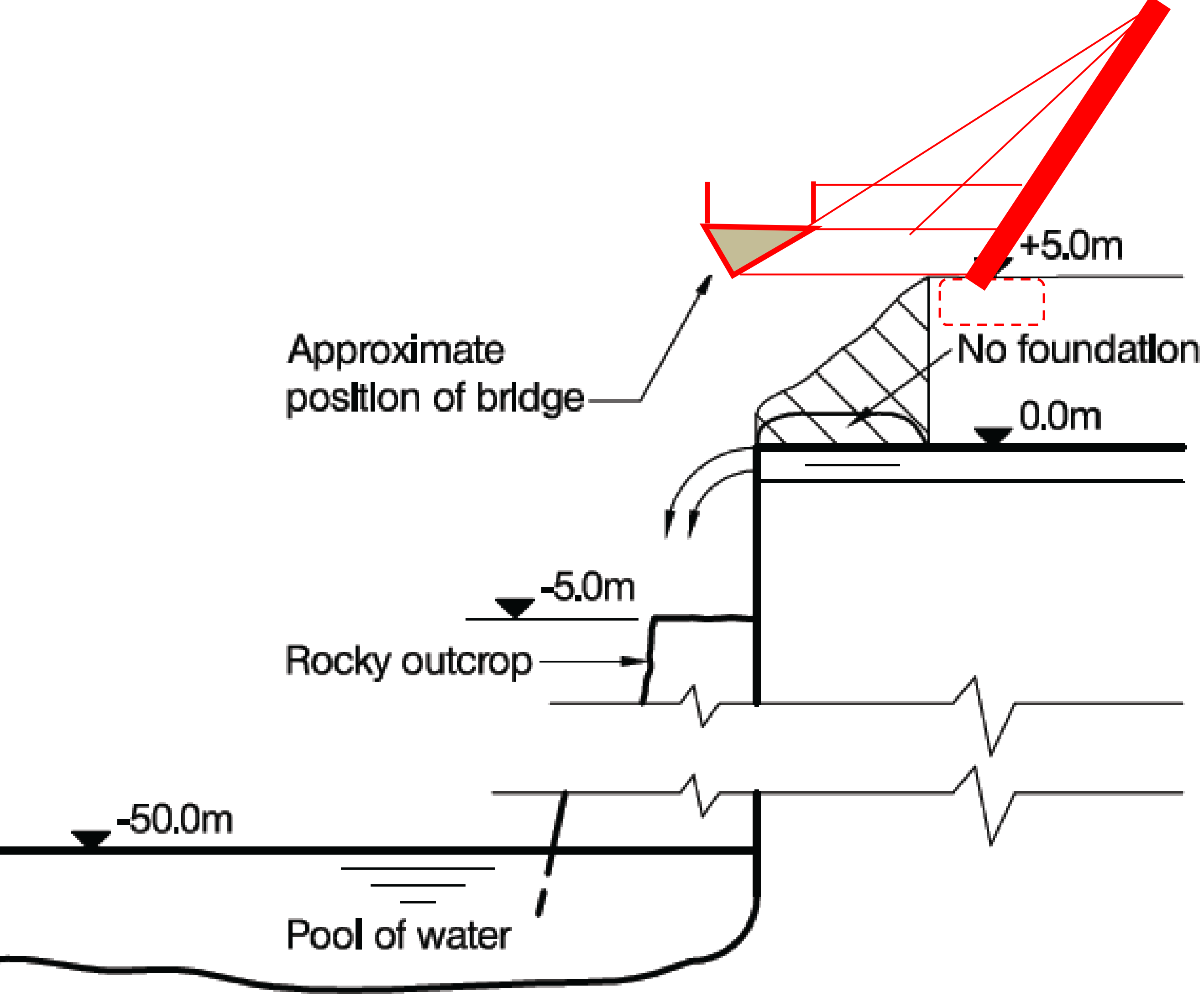


PLAN ON WATERFALL



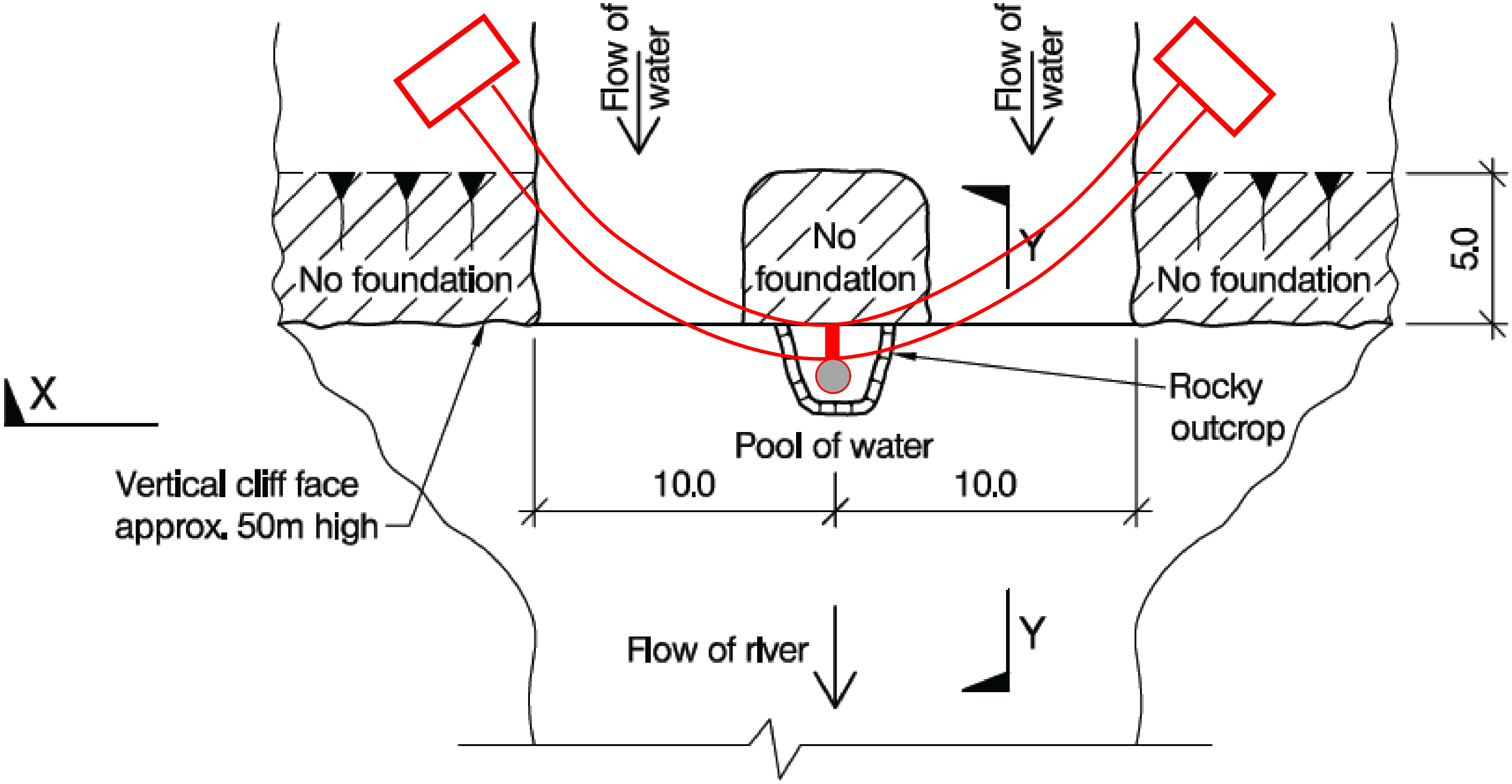
VIEW X - X

Cross section of the deck can be non standard shape to suit the geometry and the nature of the forces.

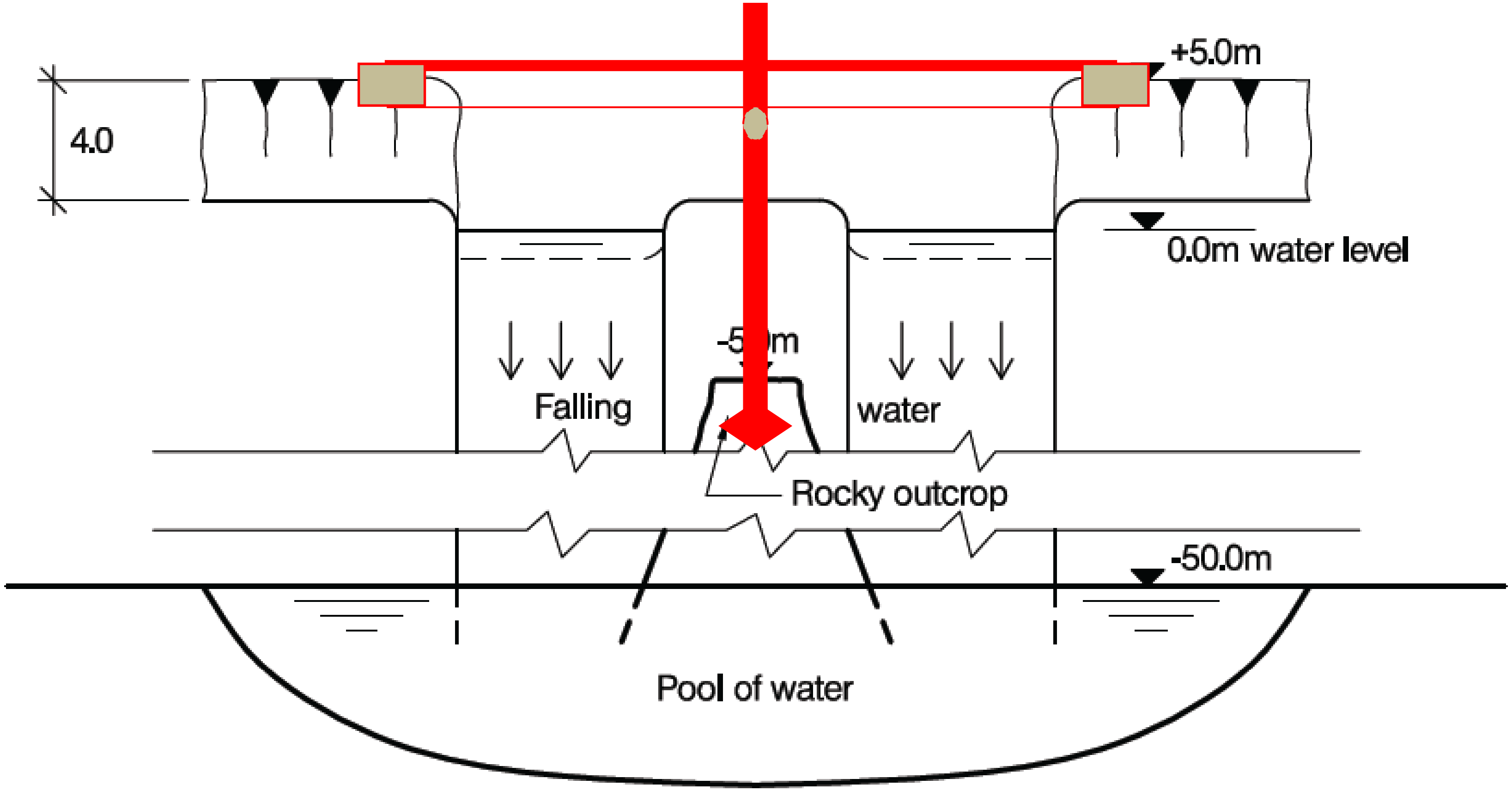

+5.0m
Approximate
position of bridge
No foundation
0.0m
-5.0m
Rocky outcrop
-50.0m
Pool of water

SECTION Y -Y

2. **Simple beam curved in plan simply supported at either end and in the middle – but calculation suggests load on middle support can be higher than allowed.**

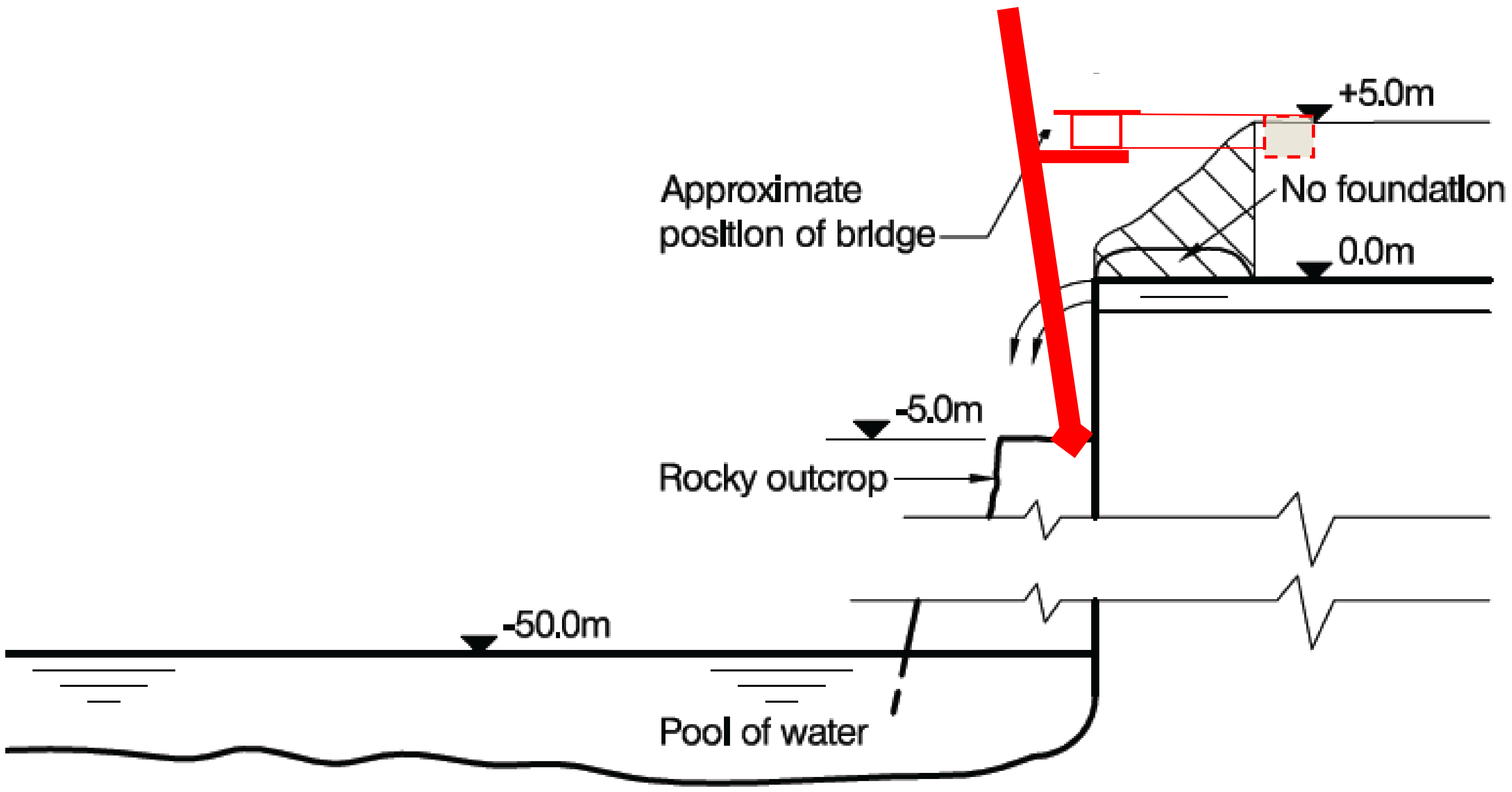


PLAN ON WATERFALL



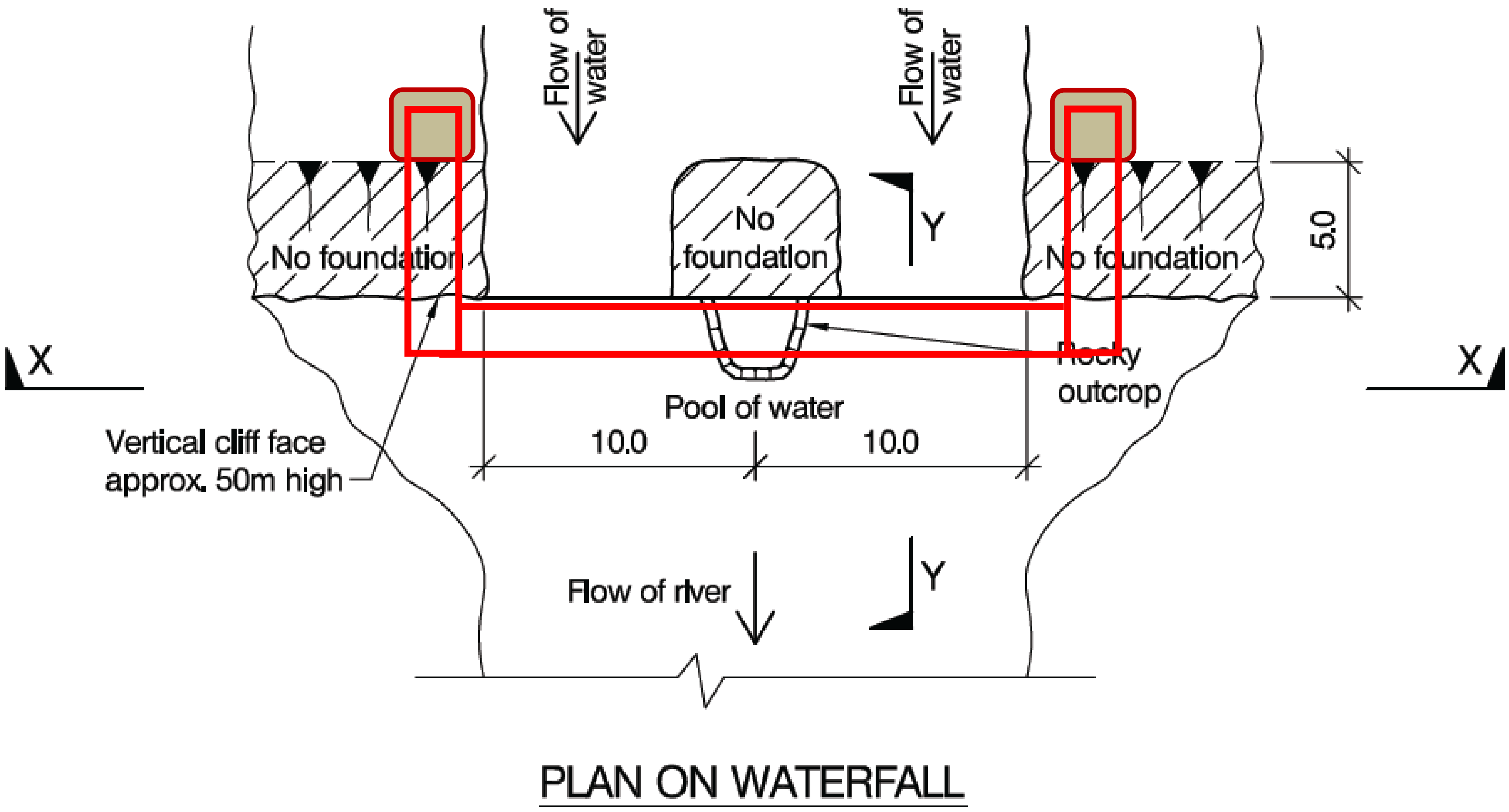
VIEW X - X

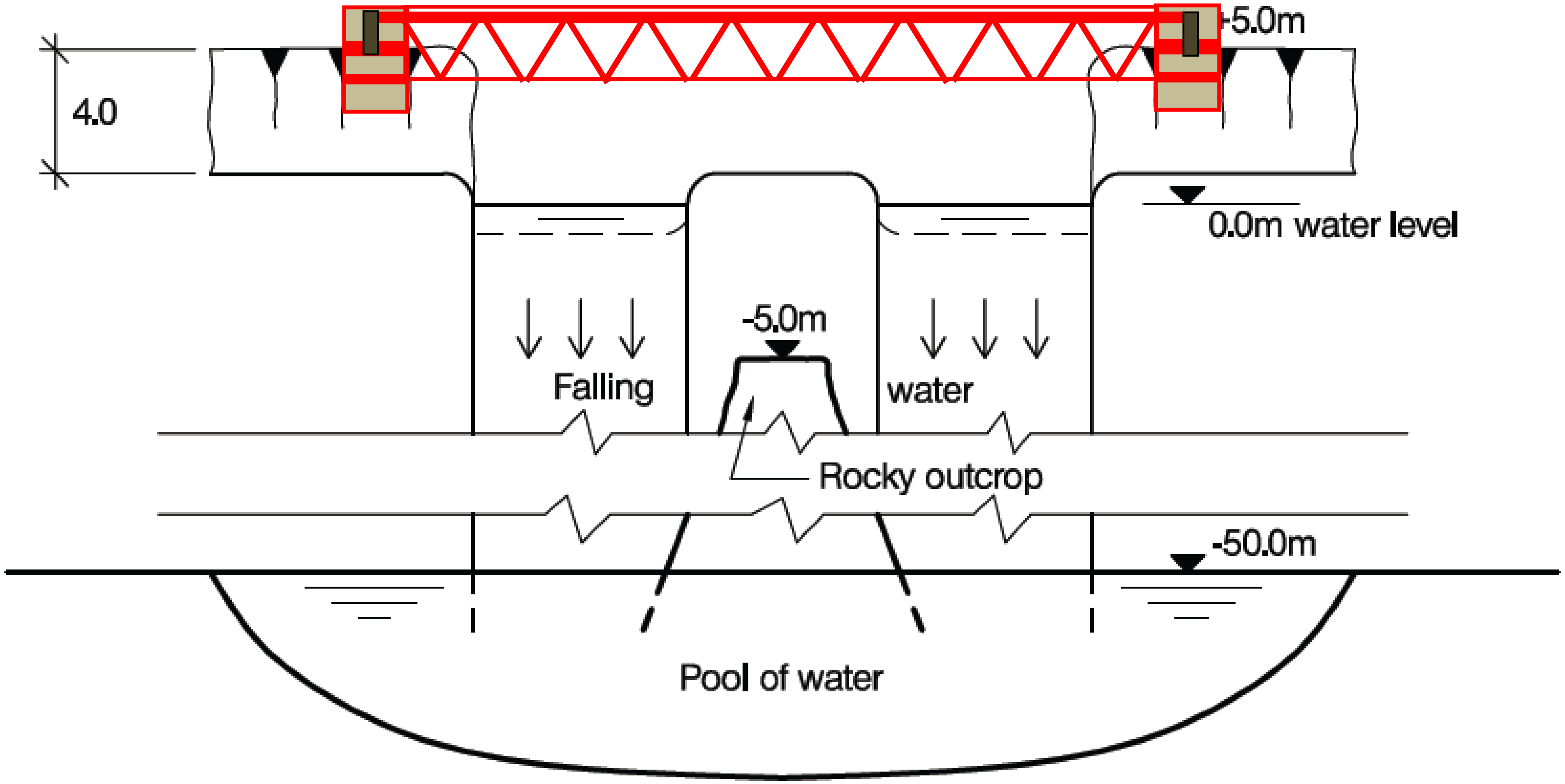
It can be a steel box girder easy for erection or can even be pair of girder with top precast concrete slabs. Cast in situ at this site is not possible. However this particular solution is not going to fulfil all the requirements from client.


+5.0m
Approximate
position of bridge
No foundation
0.0m
-5.0m
Rocky outcrop
-50.0m
Pool of water

SECTION Y -Y

3. **This is the easiest solution to go for, both design and construction point of view. Clever arrangement can eliminate torsion totally.**

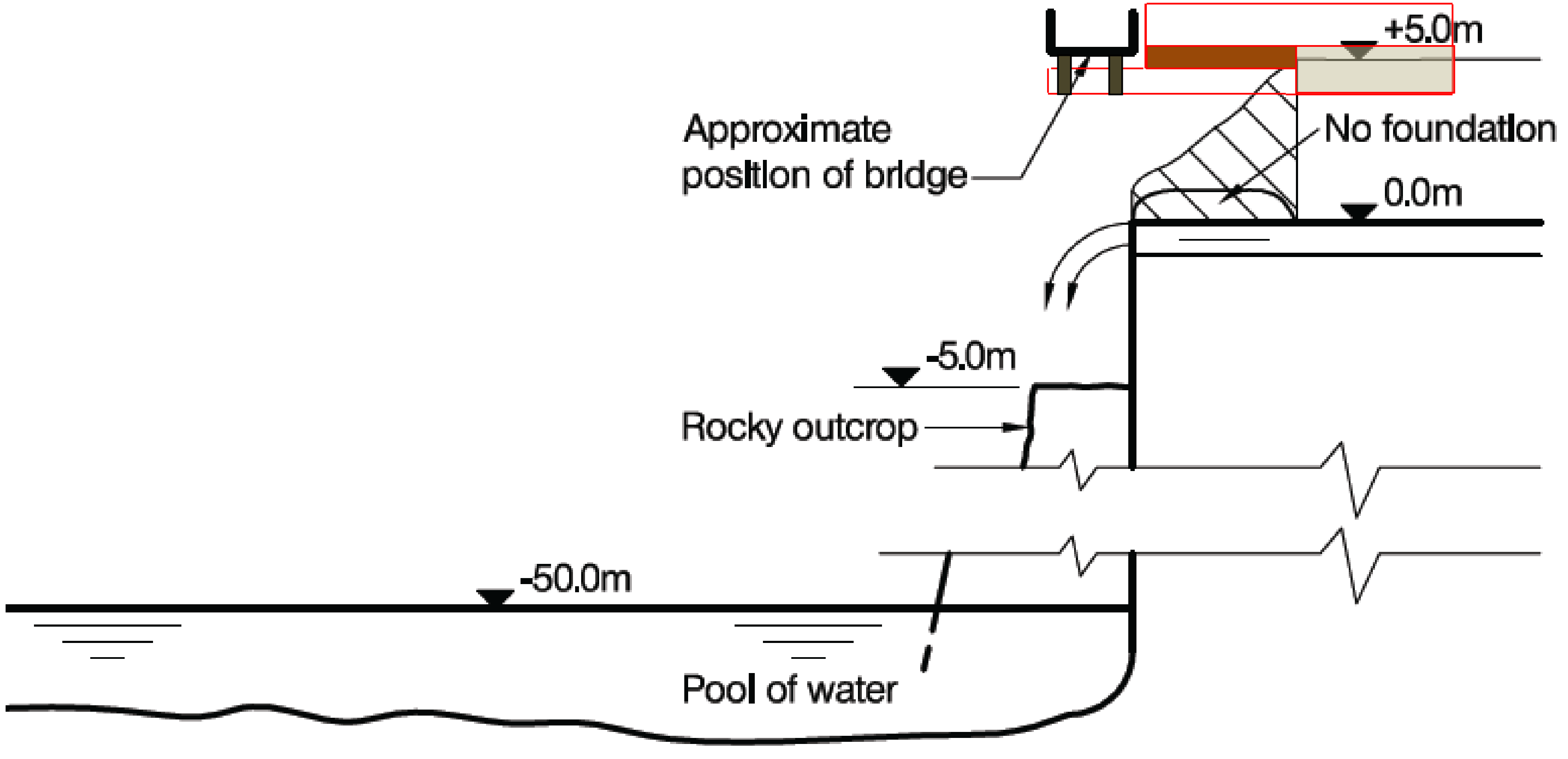




+5.0m
4.0
0.0m water level
-5.0m
Falling
water
Rocky outcrop
-50.0m
Pool of water

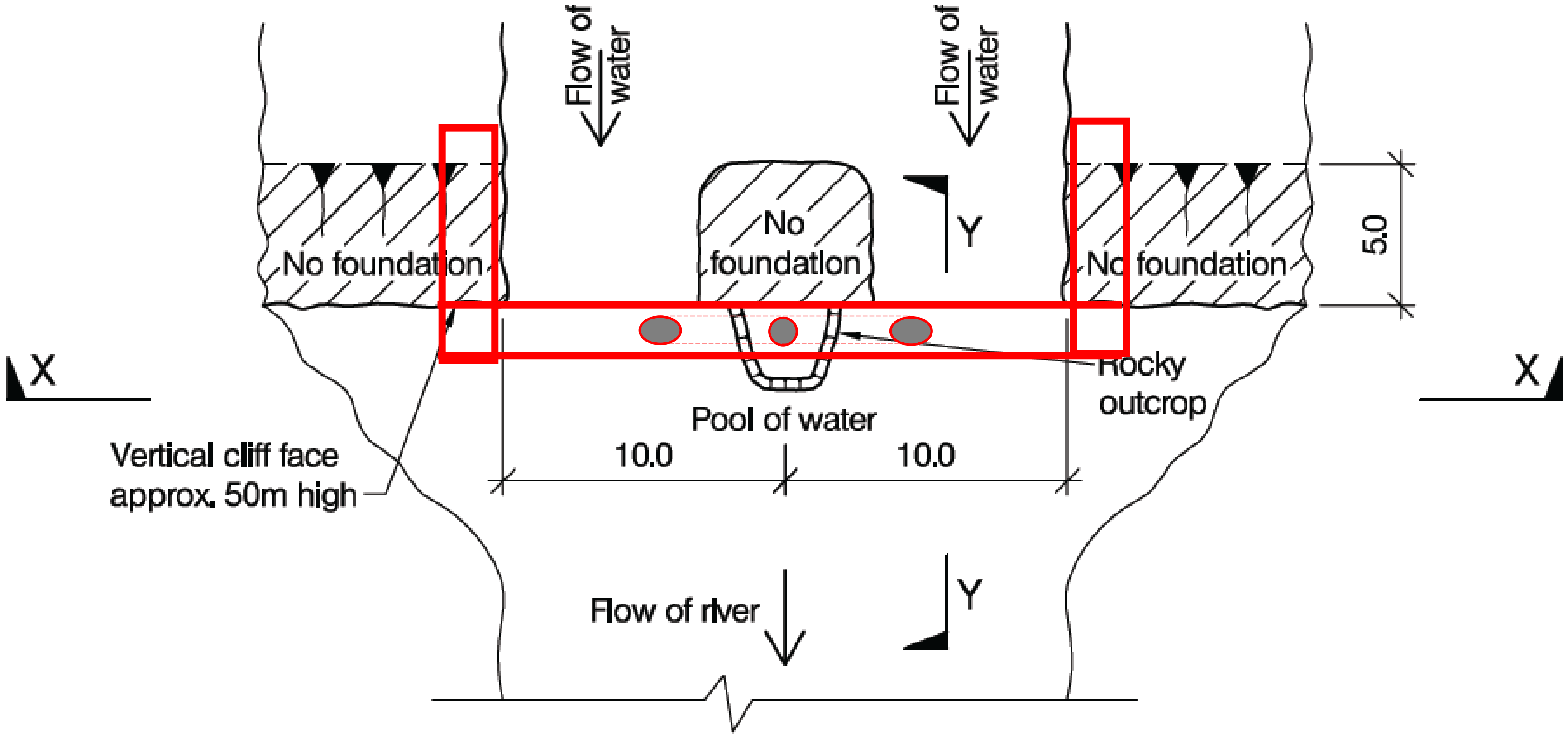
VIEW X - X

Cross section is not drawn well as the main idea is the cantilevers at either bank to support any light 20m long foot bridge. The load balancing is the main part of the calculation. Thus substructure calculation carries more weight than it used to be in the past years.



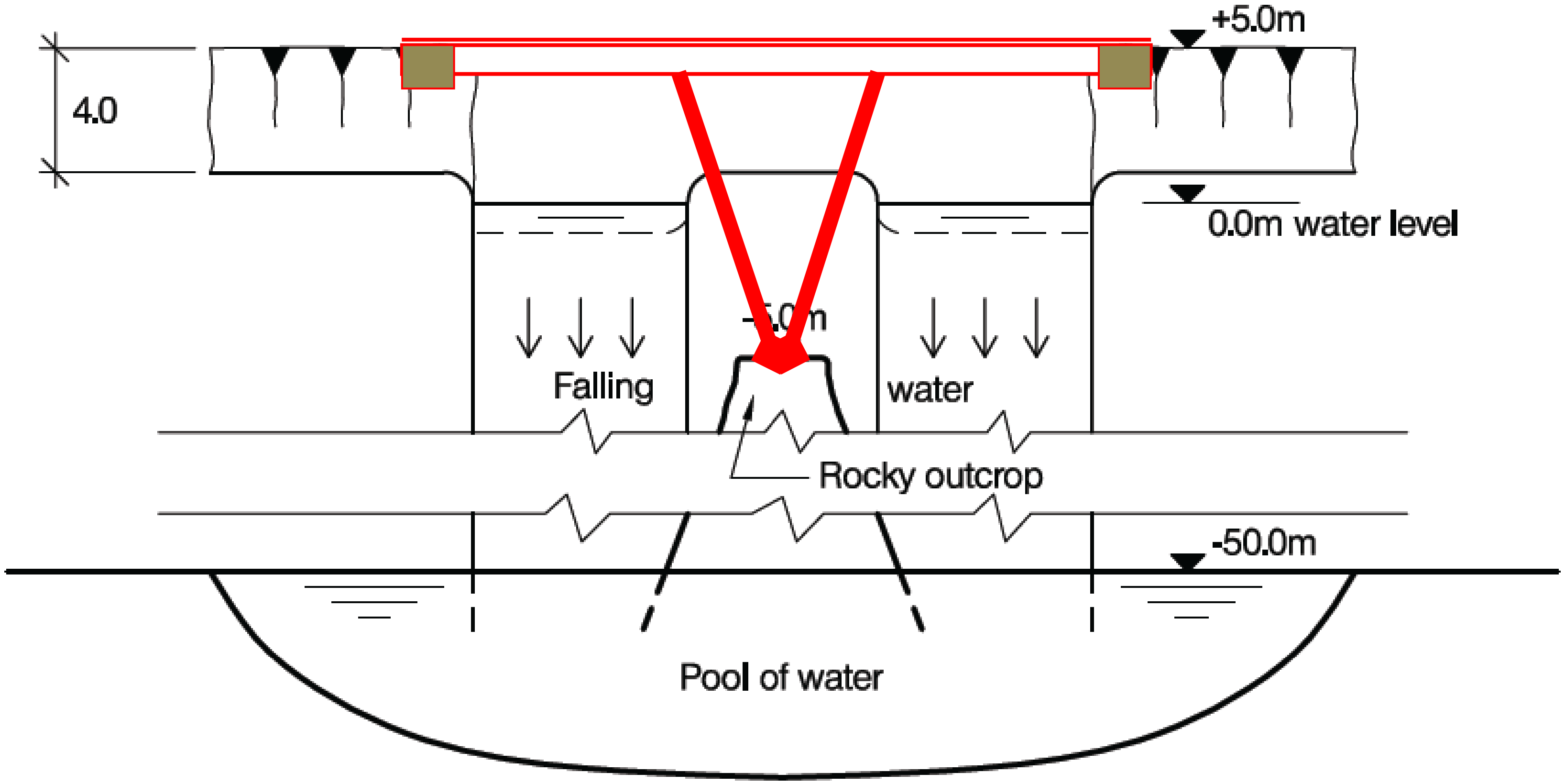
SECTION Y -Y

4. **Another simplified solution which can also be considered as a further improvement from the previous solution. A very light weight deck (may be GRP / FRP) over hanged on top of the V shaped substructure, whereas the approaches at either end are same as previous proposal cantilevered from massive bases at the ends. Depending on the capacity of the rocky outcrop given the V angle can be adjusted. However this is not a solution for examination situation.**

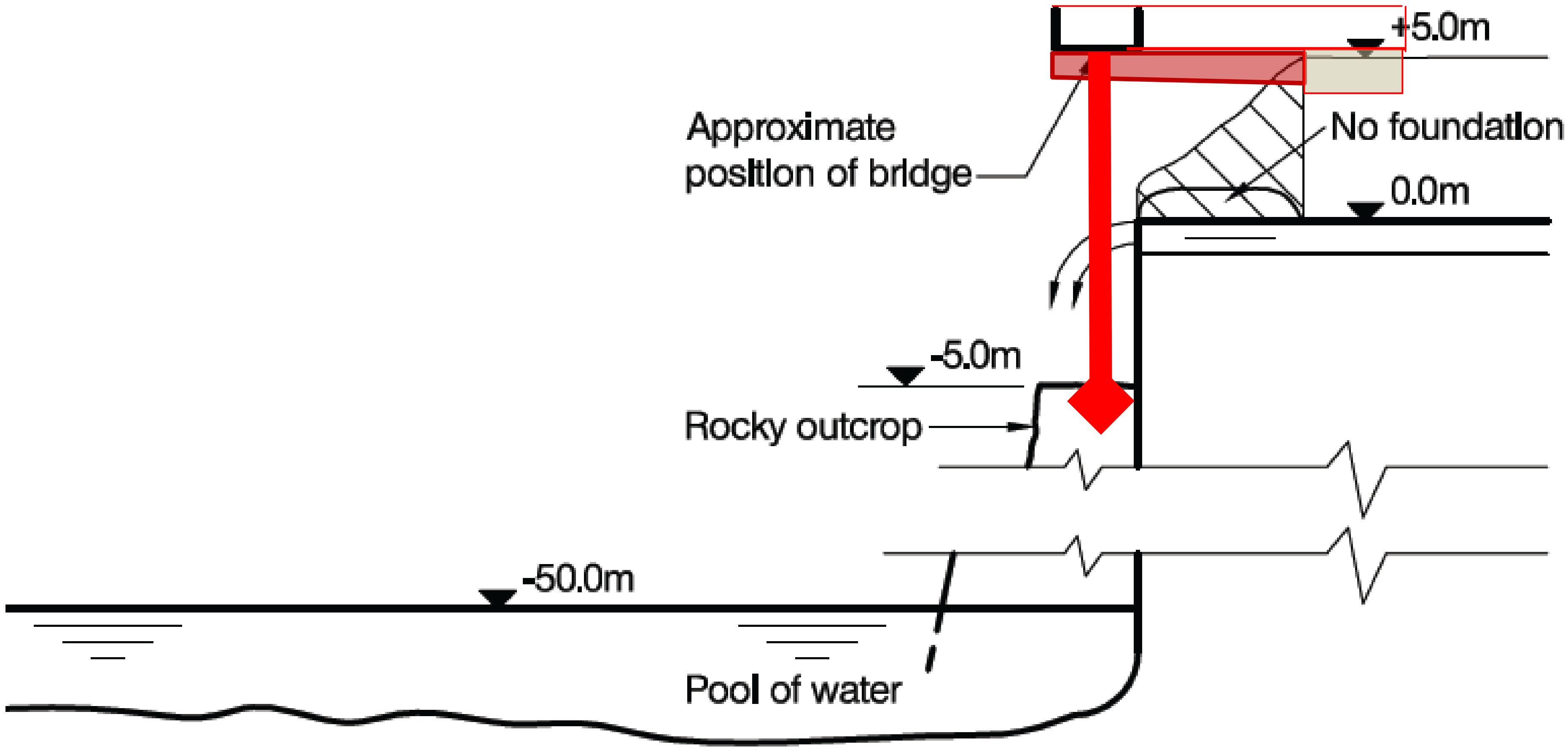


PLAN ON WATERFALL

The viewing deck can be rigidly connected to the supporting structures on top of the rocky outcrop in the middle and resting on the two arms of cantilever at either end so that optimum use of available bearing capacities. However Construction can be really difficult and risky.



VIEW X - X



SECTION Y -Y

Over all the solutions are not that difficult as it look like. In fact the amount of work to be done is much lesser compared to some simple bridge questions over the years.

Key observations from Client's requirement => *constraints*

- Major risks associated with the construction due to extremely difficult access:
    - *H&S should be reflected in each and every part of the solution.*
    - *Candidates should start writing method of statement soon after they decide two distinct solutions possible and the chosen one.*
    - *Minimum or no construction activity should be the target at the edge of the fall*
- Rocky outcrop has only 250 KN load bearing capacity:
    - *Beams curved in plan needs three supports to be a stable structure and determinate. Analysis shows the central support will be much more loaded compared to an intermediate support of a two span continuous beam.*
    - *Basically such a low bearing capacity indirectly indicates not to use any intermediate support hence the ends of the bridge must be built in.*
- Bottom of the water fall is navigable:
    - *It clearly indicates top part of the river leading to the fall can't be used at all.*
    - *However height of the water fall is about 50m hence that is also not a safe place for construction activity from downstream.*
    - *Only for erection purpose some floating barge might be used but rarely be available for 45+ m height scissor lifts are available to use.*
- Five meter from edge of the fall is no foundation zone:
    - *This also indicates that all the construction activity in the safe zone is preferred.*
    - *However anything temporary with safe construction technique and approach can use that no foundation zone of 5m.*

The most appropriate two distinct viable solutions possible for this problem:

For the two distinct and viable solutions out of four in above will be the first and the third for exam purpose and for design office 3rd will be replaced by its improved version as shown in 4th proposal. Out of those two obviously the 3rd one will be the chosen solution to develop. The reasons are:

- Safest and easiest to construct for this particular site. The main straight section can be fully prefabricated and craned in to the position.
- Aesthetically may be less attractive from others but the optimum view from the bridge can be obtained from this.
- Will eliminate torsional stress completely. Two main approach spans can be built very rigid so that dynamic response minimised.

Section 1b – letter to client:

Though the proposed changes won't have any impact to the chosen solution however it is eminent that client will expect technical advice in the reply. Hence it is essential for the engineer to explain in the letter that it is recommended client to verify the integrity and the capacity of the rocky bank where they are proposing their foundation. In addition the no foundation zone of 5m to be ensured free from instability so that during construction activity these two areas are well utilised for safe construction.

Section 2C: - Calculations.

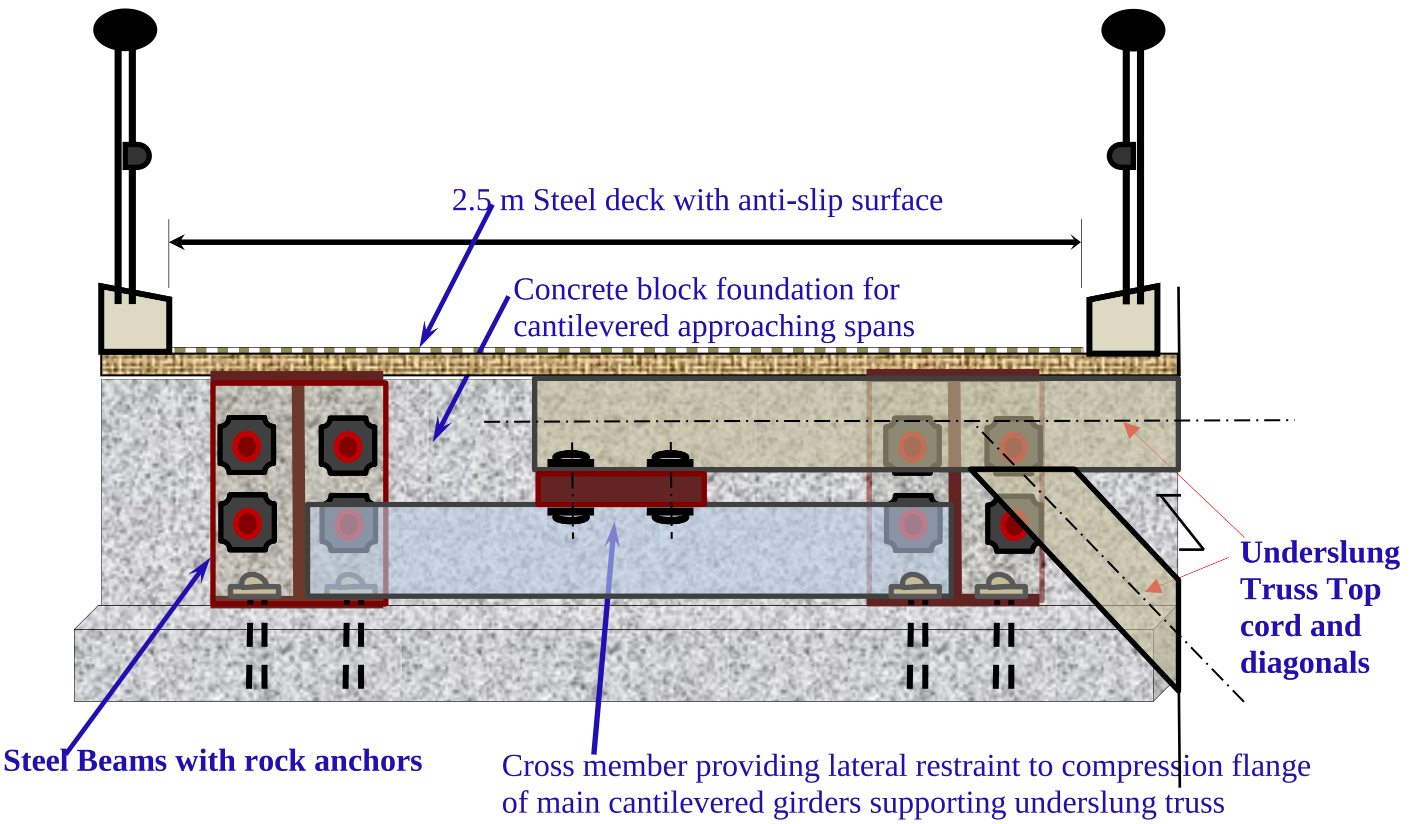
For this type of project it is essential to have calculations for each step of construction to ensure safety. However calculations must have enough to justify the rocky out crop hasn't enough capacity to be an intermediate support to justify not to be considered at all. Stability of structure is really important at all time. Hence the suspended span has to be robust and light. An underslung truss may fit in as per detailing point of view and can be very lightweight structure but offer enough stiffness against pedestrian dynamic actions.

Accurate calculation of load will govern the size of the main foundations at either end to act as counterweight too. Decking can be steel plates for exam purpose. Finally, the cantilevers and their half joints on which the truss to be supported, should also be checked in ULS and SLS.

Drawings:

As mentioned in the question the answer script must include general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimation purpose.

For the chosen solution above plan elevation sections in the form of sketch is needed to be improved to make them engineering drawings. It is also essential that the half joints supporting underslung truss are clearly shown along with the end anchorage detail in the main block foundations.



Typical cross section of Approach cantilevered span supporting Underslung Truss with half joint arrangement

Method of Statement and outline construction programme:

Finally the method of statement should have enough to justify the safety measures are adequately considered by the candidate. Erection of prefabricated structure should be the proposal rather making it a construction site for months is not acceptable. Preparation of rocky outcrop (if at all included) and the rocky bank at the top should be in days rather in weeks and months. The activities can be discrete rather be continuous but activities at site should be bare minimum.

Use of cranes and other appropriate equipment for safe construction must be mentioned with necessary sketches. Programme of work in total 6 to 9 months shouldn’t be exceeded. However site activities shouldn’t be more than a month or two as it is mostly erection of superstructure other than rock anchoring and casting of end blocks of foundation.

The Institution of Structural Engineers

Possible solution to past CM examination question

Question 4 - April 2013

Underground car park

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).

Contents:

Notes on Question 4 2013

Addendum (i)

Elements of good practice relating to Q4 2013.

These notes may be beneficial when developing solutions to similar questions.

Addendum (ii)

Notes on the allocation of marks.

These notes may be beneficial in giving a perspective on the marking of all CM questions.

The views expressed are those of the writer, who is an experienced marking examiner.

Question 4. Underground car park and garden

Client's requirements

1. An underground car park 150m long by 100m wide is to be built in a city centre. The car park is four storeys high with one level above ground level and the other three levels constructed underground. The roof of the car park will be used as a landscaped garden. See Figure Q4.
2. 4no. light wells are required at each level with a minimum total area of 320m^2 per level.
3. The storey height of each level is 4.0m.
4. The minimum fire resistance period for the structural elements is 4 hours.
5. The minimum size of each parking space is 2.5m wide by 4.8m long.
6. The minimum width of the access ramp is 7m.

Imposed loading

7. Landscaped roof garden 10.0kN/m^2
   Car park floors 2.5kN/m^2

Site conditions

8. The site is on flat level ground in a city centre. Basic wind speed is 40m/s based on a 3 second gust, the equivalent mean wind speed is 20m/s.
9. Ground conditions:

Ground level - 5.0m	Loose sandy fill
5.0m -12.0m	Silty sand, N values vary from 5 to 8
12.0m- 20.0m	Dense silty sand, N values vary from 35 to 80
Below 20.0m	Rock with compressive strength of 5000kN/m^2

   Ground water was found at 2.0m below existing ground level.
   For the design of basement use cohesion=0 and Ø=35 degrees

Omit from consideration

10. Detail design of lift and stairs.

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 receiving your completed design, the client wants to add another level of basement (with a floor height of 4m) to cater for the future increase of cars. Write a letter to your client explaining the effect of this on your proposed design. (10 marks)

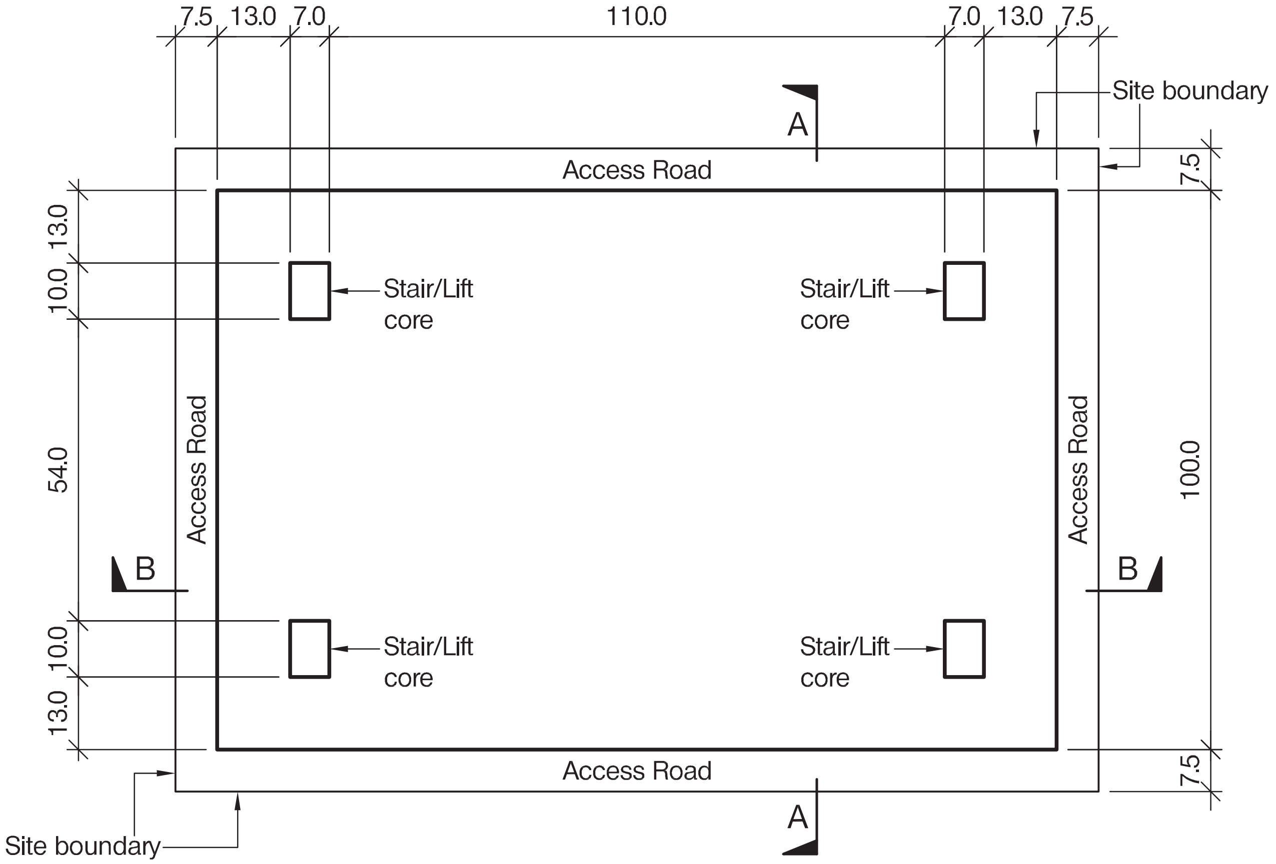
SECTION 2 (50 marks)

For the solution recommend in Section 1(a):

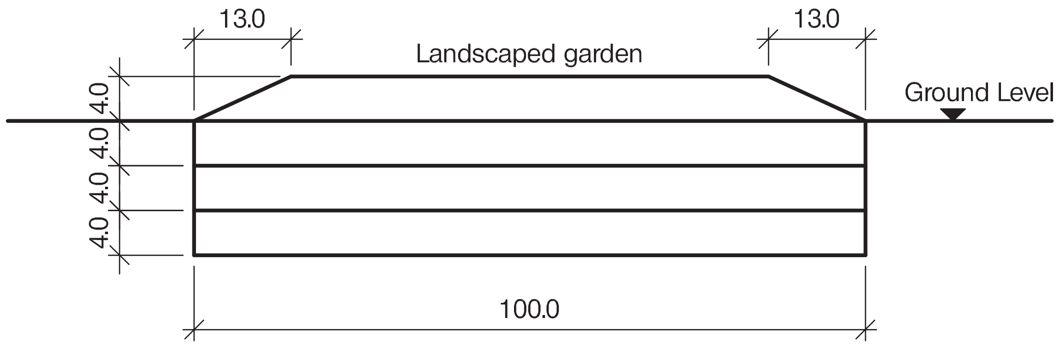
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the foundations. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimension, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

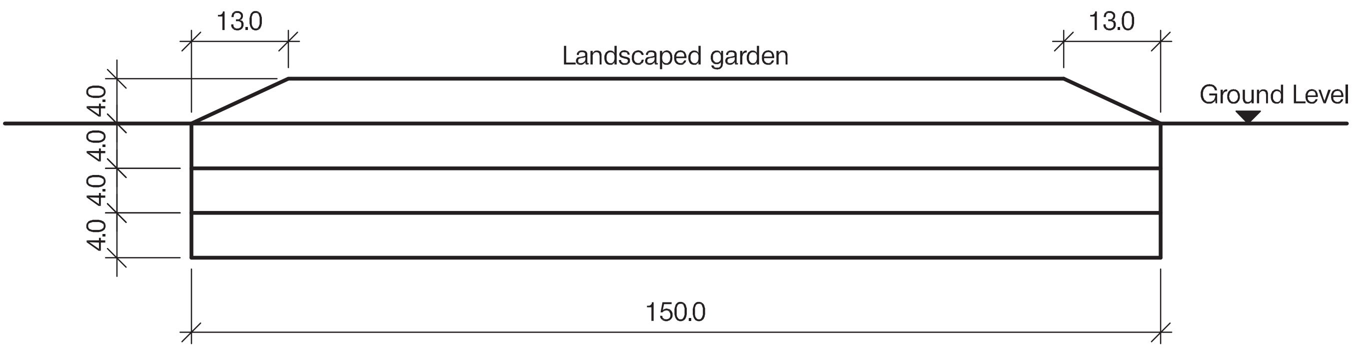
e. Prepare a detailed method statement for the safe construction of the building and an outline construction programme. (10 marks)



PLAN ON UNDERGROUND CAR PARK



SECTION A - A



SECTION B - B

NOTE: All dimensions are in metres

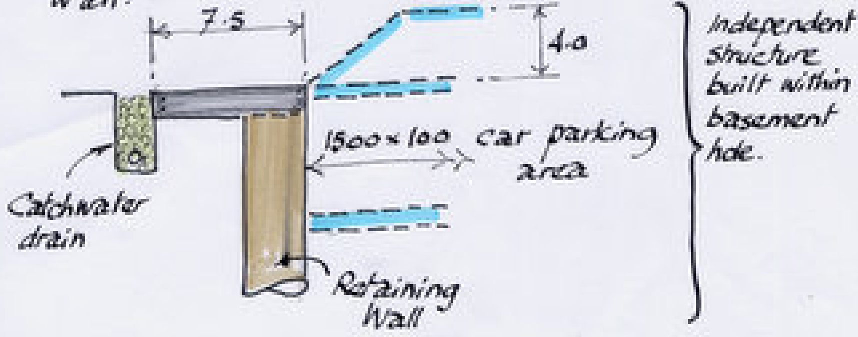
FIGURE Q4

Car park questions, in 2013 manifest in Question 4 – Underground car park and garden, need a considerable specialist experience if the answers are to be anything more than an ordinary building that has been adapted for parking cars within. If additionally it is all underground then the complexity is certainly doubled.

Like many of the modern questions, Question 4 - 2013 is not completely transparent: several assumptions have to be made by the Candidate, this is done to test whether the aspirant is a proper "problem solver."

Looking at the plan on Figure 4 you will be curious about the Access Road just within the site boundary and the broad black line that seems to indicate the outline of the basement below ground. One can swither about whether the road is a ramp and the main access to the car park, or a flat perimeter "slab" sealing-off the back of the retaining structures around the underground car park.

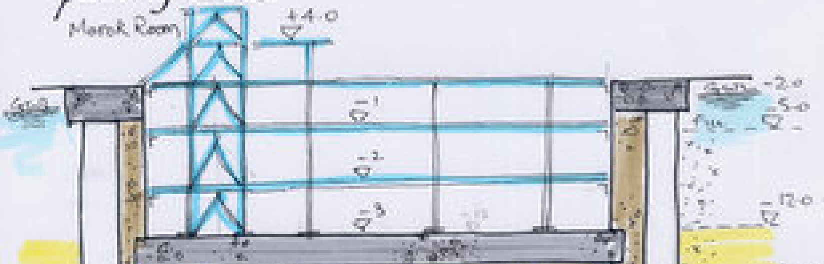
It will suit us if it is a "slab" that can be used as the top waling beam to support or prop the retaining wall:

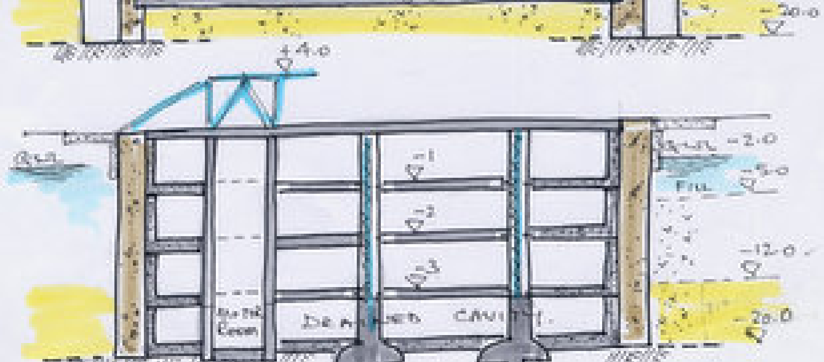


This assumption opens up two "Options" for consideration:

- the construction of a basement "hole" into which is inserted an independent (steel) frame that supports the parking levels. The sides of the "hole" are supported by propped-cantilever walls and a thick concrete base raft laid over the dense, silty-sand stratum at −12.0m level.

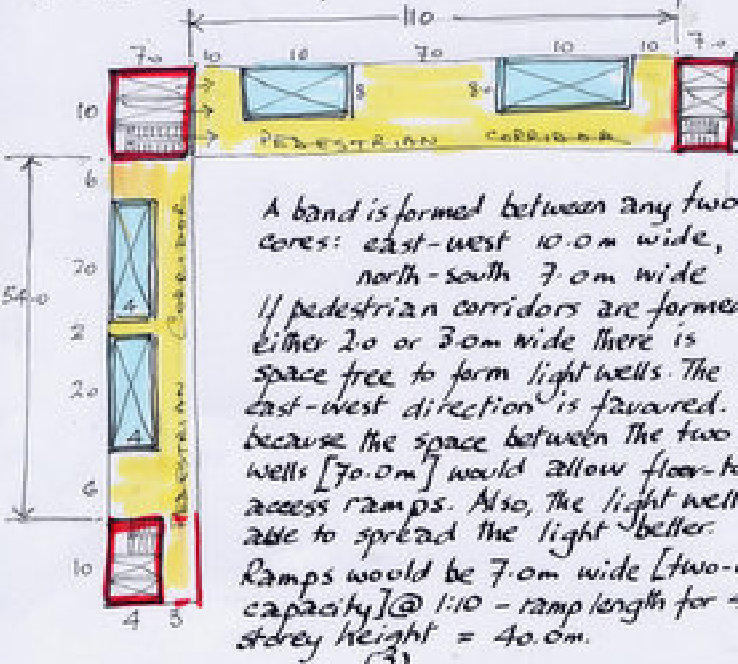
- the construction of a rigid, underground "box basement" using top-down technology and plunge columns. The columns, inside their bored and back-filled shafts [using pea-gravel], would bear on the bedrock. The bottom basement slab would be suspended, like the ones above, leaving a drained cavity and pumped sumps below the parking areas.





So far — good! I have the outline of two different and viable Options. Now I must "trim" the details. The four stair/lift cores are shown on the plan. Looking at Figure Q1, there is a core/lift shaft shown with two lifts and staircase; all inside a 4.0 × 3.0 shaft. The shafts in our question are 7.0 × 10.0 and will be assumed to be the dimensions overall the shaft walls (very comparable!). Stairs and Lifts need an assembly area around them where the people using them gather.

Client's Requirement [CR], CR#2, asks for four light wells each not less than 80m² at each level — but not in the level -3.0 basement slab! These light wells will provide the basic ventillation for the car park.

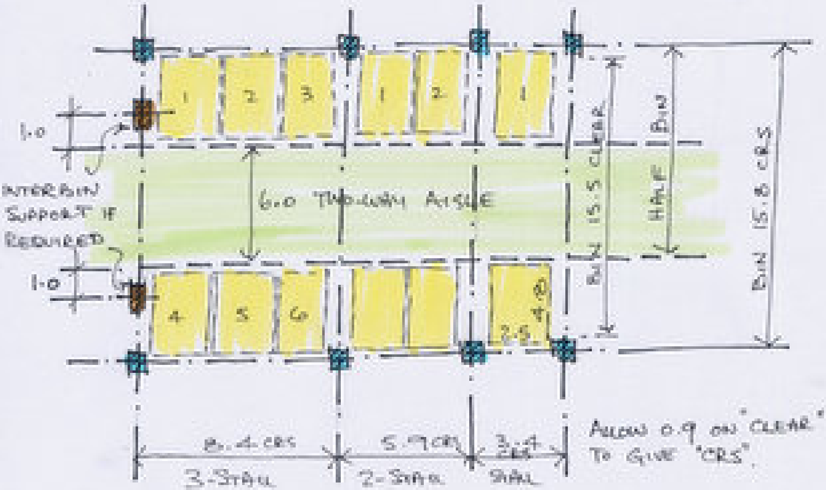


A band is formed between any two cores: east-west 10.0m wide, north-south 7.0m wide

If pedestrian corridors are formed either 2.0 or 3.0m wide there is space free to form light wells. The east-west direction is favoured. because the space between the two wells [70.0m] would allow floor-to-floor access ramps. Also, the light wells are able to spread the light better.

Ramps would be 7.0m wide [two-way capacity] @ 1:10 — ramp length for 4.0m storey height = 40.0m.

Given the size of the parking stall – the area covered by the parked car and including access and manoeuvreability [CR # 5 – 2.5m wide × 4.8 long] – and assuming a stanchion size of 305 × 305, it is possible to arrive at a typical column grid:

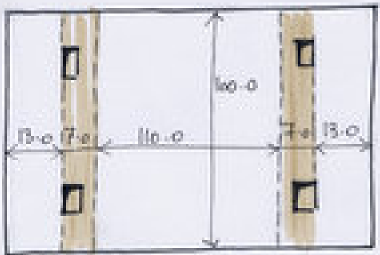


TYPICAL COLUMN CENTRES FOR COMMON PARKING

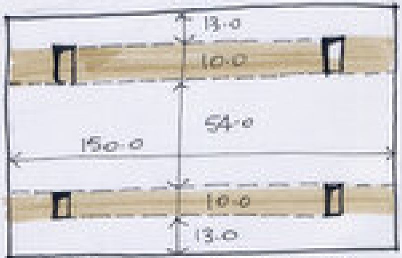
References:

- 1. Stuart E. "Design recommendations for multi-storey and Underground Car-Parks", 3rd Edn., 2002 I.S.B.N. 0-901297-23-2.
- British Steel, "Steel-framed Car Parks", 1998, reprint '99 SPCS 403 7/99. Compiled by Colin S. Harper.

Looking at the basement plan one can find the "best fit" of the typical column arrangement when combined with the core/light-well requirement. Hopefully the ramp and access/exit will emerge! The problem at this stage in the examination is that "optimum fitting" is fiddly and takes time! Please notice that there is no mention in the question of a minimum number of spaces [as in Question 6-2013 where 18 vehicles are specified] nor any "optimum arrangement" [as in Question 5-2011 where the Client requires that the number of car parking spaces should be maximised.] Two areas emerge:



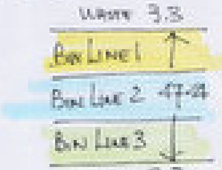
Aisles run North-South



Aisles run East-West

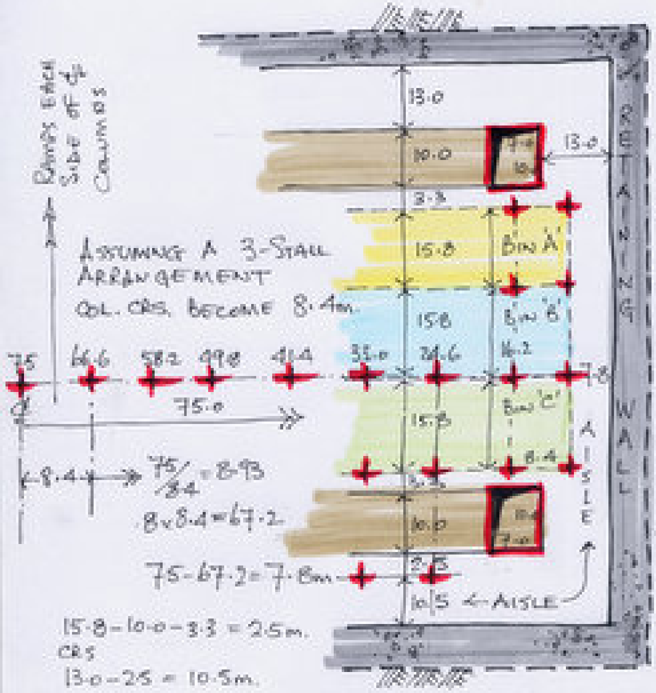
$\frac{110.0}{15.8} = 6.96$

$\frac{54.0}{15.8} = 3.42$



Clearly more efficient!

Only one column arrangement should be selected; it is very doubtful if merely turning the column axis through 90° would be accepted as producing a "different" option!



Columns arranged on 15.8 × 8.4 grid with modifications at the 4 corners

Parking capacity:

3 × 16 × 6 = 288 on each floor

× 4 floors = <u>1152</u> but could be less because of ramps and other areas.

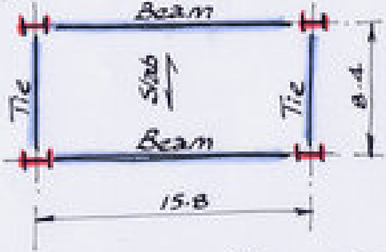
The column grid becomes 15.8m × 8.4m, with a shorter beam span of 10.5m over the North and South aisles. There is also a shorter tie span of 7.8m over the East and West Aisles. The reinforced concrete option would have shorter beam spans with additional columns providing "Interbin Support" – see p4. The slab would still span 8.4m but the beam would become 3-span: 3.9 – 8.0 – 3.9. The tie beams would be embedded in the slab.

Client's Requirement Number 3 requires a storey height [FFL-to-FFL distance] of 4.0m. Reference to the Institution's "Design recommendations for multi-storey and underground car parks", figure 4.4 shows headroom allowances of 2.1m minimum – generally, at speed humps and over ramps.

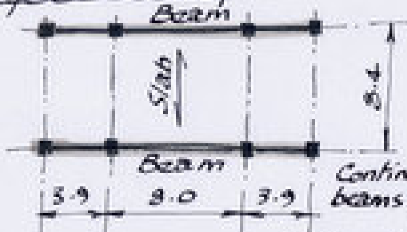
ALTERNATIVE INITIAL SIZES – STEEL VS CONCRETE

Steel frame

Basic grid:



Reinforced concrete frame



Continuity along beams & slab.

Columns: 305 × 305 UC 118# Grade S355

400 × 400 @ 2% 40 N/mm² Calcareous

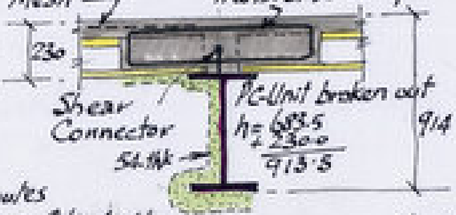
Beams: 686 × 254 UB 140# Grade S355

$\frac{L}{15} = \frac{8000}{15} = 530$ 40 N/mm² Calcareous

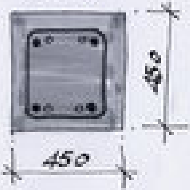
make b = 450 – min for 4hr FRP

Tie: 203 × 133 UC 25# Grade S275

Floor Construction:



Slab $\frac{8400}{36}$ = 233

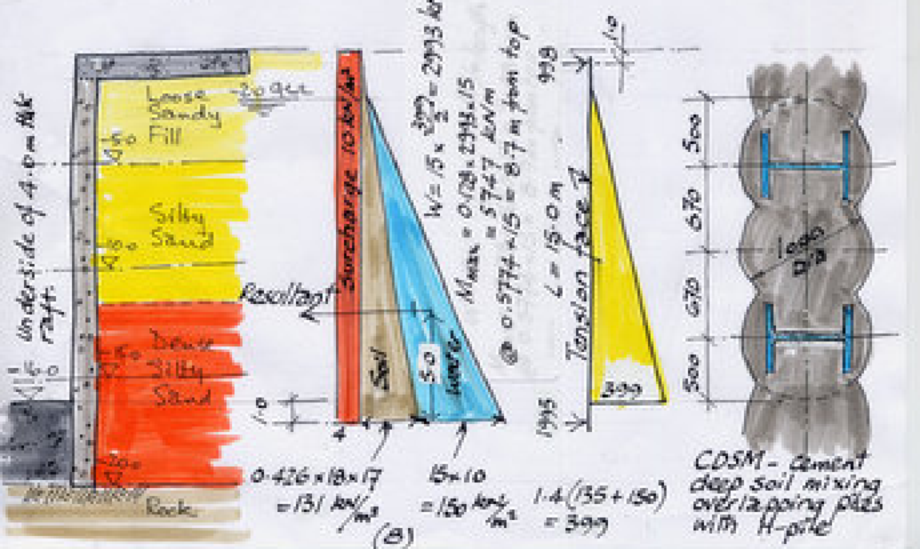


4 Hrs FRP = 240 minutes
3-sided protection – Bm : Cols – 4 sides
Critical temp 550° C
Section factor, Hp/A = 115 & 120
Monokote MK66 54 mm 73 mm
Grace Construction Products

Continuing the initial sizing the following need to be addressed:

- basement retaining walls – option 1 involving structural steel, to go with the steel frame; and option 2 to go with the concrete "top-down" frame,
- the high ground-water level and the stability under hydraulic uplift – flotation,
- the general watertightness of the underground car park – reference to CIRIA Report 139 – "Water-resisting basements". The internal environment, BS 8102: 1990, need be no better than Grade 1 (basic utility) for car parking and non-electrical plant rooms. The recommended form of protection is Type B – reinforced concrete design in accordance with BS 8110 and some seepage and damp patches are to be expected and are tolerable.

Details of "basement" walls:



It is to be noted that the bedrock at −20.0m has a compressive strength of 5000 kN/m². This must be assumed to be the actual compressive strength of the sample and would be divided by a F.O.S of 3 to obtain an allowable bearing value under vertical static loading with an individual foundations settlement not exceeding 50mm. [if the 5000 kN/m² were assumed to be the presumed allowable bearing value it would have to be multiplied by 3 and the resulting sample strength would be 15000 kN/m², or thereabouts — too high to be credible].

An allowable bearing value of 1700 kN/m² will be used and the rock could be a sandstone or mudstone — moderately difficult to drill or excavate.

It is also noted that the soil parameters of c=0 and $\phi = 35°$ are to be used for determining the soil pressure on the basement walls.

Let $K_o = 1 - \sin 35° = 1 - 0.5736 = 0.426$

Volume of water displaced = 100 × 150 × 18 = 270 000 m³

* Ditto in extreme-flood = 100 × 150 × 20 = 300 000 m³
[above ground level the basement will flood]

Walls around basement = 500 × 20 × 1.0 × 25 = 250 000 kN dead weight

Slab = 100 × 150 × 1.0 × 25 = 375 000 kN per m thick. dead weight.

Uplift = 3,000,000 kN Dead weight = 1,750,000 kN [4.0m thk basement slab]

Residual uplift = 3 000 000 − 1750 000 = 1,250,000 kN

Clearly, this basic "gravity" raft — even 4.0m thick, is not going to prevent "flotation". More complex ground engineering is necessary.

CDSM = cement-deep-soil-mixing process of overlapping "piles" with H section

Uplift on both Options - worst credible:
Flood conditions: water at ground level
12 + 2 (say) for raft = 14 × 9·81 = <u>137·34</u> kN/m² ↑ × 150 × 100 = <u>2060,100</u> kN

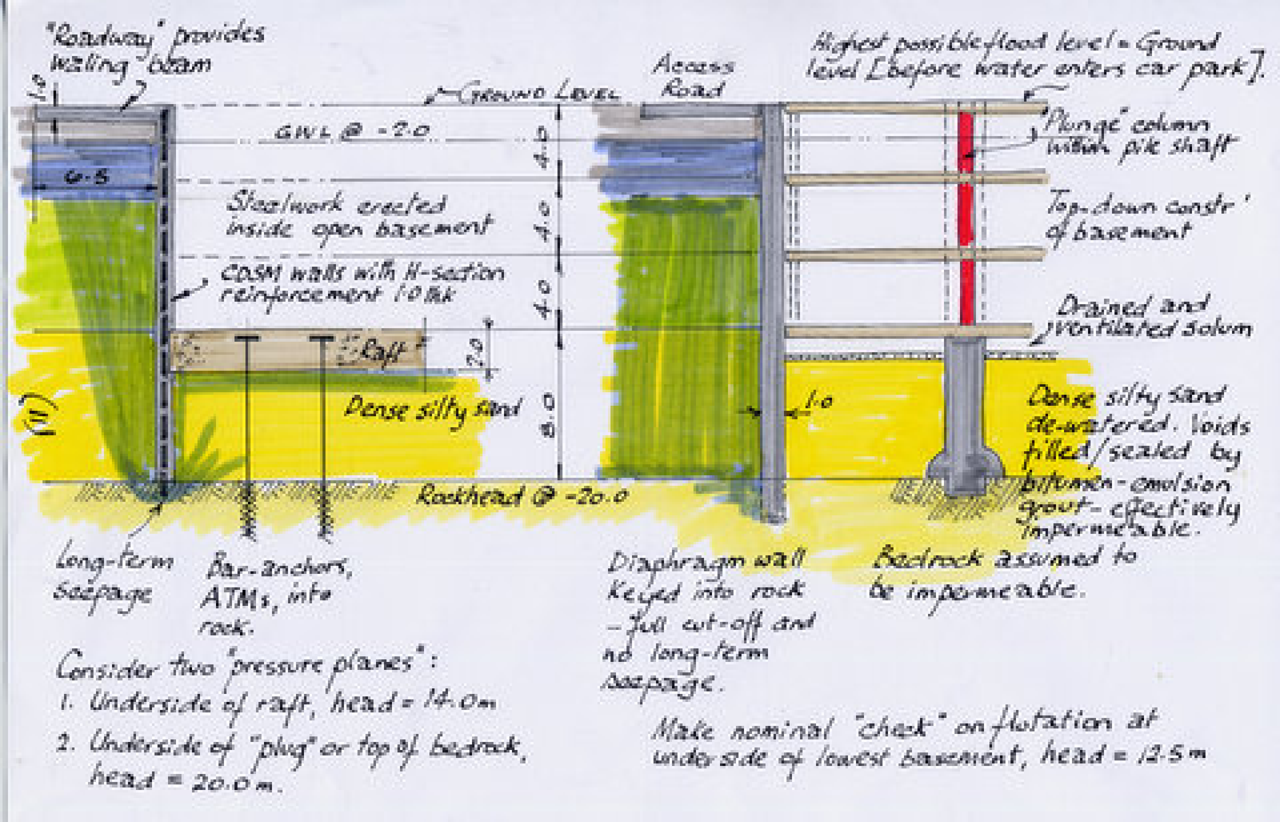
(10)

<u>Option 1</u> - CDSM walls to bedrock at -20.0m [short-term cut-off but seepage likely in long-term leading to uplift]. H-section reinforcement, for bending and possibly bar anchors into the bedrock; 2.0m thick "gravity" raft to resist uplift and to house lift pit and sump, etc. DPM under raft [to prevent hydrostatic damage/dampness as in Dublin basement].

<u>Hydrostatic uplift resisted</u> by: weight of perimeter wall; friction on outside of basement and on buried length of wall; weight of "gravity" raft; and array of antiflotation bar anchors "AfMs [Anti-flotation tension minipiles] linking raft and 6.0m of dense silty sand [See CR # 9]. Sand could be bound together by grout.

<u>Option 2</u> - Bentonite diaphragm walls to bedrock at -20.0m with rock socketting to sound rock [through weathered surface and into <u>assumed impermeable</u> bedrock] - providing full cut-off and possibly including bitumen-emulsion grouting of dense silty sands below lowest basement level [CR#9]. Large-diameter bored piles providing piers to the plunge columns [used as reinforcement in concrete columns poured later] and with under-reams at rockhead. Top-down construction with progressive de-watering. Floor slabs/strip beams act as struts at four levels to the perimeter wall.

<u>Hydrostatic uplift prevented</u> by full cut-off at the perimeter and de-watering during top-down construction. The lowest basement slab to be suspended clear of the underlying dense silty sands [CR#9], thereby creating a drained and ventilated solum. Water vapour will be present throughout. The building that should be amply durable because of the thick cover necessary for fireproofing.


"Roadway" provides
"waling" beam
1.0
6.5
GWL @ -2.0
Ground Level
Access Road
Highest possible flood level = Ground level [before water enters car park].
"Plunge" column within pile shaft
Steelwork erected inside open basement
Top-down constr' of basement
CDSM walls with H-section reinforcement 1.0 thk
4.0
4.0
4.0
2.0
8.0
Raft
Drained and ventilated solum
Dense silty sand
1.0
Dense silty sand de-watered. Voids filled/sealed by bitumen-emulsion grout - effectively impermeable.
Rockhead @ -20.0
Long-term seepage
Bar-anchors, ATMs, into rock.
Diaphragm wall keyed into rock - full cut-off and no long-term seepage.
Bedrock assumed to be impermeable.
Consider two "pressure planes":
1. Underside of raft, head = 14.0m
2. Underside of "plug" or top of bedrock, head = 20.0m.
Make nominal "check" on flotation at underside of lowest basement, head = 12.5m

OPTION 1

① Weight of perimeter wall = 150 length
+ 150
+ 100
+ 100

$500 \times 20 \times 1.0 \times 24 = \underline{240\,000 \text{ kN}}$

8.19

② Friction on outside of wall = $\underbrace{500 \times 11}_{\text{Area}} \times \underbrace{0.426 \times [18-9.81] \times 11}_{\text{Normal pressure}}$

Normal force

= 211 081 kN

26.26

Friction = Normal Force × tan (0.75 × 35°)

= 211 081 × 0.493 = 104 062 kN

062

Friction on embeded wall = 2 × 500 × 8.0 × 0.426 [8.19] × 8.0

= 223 292 kN × 0.493

= 110 083 kN

Combined = 104 062 + 110 083 = $\underline{214\,146}$ kN

③ Weight of "gravity" raft = $\underbrace{150 \times 100 \times 2}_{\text{Volume}} \times 25 = \underline{375\,000 \text{kN}}$

④ Anti-flotation minipiles = 150 × 100 × 6 × (18-10) = $\underline{720\,000}$ kN

Total anti-flotation = 240 000
+ 214 146
+ 375 000
+ 720 000

1,549,146 kN ↓ < 2060 100 kN ↑

(510 954 kN)

⑤ Anchorage needed into rock (length): $\frac{510\,954}{150 \times 100 \times 18} = \underline{1.89 \text{ m.}}$

Minimum anchorage length = 3.0 m [See FIP Recommendation "Design and construction of prestressed ground anchorages, April 1996".

Option 1 – Conclusion: that the stability against flotation is quite marginal and even improbable if the uplift pressure was aplied at the interface of the grouted dense silty sand and rock stratum [head = 20m]
Thicker walls [double 0.5m piles] and thicker raft [perhaps 4.0m thick] are needed.

Option 2, with full cut-off and no long-term seepage seems to answer the problem. However, the following gravity loads apply:

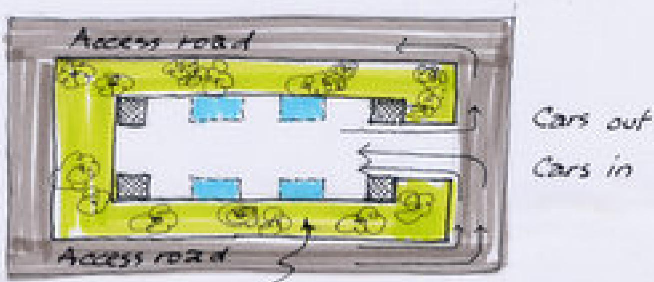
① Weight of perimeter wall [similar to option 1]	240 000 kN
② Friction forces [similar to Option 1]	214 146 kN
③ Insitu RC structure built "Top Down" 4 levels × 150 × 100 × 12 kN/m² (say)	720 000 kN
④ Anchorage of large-diameter under-reamed piles in dense silty sand = 150 × 100 × 7.0 × 18 kN/m³	1890 000 kN
	3 064 146 kN.

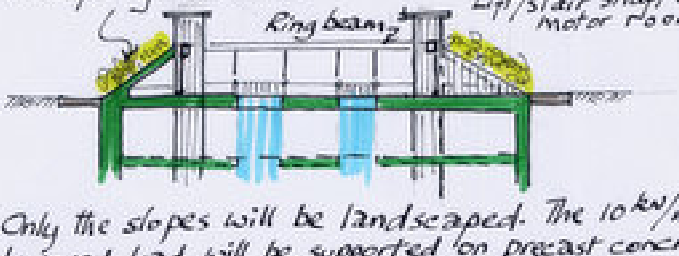
> 2060 100 kN (see page 10)

$F.O.S \simeq \frac{3}{2} \simeq 1.5$

Conclusion: adopt Option 2.

Time will be short and the Option has been seleted: the roof of the carpark – to be used as a landscaped garden [See CR #1] – will be addressed.
The main parking area at Ground Level is the 124.0m by 54.0m one inside the four stair/lift cores and sky-openings to the four light wells [See pages 5 and 6]. The 13.0m wide perimeter strip lies under the slope of the roof [See Figure Q4]. This perimeter slope will be interrupted by the entry and exit arrangements [See Fig 3.15 of ISE's "Design recommendations for multi-storey and underground car parks - 3rd Edition"].



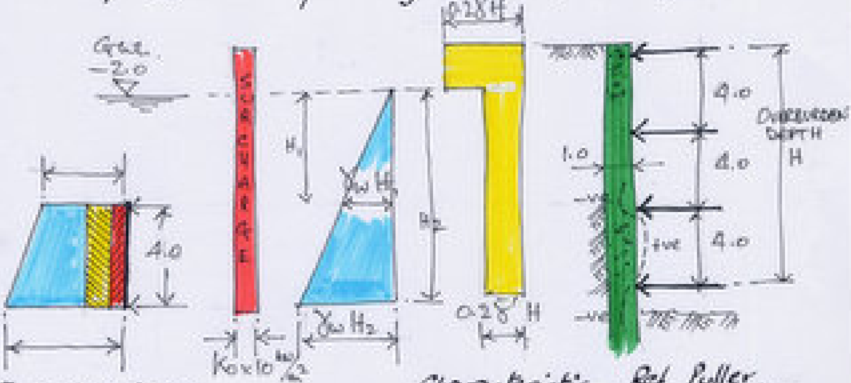


Only the slopes will be landscaped. The 10 kN/m² Imposed load will be supported on precast concrete slabs spanning laterally onto steel rafters supported off a ring beam bearing on the lift/stair cores and intermediate stanchions. All steelwork to be RHS.

Section 1b - "letter": Having selected option 2 with full cut-off the addition of an extra level of basement will not be a problem - just more work!

Section 2c - "calculations": the following will be detailed:

(i) Diaphragm wall spanning between propping slabs.



Equivalent beam within wall - max. load. $M_{max} = \frac{WL}{10}$ ±

Characteristic distributed prop load dia. proposed by Twine & Roscoe

Ref. Puller, "Deep Excavations - a practical manual".

$\bar{\gamma}$ = saturated density of soil = 18 kN/m³ H = 12.0 m.

$\bar{\gamma}'$ = submerged density of soil = 18 - 9.81 = 8.19 kN/m³ H = 12.0 m

γ_w = density of fresh water = 9.81 kN/m³

k_0 = 0.426 [see page 9]

(ii) Ground-level slab spanning 8.4 m with temporary imposed load = 10 kN/m². Combined bending with compression strut load.

(iii) 12.0 m long/slender plunge column supporting ground level slab during top-down construction.

Snippets of good practice worth knowing

From time to time little pieces of a calculation, drawing or some writing catch your attention and you think to yourself "I'll make a note of that; it might come in handy at some time." The following are in this category and have been collected:

- FOUNDATIONS AND BUOYANCY

Approximate load take down (unfactored)

	Roof	+ GF	+ B1	+ B2	+ B3		
Dead Load	10	10	10	10	10	=	50
Live Load	10	2.5	2.5	2.5	2.5	=	20
							70 kN/m²

Check on shallow foundations:

Dense silty sand $N = 35 \rightarrow 80$

q_a approx $= \frac{10}{2} \times N$ (below water table)

Minimum $= 5 \times 35 = 175$ kN/m² $\gg 70$ kN/m²

Therefore could use pads or raft on dense, silty sand.

Groundwater @ -2.0m is at its highest possible level [this assumes that flooding cannot occur!]

Buoyant force $F = 10 \times$ volume

$= 10 \times 150 \times 100 \times 12 = 1800\,000$ kN

Total weight of building approx

(see above) $= 70$ kN/m² $\times 150 \times 100 = 1050\,000$ kN

Not enough!

(See comment on next page)

Comment regarding "flotation":

- Increasing the weight of the building is not practical [in this case],
- Using tension piles is not reliable,

Therefore add drainage layer below 'B3-slab' with slab suspended and supported on piles. Any seepage under the perimeter retaining walls will be collected and drained to sumps. Permanent – i.e. for the lifetime of the building – dewatering will be done using electric submersible pumps controlled by mercury cut-off switches.

The nature, cost and maintenance needs must be communicated to the Client.

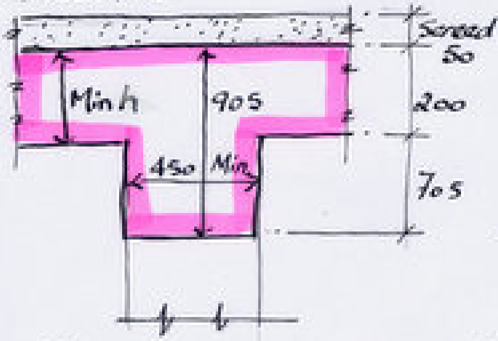
This dewatering assumes that the local Water Authority allows discharge into the mains system.

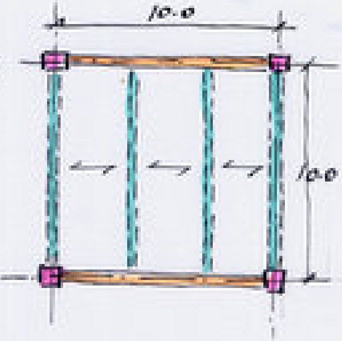
It may be necessary to install a Recharge System for the safety of adjacent buildings.

[N.B. the more comprehensive answers will include notes such as these to show that the Designer has an all-inclusive view and is not limited to calculations.]

This calculation/estimate assumes that the Dead Load of the floor-and-beam system has a typical weight of 10 kPa, equivalent to 10 kN/m². In certain circumstances this estimate may need to be justified.

4 hours FRP





Slab span = 3.0 m
FRP = 4 hrs
Min d = 170 Cover 55
Cols (min) 450 Cover 25
Durability - "Most severe"
Cover 50
Min w/c ratio = 0.45
Min cement = 400 kg/m³
Grade = C50
$L/d = \frac{3000}{22} = 137 < 170$
h(say) = 140 + 55 = 195 > 170

Beam Span = 10.0 m
FRP = 4 hrs
Min b = 280 < Min col = 450
Cover = 70
Durability - "Most Severe"
Cover 50
Min w/c = 0.45
Min cement = 400 kg/m³
Grade = C50
Rectangular Beams $L/d = 12$ $\frac{10000}{12} = 833$
833 + 70 = 903 make 905
Flanged Beams $L/d = 10$ $\frac{10000}{10} = 1000$
1000 + 70 = 1070 > 905

Self weight:
6 beams = 6 × 10.0 × 0.45 × 0.705 × 25 kN/m³ = 475 kN
475/10.0 × 10.0 = 4.75 kN/m²
Slab and Screed = 0.250 × 25 kN/m³ = 6.25 kN/m²
+ 4.75
11.00 kN/m²
Add allowance for services 1.00 kN/m²
12.00 kN/m²

Comment regarding "Dead Load":

The Candidate must be alert to any features in the question that are "out of the ordinary" and can therefore alter the values ordinarily assumed. In this question one such "feature" is the 4 hour FRP.

With a reinforced-concrete frame the thicker cover and minimum sizes of members has changed the assumed dead weight from 10 kN/m² to 11 kN/m² or more

Repeating the calculation on page :

	Roof +	GF +	B1 +	B2 +	B3		
DL	11	12	12	12	12	=	59
LL	10	2.5	2.5	2.5	2.5	=	20
							79 kN/m²

The total weight of the building becomes

$$79 \times 150 \times 100 = 1185\,000 \text{ kN}$$

And although still not enough to prevent flotation, adds 100 000 kN to the foundation loads.

Because the 4hr FRP is called for in Client's Requirement #4, it should be assumed that there are marks for dealing with this matter. To ignore the FRP is to lose these marks, and an off-hand treatment will do little better. A competent design will embrace the necessary requirements such as:

- minimum member sizes
- minimum cover to reinforcement and effects on the detailing
- durability classification
- concrete properties such as w/c ratio, minimum cement content and mix Grade.

Similar attention will be required if a steel frame is used.

• <u>METHOD OF CONSTRUCTION</u>

It must be recognised that there is no dead weight from floors with "bottom-up" construction – at least not in the early stages of the basement construction.
Assuming that the perimeter, or curtain wall, and the foundation piling can be constructed first, the next stage is to de-water the "dumpling" of sandy soil occupying the proposed basement and to excavate this "dumpling".

De-watering must continue until the lowest basement slab (or raft) has been cast. If it is required that the de-watering must stop then the basement raft must be held down with ground anchors or similar that have been drilled into the bedrock.

It will be convenient to consider the foundations, [compressive loading] separately from the anchors, a tensile loading. To try and make one system, say piling, double up for both foundation and anchorage is probably too ambitious at the concept design stage. This is a valid example where the phrase "The design will be deferred to the detail design stage" could be used – providing that initial sizes of both bearing piles and tie-down anchors were offered. The understanding being that it might be possible to provide a less-costly solution if the Designer could find a way of making the two systems combine.

In this question, and probably in others too, the Candidate has the "advantage" over the Examiner in that the Examination Rules allow the Candidate to state — – see Notes to Candidates Number 6 – <u>to state</u> any "Assumptions" made and the design data and criteria that have been adopted for the answer. It is assumed that the "Assumptions" are credible and technologically possible.

The candidate using this examination "device" in Section 1a should/must demonstrate the credibility of the assumption(s) in Sections 2c, 2d and, most importantly, in 2e – the Method Statement. The Examiner is at a disadvantage here as, <u>if clearly stated</u>, the logic of the "Assumption" must be accepted.

Hence, in this question, the two Options available to the candidate are:

- Assume that the perimeter wall around the basement forms a complete and permanent cut-off to the ground water thus allowing the dumpling of Dense Silty Sand under Basement 3 to be de-watered, or at least sufficiently so to prevent any uplift pressure.
- Assume that de-watering is possible to allow the basic construction of the basement, but that subsequent seepage under the bottom edge of the perimeter wall will restore the saturated condition of the dumpling allowing full uplift pressure on the whole basement and possible flotation.

In the first case the need to prevent flotation – either by "Dead Weight" or "Anchorage" – is replaced by a need to engineer a seepage-proof "seal" under Basement 3. If this is achieved and becomes credible then the Candidate may state his/her "assumption" that there is no uplift and that all the internal foundations to the columns and stair/lift shafts are in normal compression. The foundation Options open out into either a Raft or Piles with pile caps and ground beams, with a slab over the top.

The Raft will bear normally onto the Dense Silty Sand using a presumed bearing capacity of, say, 10×N'

If the raft is, say, 2·0 m thick and assuming that 'N' varies linearly, $N_{-14} = 35 + \left[\frac{2 \times 45}{8}\right] = 46{\cdot}25$

$\therefore 10 \times N = 46{\cdot}25 \times 10 = \underline{462{\cdot}5 \text{ kN/m}^2}$

with a possible 25 mm consolidation settlement. There should be no bearing capacity reduction even if water has been left in the dumpling because the 'N' Values were measured insitu in the submerged soil stratum.

This is, in effect, a "shallow" foundation.

The piles will be driven or bored to rockhead and will become a "deep" foundation.

The eventual selection of which foundation to use – shallow or deep – will probably be decided by the cost: something that is beyond the Examination because no cost-data is provided!

Calculations will be made in Section 2c and the Method of construction will be discussed in Section 2e.

Where the Candidate cannot convincingly "engineer" a seepage-proof "seal" under Basement 3 then it must be assumed that the full uplift pressure will eventually build-up: flotation will occur if not overcome by "Dead Weight" [i.e. a concrete structure, a thick concrete raft or full-plan landscaping of the roof], or "Anchorage".

Anchorage relies upon the weight of an "uplift cone" of solid rock or the bond strength of the anchored length of rod, tendon or pile used as an anchor.

The volume of an "uplift cone" $= \frac{\pi r^2 h}{3} = \frac{\pi r^3}{3 \tan \alpha}$

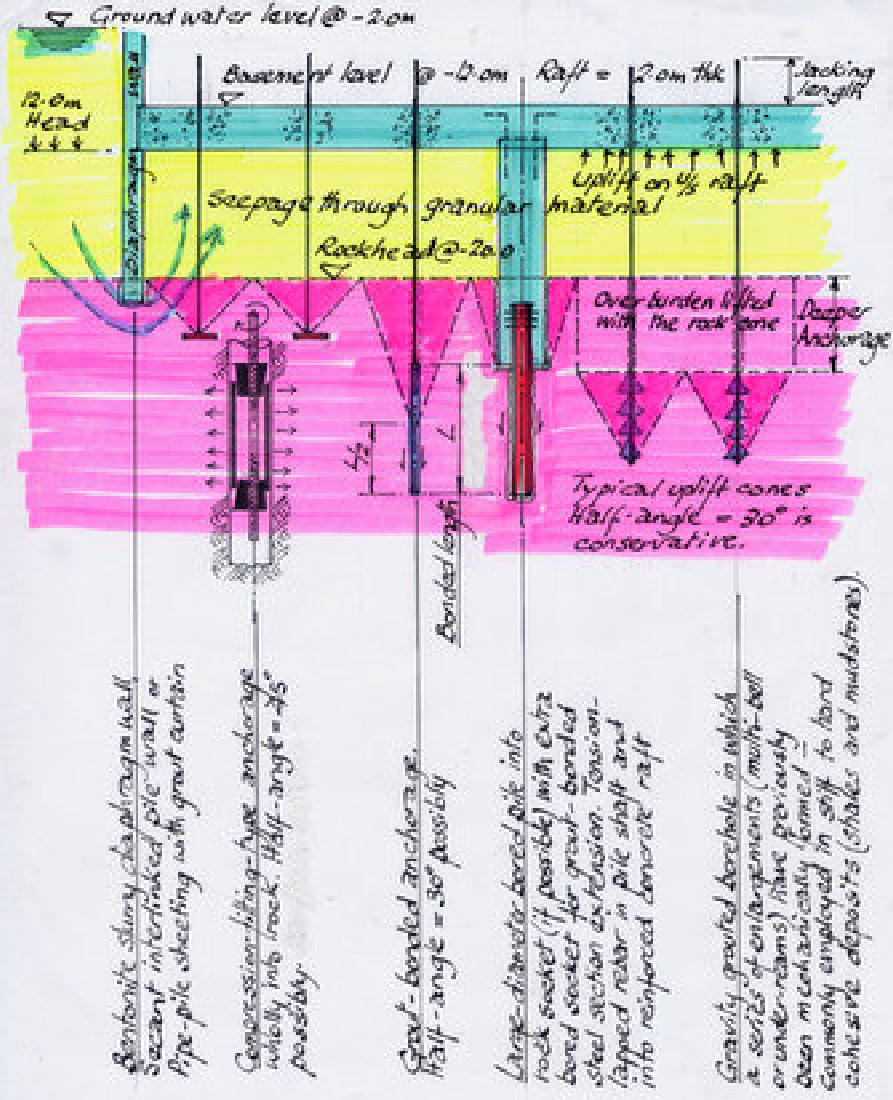
where 'h' is the anchorage depth $= \frac{r}{\tan \alpha}$ and 'α' is the half angle at the apex (inverted).

The radius of the "uplift cone", assuming no overlap of cones is $\frac{\text{anchor spacing}}{2}$.

The volume of the "uplift cone" is multiplied by the presumed density of the rock, say 18 kN/m³. Note that this anchorage is not related to the shear or tensile strength of the rock. The rock, like concrete, is presumed to be brittle and without tensile strength!

The bond strength between grout and rock may be taken to be 0.35 MPa = 0.35 N/mm² (Tomlinson 7th Edition p.313). The diameter of the rock socket, bore diameter or grout anulus must be assumed, as must the "bonded length".

The anchorage value $= \frac{0.35 \times \pi \times d \times L}{1000}$ kN where d and L are measured in milimetres.



TYPICAL UPLIFT CONES ASSUMED FOR ANCHORAGE

The uplift pressure [$9.81 \times$ Head $= 9.81 \times 12.0$ (say) $= \underline{118}$ kN/m^2] will be resisted by:

- the self weight of the basement raft $= 25.0 \times 2.0$ (say) $= 50$ kN/m^2]
- the self weight of the constructed building (if any) see page (101) $= 50$ kN/m^2 (approximate estimate)
- the weight of the uplift cone or anchorage value of the grout-bonded tendon (see below)
- the weight of the overburden rock above the anchorage rock cones where a deeper anchorage has been specified
  $=$ (say) 4.0 thick $\times$ 18.0 (rock) $= 72$ kN/m^2
  (Note: this last element cannot be applied on its own as it relies on there being anchorage cones underneath).

The anchorage cone:

Anchor centres $= 5.0$ m $\therefore r = 2.5$ m $\alpha = 30°$

Anchor depth $= \dfrac{r}{\tan\alpha} = \dfrac{2.5}{\tan 30°} = \dfrac{2.5}{0.58} = 4.31$ m

Cone volume $= \dfrac{\pi r^3}{3 \times \tan\alpha} = \dfrac{\pi \times (2.5)^3}{3 \times 0.58} = 28$ m^3

Cone weight $= 28.0 \times 18$ (rock) kN/m^3 $= 504$ kN

This is equivalent to: $\dfrac{504}{5.0 \times 5.0} = 20.16$ kN/m^2

Resistance to uplift $= \underset{(i)}{50} + \underset{(ii)}{50} + \underset{(iii)}{20.16} + \underset{(iv)}{72} = 192.16$ kN/m^2

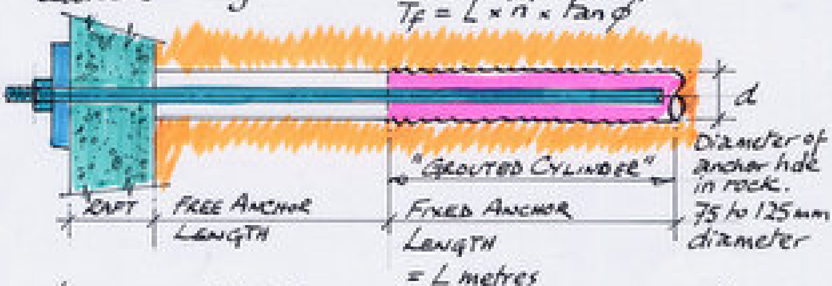
F.o.s. $= \dfrac{192}{118} = 1.63 > 1.5$ and is probably acceptable providing de-watering is continued right up to the time when the landscaping is finished.

Where de-watering needs to be turned off after the perimeter walls and Basement-3 raft slab have been completed there will be no self-weight of the construction above the basement.

The F.O.S. becomes $\frac{50 + 20.16 + 72}{118} = \frac{142.16}{118} = 1.2$

Typically, temporary anchorages are usually tested to [1.2 × the working load]: permanent anchors are tested to [1.5 × working load] or even higher, i.e. 3.
Because ground-anchor design is relatively unsophisticated and subject to many variables — none of which can be assessed in the examination — the candidate is advised to seek a more efficient anchorage in this question.
Try the type of anchor that does not rely upon the weight of an uplift cone — depending instead upon a 'cylinder of grout deeply embedded in the bedrock — a grout-bonded anchorage (page 109).

$T_f = L \times n \times \tan\phi'$



n (an empirical factor) = 400–600 kN/m coarse sands/gravels
= 130–165 kN/m fine and medium sand

ϕ' (the effective angle of shearing resistance) =

	Loose ϕ'_{cv}	Dense ϕ'_{max}
Uniform sand, rounded particles	27°	35°
Well-graded sand, rounded particles	33°	45°
Sandy gravels	35°	50°

The grout-bonded anchorage:

- Assuming bonded anchor rods – choice of 50mm and 75mm diameters.
  Yield stress = 500 N/mm² (Rebar = 460 N/mm²) designed for 30% efficiency.

  $\frac{\pi \times 50 \times 50}{4} \times \frac{500 \times 0.3}{1000} = 294$ kN for 50 φ anchor

  $\frac{\pi \times 75 \times 75}{4} \times \frac{500 \times 0.3}{1000} = 662$ kN for 75 φ anchor.

- The equivalent grout-bonded fixed anchor lengths are:
  Within a bored hole 100mm diameter and using dense sand coefficients of 'n' = 600 kN/m and φ' of 50°:

  $T_f = L \times n \times \tan\phi$ – Bond between rock and grout

  $\therefore 294 = L \times 600 \times 1.19 \quad L = 0.41$ m

  $662 = L \times 600 \times 1.19 \quad L = 0.93$ m

- Bond strength between steel and grout – deformed bars or cables = 0.3 to 0.7 N/mm²

  $T_b = L \times \pi \times d \times 0.35$ (say) – Bond between grout & bar

  $\therefore 294 = L \times \pi \times 50 \times 0.35 \quad = 5.35$m

  $662 = L \times \pi \times 75 \times 0.35 \quad = 8.03$m

Calculation for grout-bonded anchorage:

Uplift = 118 kN/m²
Dead weight of raft − 50
68 kN/m²

If F.o.S. = 1.5 Uplift to resist = 68 × 1.5 = 102 kN/m²

$\frac{\text{Anchor load}}{\text{Area}} = 102$ kN/m² $\therefore$ Area $= \frac{294}{102} = 2.88$ m² i.e. 1.7m crs

or $= \frac{662}{102} = 6.49$ m² i.e. 2.55m crs

The General Arrangement Drawing(s) will show the ground anchor arrangement in Basement 3 to be:

"75mm ϕ Anchor rods at 2.5 × 2.5 m centres in 100mm ϕ drilled holes, cased as necessary with a minimum penetration into sound rock of 8.00m."

Ideally there will also be details of the grout mix to be used and how the anchor rods will be tested and post-tensioned.

Clearly all this detail is a long way (and many marks) clear of a note such as "Flotation will be prevented using anchor piles or similar"!

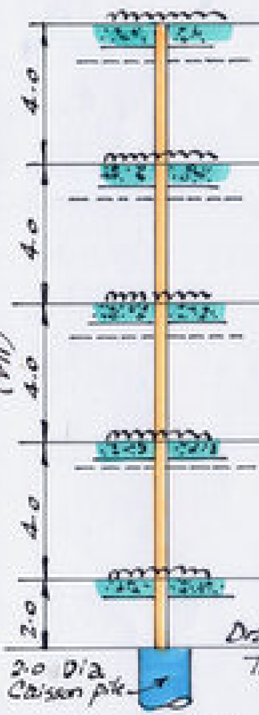
Initial design of columns and foundations.

In Section 1a the Candidate needs to estimate the column size, perhaps its size and rebar detailing, and the supporting foundation. When mistakes are made in estimating the column loads these can affect the overall stiffness of the building and the arrangement of foundations.

A clear and logical presentation will help both the Candidate and the Marking examiner.

- The foundation load/column is estimated.
- The number of piles can be determined, viz with a F.O.S. = 0.65 × Number of piles = (say) 1.5.
  ∴ 0.65 × 2 = 1.3   0.65 × 3 = 1.95 - using a whole nuber of piles. Consequently, in this case, three large piles are needed per column.
- The column sizes at each level and the necessary reinforcement are also easily arrived at. Table 2.21 on page 35 of Brooker's "Concrete Buildings Scheme Design Manual" (CBSDM) assists in sizing internal square columns. See Tables 2.22 and 2.23 too.

SECTION 12 – INITIAL DESIGN OF INTERNAL COLUMNS



Level		kN/m²	UDL over 10.0×10.0	Col. Size Table 2.21 (CBS DM)	Col. Shaft Weight
Roof	LL	10			
	SW	11		450 × 450 (4000 kN)	4 × 0.45 × 0.45 × 25
	Services	1.0			= 20.25 kN
	Σ	22.0	2200	Min. size for 4 hr. F.R.P.	
G.L.	LL	2.5	$\frac{2200}{20} \times 10^3 = 110\,000$; 332 × 332		
	SW	11.0			
	S	1.0			
	Σ	36.5	3650	450 × 450; 4000 > 3650	= 20.25 kN
B1	LL	2.5	$\frac{3650}{20} \times 10^3 = 182\,500$; 428 × 428		$\frac{2}{100} \times 182500 = 3650\ mm^2$ ∴ BT 25
	SW	11.0			
	S	1.0			
	Σ	51.0	5100	600 × 600; 8000 > 5100	4 × 0.6 × 0.6 × 25 = 36.0 kN
B2	LL	2.5	$\frac{5100}{20} \times 10^3 = 255\,000$; 505 × 505		$\frac{2}{100} \times 255000 = 5100\ mm^2$ ∴ BT 32
	SW	11.0			
	S	1.0			
	Σ	65.5	6500	800 × 800; 12800 > 6500	4 × 0.8 × 0.8 × 25 = 64.0 kN
B3	LL	2.5	$\frac{6500}{20} \times 10^3 = 325\,000$; 570 × 570		$\frac{2}{100} \times 325000 = 6500\ mm^2$ ∴ BT 40
	SW	11.0			
Drained Solum	Σ	79.0 kN/m²	7900	800 × 800	2 × 0.8 × 0.8 × 25 = 32.0 kN

Try: Add Col. = 18 × 0.6 × 0.6 × 25 — 162 — Σ = 172.5 kN

UNFACTORED — 8062 kN

FACTORED i.e. ×1.5 — 12093 kN

CAISSON PILE:

$\frac{8062}{\pi \times \frac{2 \times 2}{4}} = 2566\ kN/m^2$

$F.O.S = \frac{5000}{3 \times 2566} = 0.65$

R%	K
1%	0.017
2%	0.020
3%	0.024
4%	0.028

$\frac{LOAD}{K} \times 10^3 = AREA\ mm^2$

$SIZE = \sqrt{AREA}\ mm$

$REBAR = R\% \times AREA\ mm^2$

$\frac{12093}{20} \times 10^3 = 604\,650\ mm^2$ — 778 × 778 mm

If you refer to Tables 2·21, 2·22 and 2·23 in Brooker's "Concrete Buildings Scheme Design Manual" you will find column sizes (mm) able to carry axial loads (kN) for different percentages of reinforcement. For general use 2% rebar is found to be convenient. For any one rebar percentage the table can be simplified to a constant (say 'k') for kN/mm² of the order of 0.020 – which can be rewritten as: $\frac{20}{10^3}$. The values have been shown on page 114.

The calculation is:

$\frac{Load}{k} \times 10^3 = Area\ (mm^2)$

$Size = \sqrt{Area}$ (mm) – a square column

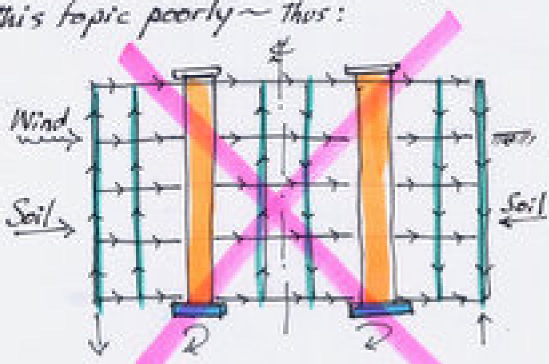
Rebar = R% × Area (mm²)

Hence select bar size and arrangement.

<u>The "problem" with "Load paths"</u> – or in "Examination Speak" – "the functional framing, load transfer and stability aspects of each scheme."

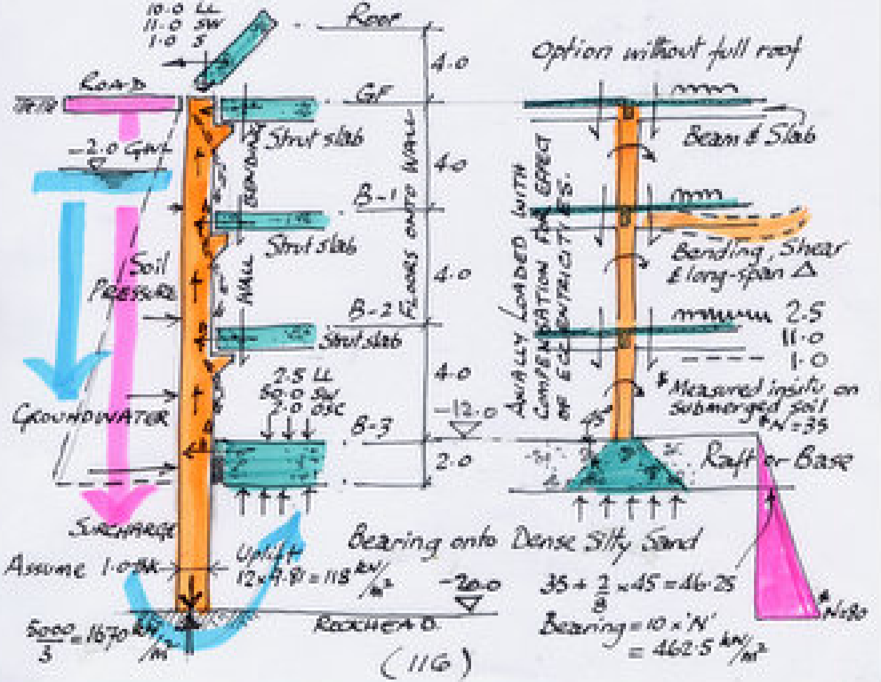
The Writer is inclined to believe that this is a topic that is particular or special to experience with Concept or Initial Design. Candidates lacking this experience usually present this topic poorly ~ thus:

Vertical loading
Moment & Shear
↓
Slab
↓
Secondary Beam
↓
Main Beam
↓
Column / Core Wall
↓
Foundation



Neither the flow diagram nor the arrowed frame are useful to the Candidate — which they should be! Both come from some course notes and are "shoved in" because they are supposed to answer that part of the question!

There should be a relationship between the "Functional Framing" and the "Load Transfer." One does not introduce structural members (functional framing) unless a load has to be carried, i.e. Load-bearing members. The "Load-Path" Diagram(s) will be specific to a structural scheme (not generalised); show how the load reaches the member supporting it; and, perhaps, how the member reacts to the load and the balancing reactions.



Contrast the attached "Load Diagram" for the perimeter wall and an internal column.

- The concrete diaphragm wall is strutted at three levels, spanning between the "Strut Slabs"
- Besides bending it also carries "Axial" loads: transferring them eventually to the "Rockhead".
- The "Strut Slabs" span horizontally along the wall possibly from corner-to-corner or alternatively from "Core"-to-"Core" – perhaps another load diagram?
- The "Strut Slabs" rest upon load-bearing "Shelves" that will need to be built onto the wall after the excavation. Alternatively a "box out" will need to be attached to the reinforcement at each level and broken out and cleared ready for the casting of the "Strut Slabs". In either case a "Critical Detail" will be created for Section 2d.
- The Basement 3 slab bears directly on the sand underneath. It also provides a strut reaction at the foot of the perimeter wall. A critical detail will be needed (Section 2d) to show how the strut action is provided and how the joint is waterproofed.
- The beam-and-slab general floors are shown being supported by the internal column. The relatively long spans (assumed to be 10.0 m) will need a "Long-span deflection" check. Note that the beams will probably have compression flanges (the adjacent slabs), making them "Tee Beams" (rather than plain rectangular beams)
- The column is axially loaded with a load-type compensation for the effect of eccentricity of the imposed loads (See 3.7.4 on page 19 of the ISE "Manual for the design of reinforced concrete building structures", 2nd Edn. 2002.

The diagram on page 116 tells you so much more than the diagrams on page 115 and becomes an essential part of the design. It becomes a record of your design thinking at this early stage – and a comprehensive explanation to anyone needing to follow your design steps – such as a Checker or Marking Examiner!

Clearly, the second Option will have its own, <u>different</u>, "Load Diagram". The question is quite clear about this matter "<u>... two distinct and viable solutions for the proposed structure</u>."

To be quite clear:

"<u>Distinct</u>" means:

- recognizably different
- not the same
- changed

"<u>Viable</u>" means:

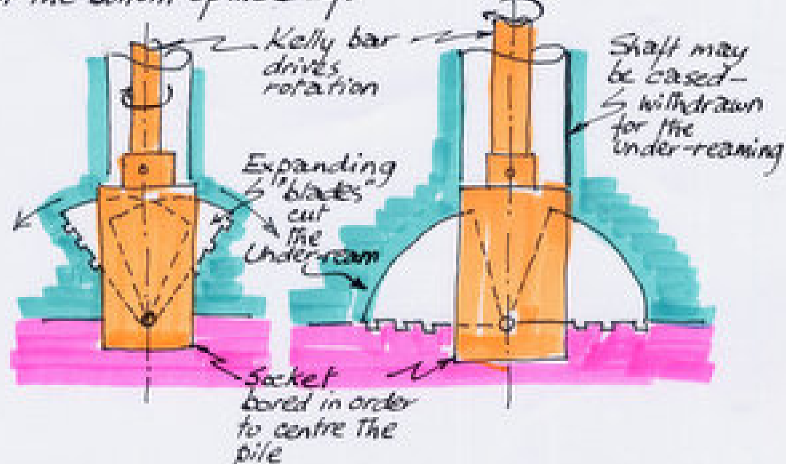
- what is possible
- what is achievable
- practicable
- credible.

So sentences such as:

"The foundation scheme is same as Scheme 1" do not collect marks! The marks may have been given for Option 1, but cannot be given again in Option 2. Similarly: "Progressive collapse same as Scheme 1" and "Provision of joints same as Scheme 1". Foundations for two different schemes cannot be the same! There will be different grids and different loads.

The proposals made in both Options 1 and 2 must be practicable, possible to build and structurally credible. Consequently both "monolithically cast" and "joints shall be provided" do not appear to be possible and must be explained carefully.

A doubtful example of viability has been provided on page 10 – see "Under-reams" on Option 2 and the diagram on page 11. The large-diameter bored piles can be bored mechanically through water-bearing soil and soft rock, the under-ream being formed by a special drilling bit that expands at the bottom of the shaft.



The under-ream enlarges the base of the pile and allows a larger load to be carried.
The doubt arrises because, in this question, the dense silty sand is saturated and will lack cohesion; consequently the roof of the "bell" is likely to collapse. Possibly the "soft" bitumen-emulsion grout will provide enough cohesion for the under-reams to be formed.
The example shows that the Candidate needs to have knowledge and experience of construction, and apply it to the answer. This knowledge can be obtained by insightful reading.

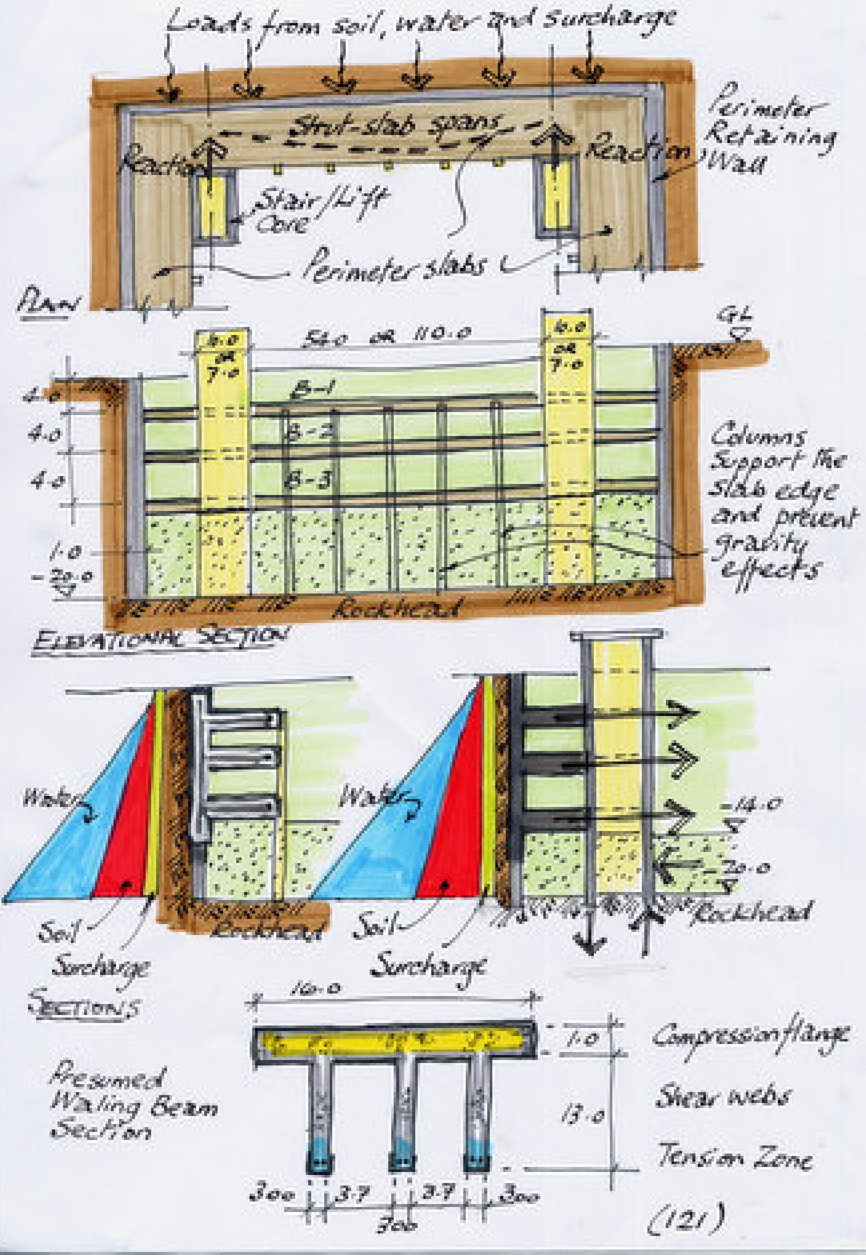
Some candidates affect knowledge by referring to Codes and Standards but expose their ignorance because they clearly do not know the reference document in sufficient detail. A couple of examples will be enough:

"... waterproofing to BS 8007..." is a common one, and "... all lap lengths and anchorage of reinforcement shall be in accordances with BS 8110..." is another.

Little or no credit is given unless the relevant clauses are applied in a specific manner to the question. As an example: 'tension laps will be needed if the building is 'held down, because of uplift, by tension piles.' So, please, there is no catch-all phrase that can be used in this Examination!

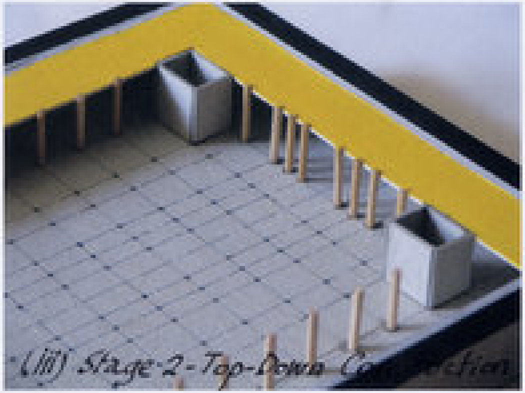
Note that a "Flat Slab" is defined in BS 8110 : 1997 Section 3.7 - Flat slabs. The column heads may be enlarged and drop panels may be added at column positions. There are no downstand beams. For the simplified method there must be at least 3 rows of panels of approximately equal span in the direction being considered. This effectively means a 3x3 panel arrangement as a minimum. The position and size of holes through the slabs is restricted. Chapter 14 in A.H. Allen' book "Reinforced Concrete Design to BS 8110 – Simply Explained" provides detailed design advice.

Unless the conditions apply a "Flat Slab" is not a simple alternative to any other concrete slab in a building and incorrectly naming it does not alter the Marking Examiner's view that it is not a "Different" Option. Unless there are nine adjacent panels without openings or other interruptions (such as access ramps or light wells) you are unlikely to have a simple flat slab.


Loads from soil, water and surcharge
Strut-slab spans
Reaction
Reaction
Perimeter Retaining Wall
Stair/Lift Core
Perimeter slabs
PLAN
56.0 OR 110.0
10.0 OR 7.0
10.0 OR 7.0
GL
B-1
B-2
B-3
4.0
4.0
4.0
1.0
-20.0
Columns Support the slab edge and prevent gravity effects
Rockhead
ELEVATIONAL SECTION
Water
Soil
Surcharge
Rockhead
Water
Soil
Surcharge
-14.0
-20.0
Rockhead
SECTIONS
10.0
1.0
13.0
Compression flange
Shear webs
Tension Zone
Presumed Waling Beam Section
300
3.7
3.7
300
300


(i) Presumed Waling Beam


(ii) Cross Section and Core Support


(iii) Stage-2-Top-Down Construction

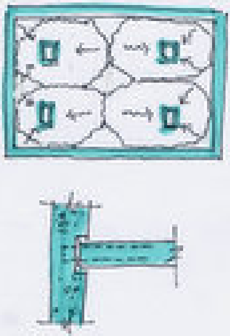

(iv) Long-side Waling Beam & Cores

Pages 121 and 122 illustrate the "Waling-Beam" mentioned on page 117 under the heading of "Strut Slabs". Here the Designer has created a "free body" in order to simplify the complex interaction of walls, cores and slabs carrying the soil, ground water and surcharge.
The design proposal follows the sequence of "Top Down" construction: stage 1 installs the diaphragm walls around the perimeter, around the lift/stair cores, and sets the "Plunge Columns" around the inside edge of the strut slabs. Excavation would be made down to Basement 1 where the upper strut slab would be cast on 75mm of compacted (and levelled) oversite concrete covered with the "parting" layer of polythene sheeting. The plunge columns would be connected to the slab edge to prevent sagging under gravity action. Stage 2 would continue the bulk excavation with undermining of the Basement 1 strut slab. Basement 2 and subsequently Basement 3 would be excavated and the increasing loads from the soil, groundwater and surcharge would be carried by the "Waling Beam" onto the two cores.

The cores would act as embedded cantilevers with a passive earth pressure component and a push-pull component to prevent overturning. The Designer should consider installing ground anchors to carry the tension or "pull" set-up by the system.

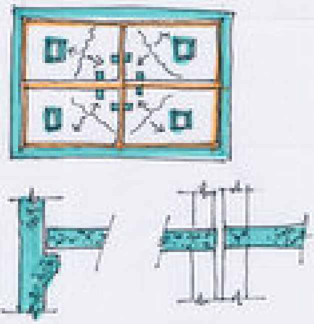
The Candidate may wish to use a "pretty-view" or three-dimensional illustration in the same way that I have used my model, but this might take too long in the Examination. The traditional Plan, Elevational Section and other sections can be sketched freehand in a reasonable time; the colouring-in takes a little longer. This page of explanational text could be omitted with the Candidate following directly with calculations.

In the I. Struct. E "Manual for the design of reinforced concrete building structures", Second Edition, 2002, section 2·4 addresses the subject of movement joints. The advice is very general and suggests 25mm wide joints at approximately 50·0m centres in both directions. This building is 100·0 × 150·0 m in size; so, by the advice given, it will need movement joints.
The Candidate will spot the possibility of two options — a monolithic structure without joints; and a jointed structure divided into a number of individual sections.



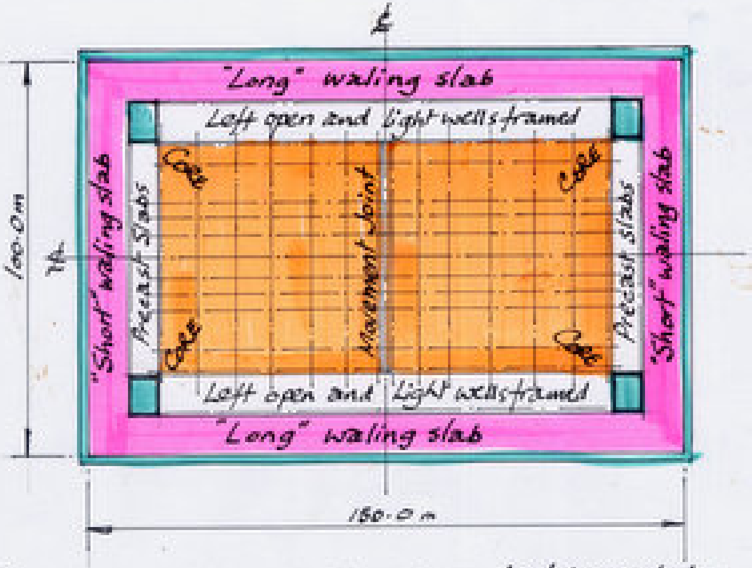
OPTION 1

- Slabs are tied into the walls and provide waling-type support.
- Crack patterns are difficult to predict, especially adjacent to light wells and ramps.
- Consider limiting any cracking using low--heat cement and other concrete technology.



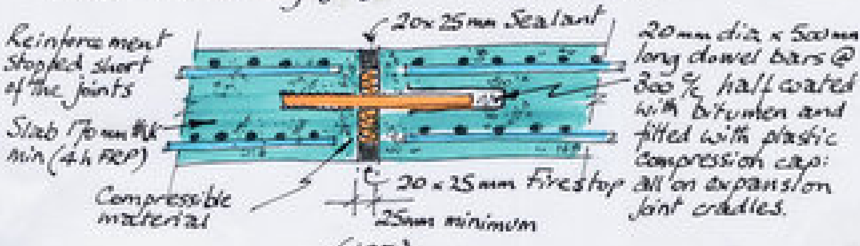
OPTION 2

- Cannot behave as a waling Beam
- Joint must pass through the element of structure
- Cores act independently
- Split columns support the joint edges
- Cracking will probably still happen.
- Joints must be sealed and incorporated into the finishes.

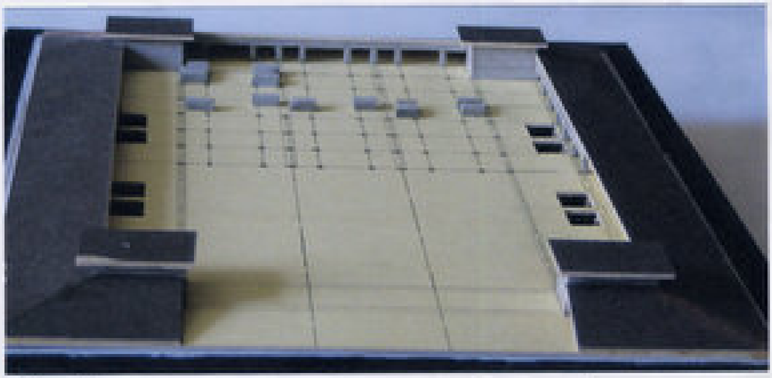


It is suggested that probably only one joint is needed – one along the North-South ℄. The four waling slabs are shown around the perimeter and are monolithic with the four retaining walls. The central two areas are supported on columns and this whole construction would be built from the Bottom-up – from Basement 3 to the ground floor – after the basement raft had been constructed (see (iii) on page 122).

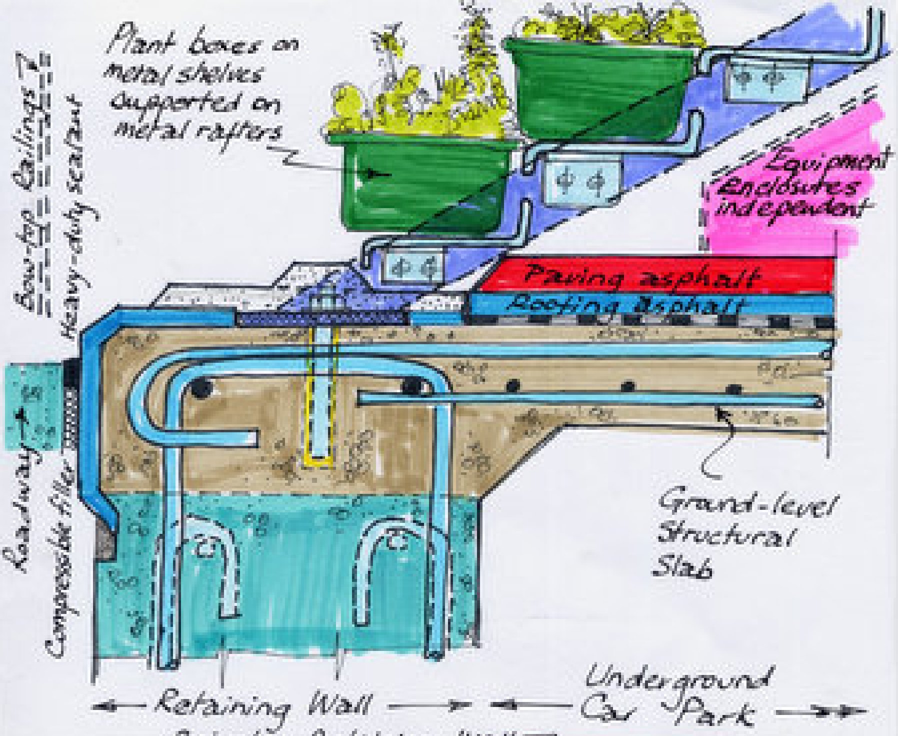
The four "Corridors" between the Cores are left open. These are filled-in with precast concrete slabs as necessary, leaving the light-well openings. This will allow the Cores to flex under the retaining wall loads without engaging the central-area slabs.

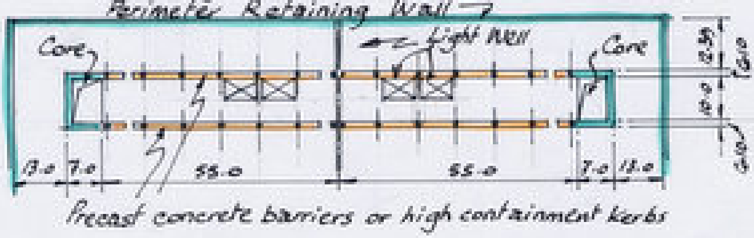


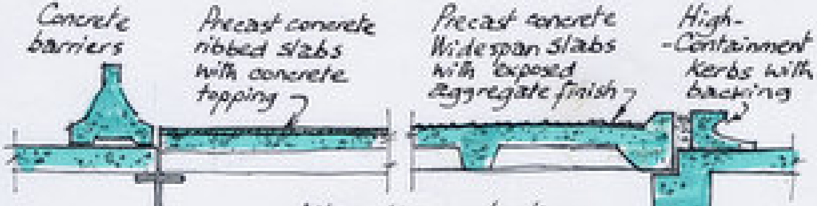
The Joint Detail is based upon a typical Road Joint Detail. However, firms such as Freyssinet have a range of expansion joints which include car-park joints; the objective is to prevent differential deflections as the cars travel over the joint, prevent flame and smoke penetration and to collect water and drain it away.
A different joint may be needed in the Roof and on the Ground Level slab: the lower Basement floors may only need contraction joints to allow movements due to creep and shrinkage effects.
The Candidate must judge carefully how many marks may be available for this work and expend a sufficient time and energy and no more! Please do not duck the issue by saying that this issue can be delegated to "...the detailed design stage."



The landscaped Roof and the Light Wells may well deserve some "critical details". Both are mentioned in the Client's Requirements – so there may be some marks available!







Alternative constructions

Section 2 d asks for "... critical details for estimating purposes.", and for some reason this seems to be a problem for some candidates. The general advice is that these "critical details" are not typical construction details as may be found in general textbooks – so what is wanted?

Most of us are accostomed to elaborating our designs and drawings with details. These may be small sections and even "key" plans that show specific construction, jointing, relative levels and layers of finish, or areas of the project where something special is wanted.

Page 127 shows some "critical details" that are relevant to this question. They are only relevant to this question and explain the landscaped edge above the ground-level deck, the position of the barriers around the pedestrian area between two of the stair/lift cores and the later slabs that are used to make the raised pedestrian corridor.

The components and features used in the details are not unique to this car park. The plant boxes are a common feature of landscaping; the roofing and paving asphalt details are standard technology; the use of precast concrete barriers or high-containment kerbs are also common practice where separation between pedestrians and traffic is necessary; precast concrete slabs are commonplace.

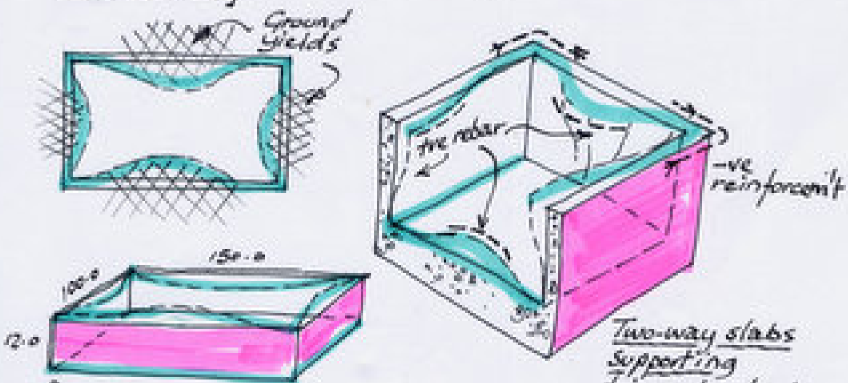
What is special about these "critical details" is that they show what the Designer wants to be built for this particular case. They require forethought, planning and selection: they explain what cannot be assumed.

One viable solution is to build a box – sunk into the ground – and then insert a structure of slabs and supports inside it. This is the essence of the "Bottom-up" method.

Candidates explain that the box is stable to the earth pressures because equal and opposite earth pressures are applied to the other side of the "box".

This is a very much simplified model and often leads to incorrect answers in the CM Examination. The basement is expected to form a rigid "box", but no calculations or predictions of the structural behaviour are given!

In fact the "box" flexes – at least in the temporary condition when the floors, columns and cores are being built. [This is quite different for "top-down" construction.]



Proportions of lengths of sides and depth

Two-way slabs supporting triangular loads

[Cannot use tables in BS 8110 because 2-way slabs have UDL]

The following typed pages were made by one of the Marking Examiners to aid him during marking. Prior to making his lists he would have spent many hours – probably more than two or three days – exploring the possible answers to the question. The idea is to anticipate the different options that the Candidates may offer: no viable alternatives may be excluded.

There is no absolute or perfect "Answer": this examination is not like an arithmetic test with exact answers. Instead it is like turning a waste space into a garden: different people will have different ideas and arrangements. Some gardens will appear to use the space better; some elements will perform better than others. Some common elements will appear in all the gardens; the paths, the perimeter enclosure and the service areas for example. Other ideas will illustrate the Designer's experience – such as water features, rose gardens and alpine arrangements.

So too in this examination: some candidates will favour steel, others concrete, timber or masonry. Some will be able to contrast suspended structures with traditional frameworks. It is most important that you choose the "right" question to answer. Candidates with experience usually find that one of the questions suits them!

The Examiners will consider each and every option that the candidates offer – without bias – providing it answers the question that has been set; is stable; and buildable. There are no restraints set on cost, contract time or method of construction – providing they are viable, i.e. practicable or achievable (see page 118).

Sometimes the Question asks for a "short construction time" to suggest pre-fabrication or pre-casting: however, the quickness of the construction is left for the Candidate to interpret within his or her own experience

The answer to the question requires the Candidate to:
Prepare two distinct solutions that meet the Client's requirements [i.e. having different structural forms and/or different forms of construction] that are viable [i.e. have the prospect of success]. Both options must be equally complete and be illustrated with appropriate sketches. Each must show all the main parts of the frame, with foundations.
Recommend one scheme.
Write a letter in standard office format explaining the problems and how these are to be overcome.
Write calculations in standard office format demonstrating that the proposed frame and foundations are stable and comply with relevant criteria.
Draw general-arrangement-style drawings to scale in the form of plans, sections, elevations and details for estimating purposes [i.e. the drawings, it must be assumed, will be sent away to another office or company and will advise about the project details]. These drawings must be presented in a clear and professional manner.
Prepare a method statement and outline programme for the structural-engineering content of the project that identifies the likely issues to be addressed when fabricating, transporting and assembling the proposed building, and their durations.

Proper communication by means of clear-to-read text and sketches or drawings is essential.

The evaluation of the two options that are offered involves:

- the differences between the two options – see Section 1a (any question) that calls for two distinct and viable solutions.
- and the professionalism exhibited by the Candidate.

The differences or distinctness should range all the way through the structure from foundation to roof. It should range through materials, structural form, structural behaviour [static through to hyperstatic], appearance, etc., etc to ease of maintenance and ultimate unbuilding. The Candidate should pick and choose as appropriate to the Question.

Many criteria used commercially cannot be dealt with because the Question does not contain appropriate data. Read the "Client's" mind and confine yourself to dealing with the <u>structurally</u> <u>critical criteria</u> — <u>MATERIAL, FORM AND STRUCTURAL MODELING.</u>

The professionalism of the Candidate can be inferred from the content and character of the presentation, such as the appropriateness of the selection of the critical design criteria; the attention to detail; the general correctness of what is presented; and the "air" of taking responsibility for what is being suggested.

How may you know that you are sufficiently professional? Here are four key features of an experienced professional:

- there will be a distinctive ability to go directly to the centre or core of the problem: not ignoring, but stepping over routine matters in favour of the serious design features:
- there will be significant attention to detail and any number of small, mental checks on the correctness of what is designed:
- there will be an acceptance of the responsibility for the design and a prioritizing system so that matters that are most important come first:
- and the work — drawings, calculations and even the handwriting — will be clear and presented at a high standard that meets the accepted commercial models.

The way that the marks are allocated may seem strange to some candidates: there are no "mark schedules" where particular words, arithmetical values or procedures are identified as having a numerical value. Because the Candidate is free to chose the two (different) Options — which is only done in the examination room — there is no "model answer" or preferred pair of options; nothing can be anticipated.

Instead the "target" is a perfect answer where everything fits and there is no waste!

How close the Candidate is to this perfect answer can be expressed as a percentage – please see the following table.

90 – 100%	Truly exceptional	Wide and detailed knowledge and understanding of design, construction and materials showing insight and originality. Evidence of extensive reading and/or experience. Appropriate use of references or exemplars. An exceptionally high standard of communication through writing, calculations, sketches and drawings.
80 – 89%	Outstanding	
70 – 79%	Excellent	Wide and appropriate knowledge and understanding of design, construction and materials. Evidence of thoughtfulness and experience. Use of references. A high standard of communication.
60 – 69%	Comprehensively good	Sound knowledge and understanding of design, construction and materials. Evidence of experience and project skills. Occasional lapses in detail [e.g. in calculations, sketches or drawings]. A good standard of communication.
50 – 59%	Generally good	Appropriate knowledge and understanding of design, construction and materials. Evidence of experience. General accuracy with occasional mistakes.
40 – 49%	Satisfactory	Basic knowledge and understanding of design, construction and materials. Basic project skills. General accuracy but with omissions and/or weaknesses [e.g. in calculations, sketches or drawings]. Poor standards of presentation and communication.
30 – 39%	*Unsatisfactory Performance*	Elementary treatment of the problems throughout, in parts the answer being limited to misunderstood technical terms. Poor knowledge and understanding of basic design, construction and materials. Unable to demonstrate experience and project skills. Serious errors, omissions and weaknesses [i.e. in calculations, sketches or drawings]. Unable to use the information provided in the question. Substandard presentation and communication. Lack of familiarity with the subject of the question.
20 – 29%	*Weak performance*	
1 – 19%		

The Examiner reads through the whole of the Candidate's script — text, letter, calculations and drawings — and perhaps makes notes. During this first reading the Examiner will form an opinion, an estimation, "Has this Candidate demonstrated sufficient "experience" and "know-how" to become a Chartered Structural Engineer?"

Here is the nub of the situation! The examination is like a doorway or threshold. Pass through and you are in a new situation. You may now be given the responsibility of performing structural design on your own. You are now the "Designer"! The decisions are now for you to make! It is not uncommon for the design organisation to shield and protect their new "Engineer" by putting him/her as an associate to a more experienced Engineer. However, in principle, you are now qualified to practice independently — and you are responsible for any omissions or mistakes, however large or small!

The initial assessment is modified/qualified during a second reading of the script. Notes are made explaining why the Examiner has "marked-up" or "marked-down" the percentage. It is a general fact that most adjustments are "marked-down" because of mistakes that have been found in Section 2c or 2d.

The final percentage (%) is translated into a mark/100. All marks are accompanied by a commentary/explanatory notes, unless self evident.

WITH REFERENCE TO CONCEPT SKETCHES, CM EXAMINATION 2011 – "IS MY WORK ACCEPTABLE?"

You will be asking, **"Is my work acceptable?"**, and **"Shall I pass the examination?"**

Assessment always starts with the assumption that everything you write or sketch is **potentially acceptable.**

As the assessment process proceeds various omissions or faults make the work less and less acceptable, until a stage is reached when the work becomes **unacceptable**: i.e. the work becomes 'Professionally unacceptable'.

There is a point when the work is unacceptable to our paying Client or to our Peers [other engineers or the Examiners].

The following include common omissions or faults:

- Incorrect or Inadequate load,
- Inadequate Section, acting in bending, shear or torsion,
- Excessive deflection, movement, or vibration,
- Instability, i.e. overturning, settlement, buckling or flotation,
- Lack of functionality, i.e. not complying with the Client's requirements; not watertight or weathertight; not adequately sound-proof or thermally insulated; services cannot be installed or accessed for maintenance; or inappropriate appearance.
- Lack of buildability, i.e. too big to transport; too heavy to lift; explanation needed of how it is to be constructed or assembled; unsafe to build or unstable in the temporary condition during assembly.

This list is not exhaustive but contains the features that most commonly bring about 'unacceptability' during the marking of examination scripts!

The worst fault of all is poor presentation or unreadable writing – i.e. Lack of communication between the candidate and the examiner! This amounts to 'Unprofessional practice' and shows that the candidate is inexperienced and not competent as an Engineer.

HOW CAN ONE PREPARE FOR THIS EXAMINATION?

Having graduated from college you must spend a period of "Initial Professional Development", IPD, with a structural engineering organisation in order to learn office and site procedures. This IPD will last for five or more years. You should find someone to be your Mentor, who can advise you. Your Supervising Engineer is often chosen, though this is not ideal when personal matters are at issue.

After a time it will be necessary to prepare yourself to take the seven-hour examination. In actual fact it is nearer 8 hours if you count the time for lunch and reaching/leaving the examination room.

You must prepare yourself in three ways:

- to maintain your concentration for the full time and write continuously,
- to draw (without computer-aided graphics) General Arrangement drawings; sections and elevations; and "Critical Details",
- to engineer solutions and schemes to answer the selected question while presenting them in a professional manner.

Concentration and practice at manual skills need personal effort. Working at a computer is not appropriate. You need to be critical of your own handwriting; and of your drawing/sketching skills. You need six-months of regular practice to develop the necessary skill level for the examination.

This acquired skill level for the examination will not be wasted because you will be using the skills again when you are the Project Engineer and moving about among your colleagues and explaining things at meetings and on site. A laptop is not convenient or efficient because you need to sit down at the thing. It needs printers, etc, before you can hand round the results. Hand-drawn sketches can be photocopied or scanned. Notice all your fellow engineers who write their meeting notes in a large notebook with a pen!

BASIC SKILLS ARE STILL VERY MUCH IN USE!

Candidates usually practice on past questions. A big concern is to get all the written answer down on paper in the allotted time. A timetable is recommended, usually based on 4 minutes per mark, so that a ten-mark section such as the "letter" should take 40 minutes, after which you move onto the next part of the question.

However, this is not <u>PREPARATION</u>!

You may have covered thirty pages in writing but it may be rubbish that you have written! Each "Practice Answer" needs to be evaluated to see if it can be improved. Candidates should do this for themselves, at home.

Start the preparation by dissecting the question into the <u>essential features that must earn marks</u> — see the example on pages 209, and 210.

CHARTERED MEMBERSHIP QUESTION 4 – 2013, UNDERGROUND CAR PARK.

MARKING EXAMINER'S LIST OF ESSENTIAL FEATURES IN THE MARKING.

<u>BASEMENT PERIMETER WALL</u>

- Construction in waterlogged sand – Propped-cantilever or Top-Down – must know the process!
- Strength – earth pressure theories for the above two are different: propped cantilever is the standard triangular theory; the multi-strutted top-down is a modified rectangular pressure diagram derived from measured strut loads [Terzaghi and Peck or more recently Twine and Roscoe]. Submerged soil, earth pressure at rest [rigid wall] and wall friction. Practical reinforcement in secant piles.
- Watertightness – damp patches allowed. Drainage.

<u>FLOTATION and Anchorage</u>

Must include adverse conditions of flood [maximum at Ground Level; higher and the car park begins to fill] and minimum dead weight.

<u>Floors and Ramps</u>

Column centres must suit car parking requirements and layouts including 'Bins' and 'Aisles'. There needs to be separation between pedestrians and cars, particularly at the stair/lift cores.

- Steel
- Concrete – insitu or precast
- Composite – unpropped construction
- Long spans – strength and deflection,
- Stair/Lift cores and lateral bracing, braking and unsymmetrical loading,
- Combined strut and floor action, if relevant,
- Long, slender columns, if relevant, such as with 'plunge columns in the Top-Down construction method. This could be a temporary condition.

<u>4-hour fire resisting period</u>

- Applied
- Inherent [e.g. reinforced concrete – cover and wrapping mesh/reinforcement]
- Details of thickness or construction
- Prevention of damage. Provision of durability.

<u>Rooftop and landscaping</u>

- Interpretation of the brief; motor rooms and ventilation; entry and exit arrangements
- Root barriers and drainage, waterproofing,
- Long-term loading from landscaping; deflections.

CONSEQUENCES OF THE CHOICE:

For the Propped/tied cantilever wall:

- Strut or tie anchor,
- Soil support or thrust from base slab at the root of the cantilever,
- Strength of the wall in bending,
- Practical reinforcement within the section, [i.e. circular for a secant pile or rectangular for a section of diaphragm wall]

For the Top-Down strutted wall:

- Long/slender plunge columns; shape, size, strength, handling. Drilling through waterlogged sand – casing? Enlarging base in waterlogged sand?
- Ground-level strut with slab; increased imposed load to 10kN/m^2, strength under combined strut/waling and slab bending modes, detail of parting layer and underpinning when under-dug, connection to plunge column, loading of the wall in bending over several spans [derived from strut-load measurements, Terzaghi and Peck]
- Strength in bending
- Detail of the connection of the slab to the wall

Car-parking function:

- Bin and aisle layout dictates column positions and overall grid
- Ramps at 1:10 or 1:12 within the column grid and generation of lateral loads
- Headroom and deflection issues
- Durability and damage issues
- Ventilation issues
- Drainage issues

Viability issues:

#1 – can one under-ream in waterlogged sandy soil without pre-grouting or using bentonite slurry?

#2 – does one *need* to construct a "facing" wall on the inside of the basement?

#3 – how much does one *have* to say about durability, early-thermal cracking, drainage, lighting, etc?

#4 – movement joints are not necessary; but if used must be detailed

#5 – does the letter require a new basement design, or can it just be suggested? With top-down construction and the diaphragm walls taken to a complete cut-off at rockhead excavation can be carried on below Basement Level 3 to create a Basement Level 4.

These features are all in the question either as Client's Requirements or Site Conditions. Where you are doubtful about what is wanted – for example see "The roof of the car park will be used as a landscaped garden." – you may need to break off and investigate the topic [i.e. landscaping]. You may be lucky to have had some recent experience, which would be good, but our doubts arrise because we have no idea of sizes, layouts or materials to use.

This investigation and research is PREPARATION!

Here is a skimpy list of topics to get you thinking!

- Damp- and water-proofing : weather-proofing.
- Prevention of flotation: uplift calculations; anchor piles; ground anchors; de-watering and ground treatments.
- Retaining walls: types, and various stability-proving calculations; rebar arrangements; construction and movement joints; corners and junctions; waterstops.
- Pad and Raft foundations: bearing on soil and rock; differential settlement and allowable limits.
- Bored and Driven piled foundations: steel, concrete and timber piling; estimates of load-bearing capacity; negative friction; group effect; pile caps and ground beams.
- Steel superstructure framing: simple and moment connections; bracing and portalization; floor systems — continued ...

...continued from page 211 — floor systems, traditional, composite and post-tensioned; unpropped construction; continuity and deflection; vibration of floors; fire and corrosion protection.

- Concrete superstructure framing: cast-in-situ, one and two-way slabs; downstanding beams; strip beams; flat slabs to BS 8110; columns, internal, intermediate, and corner; precast-prestressed slabs, beams and columns (piles); connections and continuity; long spans – strength and deflection; long, slender columns; post tensioning; fire and corrosion protection.

NOTE! THIS IS NOT A COMPREHENSIVE LIST! YOU ARE ADVISED TO DRAW-UP YOUR OWN SYLLABUS.

"Completeness" is the watchword: structural form, analysis, calculation (within time constraints) of the critical limit state; essential – not typical – details; and aspects of buildability.

There are innumerable other topics: some are equally basic, such as timber superstructure and masonry [both traditional stone and brick as well as the modern concrete block and concrete brick]. Then there are the more specialised subjects such as Slipforming (for cores), Deep Beams [where the depth ≥ span], Atria [shopping malls and city office blocks], floors with heavy loading [of the order of 10 kN/m² or larger] and many more!

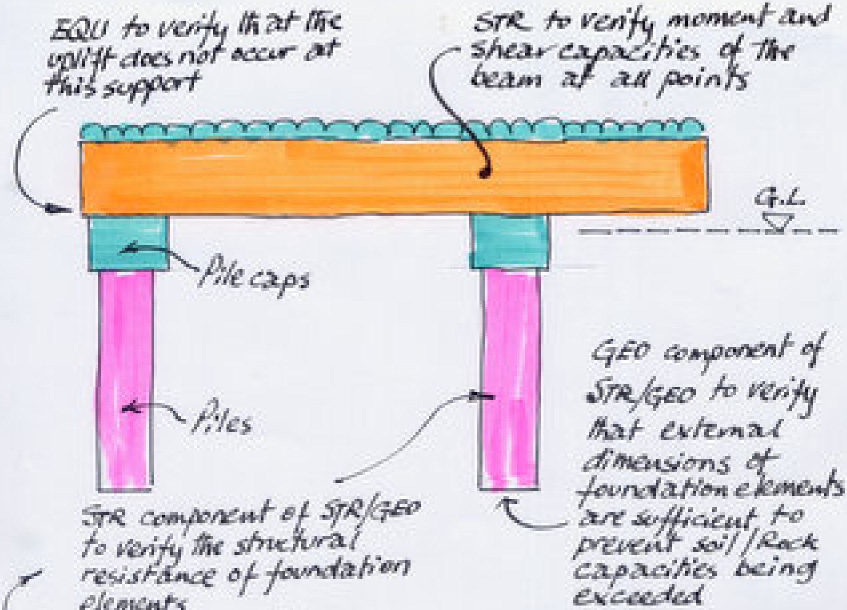
It is important that the Candidate clearly understands the major failure modes: loss of static equilibrium [EQU limitstate], internal failure or excessive deformation (STR limit state), failure or excessive deformation of the ground (GEO limit state) and fatigue failure (FAT limitstate). This will allow the Candidate to identify a critical failure mode and focus a limited amount of exam-time work into an appropriate answer.

The Candidate's familiarity and preparation needs to extend to preparing quick calculations (20 to 25 minutes) of the distinctive structural behaviour. These may be Ultimate or Serviceability limit states, and include all-round consideration of the application of load arrangements for floors, beams and roof and of extreme loading conditions, the analysis of bending moment, shear or deflection and the selection of a section able to resist.

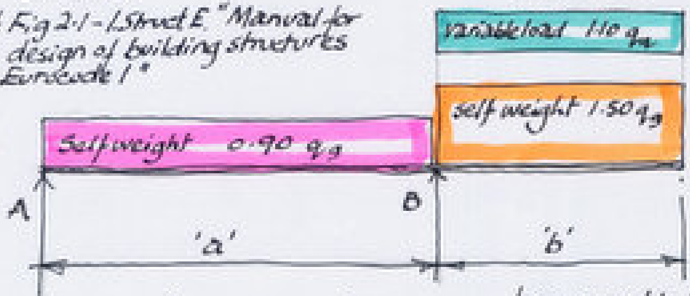
In Section 2c — the "calculations" — there are 20 marks and these will be spread between three or four calculations that must be specific to the question's answer. One <u>must</u> relate to the foundation [the question always says, "... including foundations".]

Other calculations might relate to a transfer beam or structure, a retaining wall, a long-span truss or roof, or a slender column.

Please avoid simple or "typical" slabs and beams as these are rarely "principal structural elements" (viz. Section 2c) and are not specific enough to the question, especially if more important elements have been "passed over" indicating that the Candidate does not know how to design them!



Ref. Fig 2.1 - I.Struct.E. "Manual for the design of building structures to Eurocode 1"



$R_A = \frac{1}{2} a q_g (0.35 - 0.75x)$

$x = \frac{\text{free variable load}}{\text{self weight of beam}} = \frac{q_q}{q_g}$

Static equilibrium STR limit state ensured by an anchor at A

EQU limit state verified if $x \leq 0.47$

Ref. "Designers' Guide to EN 1990", ISBN 0 7277 3011 8.

Furthermore you need to be familiar enough with the construction to be able to highlight special requirements in the Method Statement - Section 2e:

E.G. • 24/7 working for slipforming
- special procedures when working at height
- special practices when on-site welding is specified.
- etcetera

The next three pages illustrate how a Marking Examiner might catalogue "mark-down" examples in order to maintain consistency in the process of marking.

The "Check List of Minimal Contents" allows the Examiner to keep notes about the individual answers. The Options can be summarised and the pages can be used as a "tick list".

If you are working with a colleague you might prepare similar pages and use them for marking each other's answers to past questions. The exercise can concentrate the mind wonderfully about what the question is really about and what further topics need to be prepared.

This all adds emphasis to the importance of choosing the right question to answer!

MARK-DOWN EXAMPLES:

- Intends that the construction is to be "Top-Down", presumably as described in the ISE Report on Deep Basements, but then describes a different method.
- The different method is unstable or impracticable in some way, e.g. flooding with groundwater.
- The programme does not show the intended method of construction.
- The column grid is not clearly related to car parking.
- Unstable under-reaming in sandy soil in waterlogged ground.
- Confused ideas about resisting lateral loads on the stair/lift cores. Not demonstrating that the cores are designed to carry lateral loads, especially when the loads are to be transferred to them.
- Introduction of movement joints into the structure, especially when they are not detailed and shown to be watertight. Introducing movement joints through slabs that carry compression loads as struts.
- Incorrect soil pressure distribution on surrounding walls, especially if the walls are strutted by floor slabs as in "Top-Down" Construction.
- Impractical reinforcement in secant piles or diaphragm-wall panels. Lack of reinforcement between walls and slabs or between walls and lining walls.
- Not clearly including ramps for car access. Not separating pedestrian access sufficiently from the vehicle access, especially at the stair/lift cores. Not including entrance/exit from street into the car park.
- Not including the Landscaped areas on the roof of the car park or making suitable provision.

OUTRIGHT FAILURE:

- NOT RESOLVING THE FLOTATION PROBLEM.
- NOT RESOLVING THE EARTH-SUPPORT PLOBLEM – i.e. the retaining walls.
- NOT PROVIDING SUITABLE CAR-PARKING SPACE.

<u>CHECK LIST OF MINIMAL CONTENTS:</u>

<u>TWO OPTIONS:</u>

OPTION 1:

OPTION 2:

SOUND AND SENSIBLE REASONS FOR CHOICE OF OPTION.

<u>DISTINCTLY DIFFERENT; *COMPLETENESS* *AND* *SOUNDNESS*</u> <u>OF BOTH PROPOSALS</u>

BASEMENT WALLS

FLOORS, AND SUITABILITY FOR CAR PARKING

MATERIALS and FUNCTIONAL FRAMING

INTERNAL COLUMN FOUNDATIONS

ROOF

<u>VIABILITY OF BOTH OPTIONS</u>

LOAD PATHS/UNDERSTANDING OF THE STRUCTURAL BEHAVIOUR

INITIAL SIZING CALCULATIONS FOR BOTH OPTIONS

DEFLECTION, FIRE, IMPACT, WATERTIGHTNESS

<u>STABILITY FOR BOTH OPTIONS</u>

FLOTATION AND MASS/ANCHORAGE/DEWATERING **/40**

<u>LETTER:</u>

APPRECIATION OF THE PROBLEM WITH SKETCHES

COMPLETENESS OF THE SOLUTION

REALISM/USEFULNESS OF THE ADVICE GIVEN **/10**

SECTION 1 /50

SECTION 2:

CALCULATIONS:

RETAINING WALLS – PRESSURES ON, STABILITY

RETAINING WALLS - FLEXURAL/SHEAR STRENGTH

LONG-SPAN FLOOR BEAM

GENERAL BASIC CALCULATIONS

PRINCIPAL SUPPORT/INTERNAL COLUMN

FOUNDATIONS UNDER INTERNAL COLUMNS **/20**

DRAWINGS:

G.A. PLAN AND CROSS-SECTIONS

CRITICAL DETAILS **/20**

METHOD STATEMENT/PROGRAMME:

IRRELEVANT ACTIVITIES FOR WHICH THE CONTRACTOR IS RESPONSIBLE

GENERAL LIST

CONSTRUCTION METHOD – RELEVANT KEY ACTIVITIES AND DURATIONS SUCH AS THE BASEMENT WALL, THE INTERNAL FOUNDATIONS, THE EXCAVATION METHOD, WATERPROOFING, PERMANENT DEWATERING, PLUNGE COLUMNS, SLAB CONNECTIONS TO COLUMNS OR BASEMENT WALL, CONSTRUCTION JOINTS, ABOVE-GROUND CONSTRUCTION AND LANDSCAPING, FLOOR AND RAMP FINISHING, FIREPROOFING, ETC.

CRITICAL PATH/KEY EVENTS

CONTRACT TIME

/10

SECTION 2 /50

TOTAL /100