CT3
Actual Exam Questions
Questions and Potential Answers
Aug 2010/11 (Answer 3Qs from 5Qs)

Q1  Basement Technology

Figure 2 indicates that the office development is to be provided with a two storey basement, for carparking and staff recreational space. The client is keen to avoid the use of any temporary support during the construction due to time restrictions.

(a) Evaluate, recommend and sketch two alternative methods that could be employed to construct the basement for the proposed office development shown in figure 1 and 2. Outline any specific problems that may have to be overcome with each method proposed. Sketches should be clearly annotated and with an approximate scale of 1: 10 as appropriate. (33 marks)

There are three set of keywords: 2 storey basement, avoid temporary support, time restrictions.
There are five set of instructions: Evaluate, recommend and sketch 2 alternative methods, outline specific problems with each method, sketches in 1: 10

Students need to explain what the four available methods are......

Considerations
For this situation, first consideration is do we have to save construction duration? If we choose top-down construction sequence, permanent basement wall construction method is recommended. If construction duration is not an issue, temporary basement wall construction method would suffice. Furthermore, the water table is below the basement, as such contiguous bored piles construction method is also feasible.

When the basement wall construction has completed, construction shall proceed with the top-down construction method.

As time is of an essence, we choose top-down construction sequence, the two approaches are: (can choose any two of the following four)

Approach 1 - Diaphragm Walling

The excavation of the deep trenches for segments of the diaphragm wall can be achieved by means of hydraulic grabs, by means of hydrofraise or by means of rotary auguring, overlapping holes are drilled to form a wall section as opposed to individual pile holes.
Traditionally, as the spoil is removed from the excavation it is replaced by material called ‘bentonite’ slurry. This can be used to support the walls of the excavation shaft in order to prevent collapse as the excavation proceeds. Once the excavation of a particular section of walling is complete, a reinforcement cage may be placed into the slurry and concrete placed using a tremie pipe.
Diaphragm walls of 450mm to 1.0m thick can be formed by hydraulic grabs and hydrofraise, whereas thicknesses of up to 1.50m can be achieved using rotary methods. Diaphragm walls can be constructed to depths of up to 50.00m.

Once the diaphragm walls are placed and completed, the deep excavation work can proceed virtually unobstructed. Some degree of lateral support is normally required to resist the bending stresses that are set up by soil and water pressure as before since a diaphragm wall is not normally intended to act as a pure retaining wall.

The support can be provided by steel beams, flying shores or by ground anchors.
Approach 2 - Contiguous bored piling

Bored piles are installed in a line touching one another, or overlapping one another. The piles may be rotary augured or continuous flight augured. Because the piles are only close to one another or overlapping, the resulting wall is not generally watertight. Grout can be injected or a grout pile can be formed between the two closely spaced piles to improve this situation although the complete exclusion of groundwater remains difficult. The construction process is relatively straightforward; once the piles have been placed, excavation work may begin. However, a degree of propping will be necessary as the excavation proceeds. This can be achieved using raking shores, flying shores or ground anchors depending upon the site conditions and upon site constraints.

Approach 3 - Stent wall piling

The stent wall system offers a robust method of constructing a piled basement wall. It is claimed to be watertight. It consists of a series of alternate bentonite/cement CFA piles and reinforced concrete piles which interlock to form a solid wall. The interlocking is achieved by placing the reinforced concrete piles partially within the cement piles, thus producing a solid, continuous wall which can be expected to be watertight.
The bentonite/cement slurry piles are soft enough, even once cured, that the rotary auguring equipment used to bore the intermediate reinforced concrete piles is sufficient to chisel out the necessary channel in the slurry piles to allow the interlock to be formed. Where a heavier, more robust wall is necessary heavy section secant piled walls may be used.

**Approach 4 - Secant wall piling**

Secant wall piling is a further method for constructing a stronger interlocking piled wall. This time the system is a hard/hard system. This time a series of primary reinforced concrete piles are bored in an alternate fashion. The reinforcement cage is shaped in such a way as to permit the perimeter of the piles to be removed. Once these primary piles are in position, the remaining soil in between them is removed ready to place secondary piles. In this case, since the primary piles are formed from structural concrete, the auguring equipment is not sufficient to form the grooved channels that are required to complete the interlock, therefore specialist chiselling equipment must be utilised.

Once this is done reinforced concrete secondary piles are formed in the gaps to produce a solid continuous wall having good, robust, structural properties.

Excavation may begin once the secant wall is complete, however, as the excavation proceeds it may once more be necessary to use temporary support systems such as raking shores, flying shores or ground anchors.

**Figures Showing Construction of Secant pile wall**

Next to explain use of top down method after any of these approaches. To explain the method if time is sufficient.

After any of the abovementioned method, proceed to use of Top down basement construction.

**Top down basement construction**

- This is a method that can be employed to further speed the construction process.
- In the top down method, the construction of the basement begins with the installation of the basement walls using one of the methods described in relation to using the permanent basement structure.
At the same time, the internal columns within the basement area can be installed in one of two ways.

First, the **columns can be installed as replacement piles** which are designed to double as foundations & columns once the basement excavation is complete.

Second, **if the superstructure is to be a steel frame, a piled foundation can be installed by rotary auguring.**

Rather than bringing the concrete pile up to ground level, the **concrete replacement is stopped off at Steel columns can then be placed & secured using a concrete plug.**

**Great accuracy is required to locate steel columns in this fashion to ensure that they are positioned correctly & that they are truly vertical.**

**Once the basement walls & internal columns are in place, the ground floor slab can be placed using the earth as formwork, but, suitable access holes must be left to allow excavation equipment to enter & conduct the basement excavation.**

At this point, since all the foundation systems are essentially in place, **construction of the superstructure can begin even though the excavation of the basement is not complete.**

This can obviously **speed the construction of a complete bldg significantly.**

The **ground floor slab provides the necessary lateral support to basement walls** removing the need for temporary support systems such as shores or ground anchors.

The basement excavation can now proceed to the level of the 1st basement floor.

This can once more be constructed using the earth as formwork.

Access must once more be left & the excavation can once more continue to the level of the 2nd basement floor.

And so on until the basement floor is reached.

Once the level of the floor is reached, the excavation plant must be removed.

Typically this is partially dismantled & then craned out through the access hole.

Once this is done, the basement floor can be placed & the access holes replaced by permanent floor slabs depending on the design of the bldg.

This process, although complex & requiring much planning, can significantly improve bldg delivery times.

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**Figure 3.10: Top down basement construction**
Next to explain the Evaluation, Recommendation and sketch, specific problems

Evaluation:

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diaphragm walling</td>
<td>$3x</td>
<td>x</td>
</tr>
<tr>
<td>Contiguous bored piling: c</td>
<td>$x</td>
<td>3x</td>
</tr>
<tr>
<td>Stent wall piling</td>
<td>$1.5x</td>
<td>1.5x</td>
</tr>
<tr>
<td>Secant wall piling</td>
<td>$3x</td>
<td>x</td>
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Recommendation:

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</table>

Reason: Due to speed as required (time restrictions), costs.

Specific Problems with each method:

1. **Contiguous Bored Piles (CBP):**
   - Have water tightness problem.
   - If the basement is submerged in ground with high water table, shotcreting followed by waterproofing membrane need to be applied or sprayed onto the surface of the CBP.

2. **Stent Wall Piling**
   - Need to set up water tank for the mixing of bentonite slurry.
   - Mixing of bentonite slurry and pumping of slurry into holes is messy for site.
   - Site will be very much water ponding every where
   - Site needs proper soil erosion control, else water draining out of site failed to meet statutory requirement

Sketches:

1. **Contiguous Bored Piles (Bored piles lined side by side, with capping beam on top )**
   To remove the ground anchors

2. **Stent Wall Piling (A: Bentonite slurry piles, B: Bored Pile)**
Q2  Roof Coverings and Green Roofs

(a) The client needs advice on their choice of roof coverings for the office development buildings shown in figures 1 and 2. Initially, they are considering how appropriate it is to use a flat roof construction, and they are unsure of the choices available. Compare and contrast in a brief report to your client discussing the two choices of flat roof construction that you consider are appropriate. (15 marks)

(b) The client for the office development is also keen to incorporate green and sustainable technologies within their new building. Explain to the client with supporting annotated sketches, the main advantages and technical challenges that a green roof may offer the client if incorporated on the new office buildings. (18 marks)

Q3  Cladding and Double skin facades

(a) The client is unsure of the performance requirements for any cladding system. Fully explain to the client the performance requirements that the glass cladding system must accomplish and discuss in detail how each performance requirement would be satisfied. (13 marks)

There are three set of keywords: client is unsure, glass cladding, performance requirement
There are Two set of instructions: fully explain performance requirements of glass cladding, discuss in details how requirement would be satisfied.
In this case, we explain the glass cladding performance requirements:

Performance Requirements of Glass Cladding

Load Transfer
Support and transfer wind loads to the structural frame & subsequently to the foundations

Thermal Insulation
Restrict heat transfer and excessive solar heat gain into the cooled air-conditioned indoor environment.

Temperature Movement
Capable of coping with expansion & contraction forces due to changes in external temperature.

Relative Movement
Able to cope with relative movement between itself and the structural frame.

Weather Exclusion
Prevent the ingress of wind driven rain or air.

Sound Insulation
Prevent sound penetration in both directions between internal & external environments.

Ventilation
Control the amount of outside air infiltrated into or alternatively to prevent room air leaking out of an air conditioned building.

**Openings**
Reduce excessive solar glare on work surfaces through windows.

And how these performance requirements are met in five of the criteria:

**Meeting these Performance Criteria for Glass Cladding:**

1. **Preventing moisture ingress**
   - Neoprene or EDPM gaskets are used to seal all joints between mullions, transoms & glazing/infill panels.
   - Details depend on manufacturer & their particular recommended design details.

2. **Preventing air infiltration and wind penetration**
   - Neoprene or EDPM gaskets are used to prevent excessive air penetration.

3. **Thermal Performance**
   - Insulation is generally incorporated within infill panels between separate rows of glazing.
   - Glazing units will be doubled or triple glazed.

4. **Prevention of excessive solar heat gain/glare**
   - Glazing can be treated with a low emissivity coating & manufacturers (Pilkington & Saint-Gobain) produce special glazing units to deal with the problems raised by solar heat gain.

5. **Acoustic performance**
   - Curtain walling does not perform well in relation to acoustic criteria.
   - Thus, acoustic glass or thicker glass sections may be used to improve performance.
   - Triple glazing may also be used or a continuous air gap may be provided.

(b) With the aid of fully annotated sketches, to an approximate scale of 1: 10, illustrate the methods of supporting the glass which would be suitable in the proposed office development. Sketches should clearly indicate a typical interface between glazing and main structure of the building. (10 marks)

There are Two set of instructions: Illustrate Methods of supporting glass for office development, sketches indicate typical interface between glazing and main structure

The method proposed will be the unitized method, but you need to explain the existing methods available.

*Main approaches to the provision of Glass Curtain Walling:*

- **Stick Method**
- **Unit System**
- **Unit & Mullion System**

**Proposal**
Since this is an office development, we could select unit system.

**Unit System**
- Large factory *assembled units are attached to the frame* in the same manner as precast concrete cladding panels.
- Vertical edges may form mullions & horizontal edges interlock to *provide a concealed joint and allow for thermal movement*.
- This system has the *merit of factory-controlled production*, but the size of the individual units can increase transportation requirements & plant on site.

**Reasons for selecting unit system**
Unit system enables better quality control, as the production is done in factory environment. The only worry is the size of the panel that would be loaded up onto the trailer for transportation to the site.

![Typical isometric of the mullion/ transom intersection in a curtain wall.](image-url)
Typical vertical cross-section showing a curtain wall being secured back to the structural floor slab. Note the detail at the edge of the intermediate floor which closes the gap around the edge of the floor.

(c) The client is interested in incorporating a double skin façade into the design. Provide guidance to the client detailing what is meant by the term “double skin façade”. Also evaluate the main technical challenges that could be expected by adopting this approach for the proposed office development.

There are four set of keywords: double skin façade, client unsure meaning of double skin façade, main technical challenges, office development

There are Two set of instructions: meaning of double skin façade, evaluate main technical challenges expected for double skin façade.

In this case, we explain the meaning of double skin façade first:

**Double Skin Façade:**
- In simple terms a building employing a double façade has two separate (but interconnected) cladding layers or skins and having significant air gap between the two.
- Both skins are connected back to the structural frame.
- Normally the inner skin can be secured using the normal cladding fixing techniques.
- More complex outrigger beams or trusses are normally necessary to hold the outer skin and secure it back to the structure.
- Alternatively, the outer skin could be designed as a freestanding wall that is not directly connected back to the structural frame at storey height intervals.
• Various different combinations of materials can be used for each facade; two skins of glass is particularly common, but an outer layer of glass used in conjunction with a solid inner skin is also popular.
• In between the two skins there is an area for vertical air circulation. There are different ways in which this air circulation space can be used, but in the simplest analysis, the circulation utilises the stack effect to draw air into the building, so that the internal space within the building can be naturally ventilated. This means that there is no need for air conditioning or mechanical ventilation within the building which can reduce the servicing and energy costs associated with the use of the finished building.
• To allow the natural ventilation to take place, the inner skin must have a series of openings. These may be manually operated, such as ordinary windows, or, in more complex systems will be automatically controlled openings or windows that are opened and closed by a building management system as and when required to optimise ventilation flow.

Main Technical Challenges:
• Difficulties faced by design consultants in selecting suitable double façade material and supporting structures as not many case studies or projects for consultants to take reference from
• Difficulties in securing the outer skin back to the structure
• Difficulties in demarcating and sorting the façade panels on site, especially when the site has space constraints
• Fire spreading throughout the building, due to stack effect
• Difficulties in maintaining (cleaning) the outer skin due to difficulties in securing anchoring points
• Difficulties in maintaining (cleaning) the space between inner skin and outer façade, due to congestion of supporting structures between inner and outer façade.

Q4 Advanced Foundations
You have been asked to provide advice to the client concerning the foundation system for the new office building. The three office towers shown in figure 1 and 2 are to be built upon a soil having the following composition:

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 m – 1.30 m</td>
<td>loose fill material of low bearing capacity</td>
</tr>
<tr>
<td>1.30 m – 2.50 m</td>
<td>sandy clay of moderate bearing capacity</td>
</tr>
<tr>
<td>2.50 m – 11.50 m</td>
<td>clay of moderate bearing capacity</td>
</tr>
<tr>
<td>11.50 m – 18.00 m</td>
<td>boulder clay with high bearing capacity</td>
</tr>
</tbody>
</table>

The water table is located at 3.50 m below the ground level.

(a) Fully describe the main performance requirements that the foundation system must achieve for the new office development consisting of three towers shown in figure 1 and 2. (18 marks)

There are four set of keywords: new office building, three office towers, boulder at 18m, water table at 3.50m below ground.
There are one set of instruction: Fully describe main performance requirements of foundation system for the new office development consisting of 3 towers.

In this case, we explain the foundation system performance requirements:

**Performance Requirements of Foundation System** for the three office towers:

- The foundation is required to safely transfer the loads carried by a bldg to the ground & to ensure that these loads are appropriately distributed thru’ the ground where the bldg rests.
- The *foundations must also resist the forces set up by settlement, differential movement, subsidence and other possible ground movements (e.g. earthquakes)*. In designing to allow for resistance to differential settlement, the following issues should be considered. Attempts should be made to *avoid differential settlement* as far as possible thru’ appropriate design of the bldg superstructure. This can be done by attempting to *ensure* that the *loads transferred down each column are pretty much equal*.
- There is bound to have differential settlement due to the weight imposed by the three towers of different height. As such the foundation system is to be designed to cater for these differential settlements.
- The foundation must be designed to withstand the *wind loads & other forces* acting upon the bldg.
- As the water table is 3.50 m below the ground level, there is this uplift force. The *foundation is required to provide resistance to uplift forces* that may exert themselves upon large, particularly tall bldgs. The *location of the water table* can have a particularly significant impact upon the design of foundations since the bearing capacity can be *affected by as much as 50%* depending on whether or not the water table is well beneath the base of the foundation or whether it is at ground level. *As such, the design of the piles must cater for this 50% reduction in capacity.*
- As soil mechanics is a relatively approx. science in as much as that many of the variables require be estimated approximately, the *factors of safety* tend to be relatively large, in the order of 3.0 to 3.5. These factors are important but in the main the engineering design responsibility belongs to the structural engineer. It is this pressure that the foundation must be designed to so that the *actual force applied to the soil is in the region of 1/3 less than the pressure that would cause the soil to enter a failure mode.*

(b) Critically evaluate and sketch with full annotations, three alternative foundation systems that could be considered for use in new office development shown on figure 1 and 2, based upon the above soil and water table conditions. (15 marks)

There are four set of keywords: new office building, three office towers, boulder at 18m, water table at 3.50m below ground, three foundation systems

There are six set of instructions: 1. Critically evaluate and 2. sketch with full annotations, for three foundation systems.

**Typical Replacement Piles / Bored Piles**

**Approach 1 – Bored Piles**

These piles act only in an end-bearing manner, and acting as replacement piles. They are appropriate for sites constrained by existing bldgs or by other considerations that may limit the noise & vibration pollution
that is typically associated with driven & driven tube piles. In essence bored piles are formed by drilling the hole into the ground & removing the spoil. Re-bars & concrete can then be placed & the pile foundation is formed relatively easily with comparatively little noise & vibration. There are a number of methods appropriate for drilling & placing the piles; these are discussed in the notes dealing with the installation of foundation systems. 'cause these piles act only in an end-bearing fashion they spread the loads at their base in the same manner as the near surface spread foundations discussed earlier. This means that there is a benefit associated with enlarging the toe of end-bearing piles since the larger the bearing area the lesser are the stresses imposed on the soil. This allows the piles to be sunk to lesser depths than may otherwise be the case. The process of enlarging the base of end-bearing piles is known as ‘under-reaming’ & under-reamed piles are illustrated below. The process of installing an under-reamed pile is described in the note concerning installation.

Approach 2 – Raft Foundations of Slab and beam raft foundation

This method can be used, provided engineer designing the raft foundation cater for the differential settlement.

Raft foundations can be used to smooth the construction process where the structure is a simple grid of relatively closely spaced columns. In these cases an overall raft avoids disruption and inconveniences that are associated with a relatively large number of excavations for large numbers of independent pad foundations and ground beams. It is sometimes suggested that if more than 50% of the footprint of the building is going to be occupied by individual pad footings or by wide strip footings, it will be more economical to provide an overall raft foundation instead. This is not always true since a raft carrying unequal column loads required complex reinforcement to avoid unacceptable cracking and deflection, however, in the case where column loads are pretty much equal the raft will often present a more economic solution. The rafts that have been illustrated so far are suitable for carrying lightweight, low rise structures, however, to support loads imposed by larger, more substantial structures, these rafts would require to be substantially thicker. They would quickly become uneconomic in the case of larger buildings.
In practice, the most common solution for driven piled foundations to medium to large scale bldgs will be to use concrete.

Precast concrete piles for driving come in a variety of shapes & forms.

They may be square, rectangular, circular & they may be solid in section or they may be hollow.

Precast concrete piles are typically 15 to 18m long. Since for this case, it is 18m, select piles of 18 m length.

Re-bars in precast piles must be arranged in such a way as to resist the loads that are to be placed on them by the bldg columns in addition to resisting forces & stresses that are set up during transportation & driving.

Driven piles are most appropriate for sites that are relatively unconstrained, that is green or brown field sites that are not located in constrained urban sites with many existing bldgs in close proximity.

This is simply 'cause much noise pollution is generated by the driving process & the vibration caused may damage finishing & fitting in adjacent bldgs.
**Evaluation and Recommendation**

All these three methods are suitable for this particular scenario. The consideration factors are 18 m depth hardrock, 3.5m water table below ground level. For economical reason, the concrete driven displacement pile foundation is recommended, as for normal case, the cost for driving driving one bored pile to 18m is equivalent to driving 4 nos of concrete piles. After considering the fact that due to the uplift, the skin friction is cut down by very as much as 50%. This will mean driving one bored pile equivalent to driving one concrete displacement pile. The consideration factor will be:

i) If Cost is the consideration factor, choose concrete driven displacement pile

ii) If noise is a concern, choose bored pile to comply to statutory requirement.

**Q5 Structural Frame**

The proposed office development that is shown in Figure 1 and 2 needs to be constructed quickly, with only a small amount of storage space available on site for materials. The client has very strict quality constraints and is happy to consider construction methods embracing prefabrication offsite.

(a) Advise the client which structural frame materials and framing system are appropriate, based upon client information above. Recommend one material and frame system for use on the project. Include sketches with full annotations to show how the frame components will interface. (33 marks)

There are five set of keywords: new office building, constructed quickly, small amount of storage space, strict quality constraints, prefabrication offsite.

There are three set of instruction: which structural frame materials, framing system, sketches with full annotations how frame components interface.

**Choice of Steel Frame or in-Situ Concrete Frame and Material**

The issues that must be addressed in considering the selection of an appropriate Structural Frame system for a large commercial building are basically as follows:
A key aim in a skeleton frame is 'structural efficiency'. A frame's efficiency is a function of its own self weight, its strength and the loads that it is capable of supporting. We need to consider that a buildings cost will increase significantly with its height. Frames need to be very cleverly optimised so that their strength to weight ratio can be as efficient as possible.

Second issue concerns construction efficiency, Construction Method and Speed of Construction.
This concerns the economy (or cost) with which the frame can be erected and the way in which the frame interacts with all of the other construction components which must be attached to it to produce a completed building.

- Advantages and Disadvantages of either Concrete or steel frames
- Fire Protection
- Design of the frame as a total structure – Whole Frame Action
- Resistance to wind pressure & overturning moments
- Layout of the structural members – The Structural Grid
- Availability of Materials and Labour
- Cost
- Ability to Standardise
- Size and Nature of Site

Framing System Considered:
Either one of the following methods may be used:

Structural Steel frames encased in fire resistant materials (e.g. Vermiculite), with composite cast-in situ concrete slab on Spandek formwork. False ceiling will cover up the underneath of Spandek.
i) **SlimFlorR and SlimDekTM steel systems**

- *Floor structure is contained within the depth of the structural beams* and the floor and beams work together as a composite structure.
- *Advantage of reducing the structural floor depth* in framed structures is that the overall height of a given building can be reduced, leading to an additional storey can be incorporated into a building, which means client could offer *additional rentable or useable space* for relatively little additional cost.

ii) **In situ reinforced concrete slabs built off permanent formwork.**

- *Shear studs* may be welded to the flanges of beams under factory conditions as part of the prefabrication process, which allows a *robust connection* between the top flanges of beams and the in situ structural floor.
- Allows the beams to be laterally restrained and allows the floor to act as a diaphragm transferring horizontal wind forces between columns and to cores and shear walls.
- Floor now contributes to the overall robustness of the frame system and this allows the *structural steel sections to be less deep*, which means *less weight of steel* which in turn means *less cost and greater efficiency*.
- Typical depth for a floor slab of this type would be 100mm to 225mm.
- Spans of up to 12m can be achieved.
Frame Components Interface

1. **Beam – Column connection**

   ![Diagram](image1)
   
   (a) Simply supported steel beam/ column connection

2. **Beam – Beam Connection**

   ![Diagram](image2)
   
   - Web cleats
   - Flange cleats
   - End plate
   - Flange plates
   - T- sections

3. **Beam – Slab Connection**

   ![Diagram](image3)

Figure 1  Connections in a multi-storey frame
4. **Column-Column Connection**

5. **Column-Foundation Connection**