The Construction of Deep and Complex Basements and underground structures within extremely difficult urban environment

by Raymond W M Wong
Attributes that affect the construction of deep basement:

1. Size of a site
2. Volume of work
3. Shape and Typographical conditions of site
4. Neighbourhood conditions of a site
5. Geotechnical conditions
6. Internal layout of the basement or other related structures
7. Availability of resources for the project
8. Availability of expertise skill
9. Appropriateness of the methods selected for the construction
10. Special performance requirements imposed
Besides, there are situations like:

- where a new basement is required to construct simultaneously to replace an old one.
- working under very fast-track schedule.
- some basement works need to be carried out at the same time with the new foundation or even with part of the future superstructure.

This situations will create very difficult coordination problems that involve various contractors and complicate the contractual position of the entire job.
Examples of projects – working in close proximity of sensitive and unstable slope

Hollywood Terrace

Belcher’s Garden
Example of very large-scale project – the Hollywood Plaza
Basement Project in very congested urban environment – the Redevelopment of Kwong On Bank in Queen’s Road Central, Central District, Hong Kong
Examples of very difficult environment for constructing basement

- Work in close proximity to seawall
- Work in extremely small site
Complicated soil support arrangement
Large-scale basement project involved very complex phasing planning

Royal Peninsula

Festival Walk
Site formation, slope work and basement construction work at the same time under carefully planned phasing arrangement.
Large-scale basement project involved very complex phasing planning

Traffic roundabout and related development
Large-scale basement project involved very complex phasing planning.
Complicated phasing arrangement in constructing the basement of Lee Garden
The Center - Foundation and Basement construction arrangement
Underground services encountered during excavation
Complicated surrounding environment as seen in the TST East Station – underpinning to a section of pedestrian subway
Common managerial problems identified in the construction of deep basement:

1. - Very expensive and time consuming in nature, often involved huge amount of work resources.

2. - Inconsistent and sensitive to the quality of planning and management of individual projects.

3. - Works are highly hazardous, both to human operatives working within and the life and properties of third parties that within the vicinity.

4. - Works involved a lot of managerial challenges. Such as, in the preparation of a highly efficient working programme, monitoring and rectifying the progress of works in case problems arising, or in resources planning where materials, labours & plant equipment are involved.
There are many methods to construct large-scaled and deep basement

1. Deep basement can be constructed using some traditional ways such as cut & fill or bottom up methods. These methods are relatively economical and effective when dealing with certain jobs which are simpler in nature.

2. On the other hand where basement is going deeper and the surrounding environment getting more complex and sensitive, top-down or combined method may be a more appropriate option to construct.
Construction of basement using traditional bottom-up arrangement

Church for the Witness of the Christ Project

Redevelopment of the Lee Theatre
Example of very large-scale and complicated project – the Hang Hau Station of the MTR Tseung Kwan O Line
Other considerations when doing basement works

• Accurate cost analysis or work study is difficult to carry out for there is limited commonality to make comparisons.
• Every project, though look relatively similar from certain indicating factors, is in fact unique in itself.
• A great number of random and uncontrollable variances are likely to arise during the courses of work. This makes planning and scheduling almost cannot be exact.
• The actual effectiveness of works is highly depended on the as-constructed site environments.
• Quality of the management and the executing parties, as well as the problems solving ability of the frontline personnel, also seriously affects the performance and effectiveness of works.
Commonality found in recent basement projects

- Recent basement projects are usually very deep (below 20m) and very big in size (say up to 10,000m²)
- Majority of the basements are constructed in a top-down manner. Some other methods such as combining top-down and bottom up, or combining open-cut and top-down arrangement, can sometimes be seen.
- Complicated coordination problems and teething arrangement often exist between various major contracts or other major building works.
- Layout planning especially in phasing and sectioning of the job forms a very important consideration mastering the success of the project.
An extremely large-scale and complex project – Construction of the International Finance Centre Phase II

(Top-down for the podium portion and bottom up for the building core portion)
Examples of very complicated phasing arrangement during the basement construction

Festival Walk

Lee Gardens Redevelopment
Commonality found in recent basement projects (Cont.)

- Dynamic layout arrangement is usually required for the removal of the excavated spoil from the basement. This may involve the forming of temporary ramp, provision of special equipment, or the taking over of part of the completed building as temporary access in an advanced stage.

- Diaphragm walling is the most common cut-off provision being used.

- System formwork can hardly be applied for most basement jobs due to access problems as well as the confined working condition inside the excavated.
Commonality found in recent basement projects (Cont.)

- Constructing the basement in “double bit” arrangement is becoming common.

- Protection and safety measures in particular to the life and property of third parties are highly concerned in basement jobs. Accident in this area is maintained at a relatively very low rate.

- Progress of work can hardly be predicted or monitored accurately due to the existence of numerous unforeseeable problems during the construction process.
Special arrangement for the removal of spoil to facilitate basement excavation
Basement construction using “Double Bit” arrangement – i.e. excavate two levels of basement, form the lower slab and fill in the intermediate level at a later stage.
Construction of Deep Basement and Large-sized Underground Structures

Examples of underground structures include:

- Basement of buildings
- Semi-basement with slope stabilization purpose
- Transport facilities such as railway station, tunnel and pedestrian subway
- Access or services shaft
Construction of Deep Basement and Large-sized Underground Structures

Involvement/provision when constructing these structures

- Ground stabilization provisions
- Cut-off walling provisions
- Lateral soil support provisions
- Excavation arrangement
- Dewatering arrangement
- Spoil removal arrangement
- Basement construction arrangement
Ground stabilization

Usually grouting method is used to stabilize ground weaker in nature. Grout is a kind of fluid form material for injecting into the sub-soil. The material can be of cement or chemical base. It can get hydrated inside the soil and make the sub-soil much stronger to withstand itself or to resist penetration of ground water.
Cut-off wall can be constructed using the below methods

- Sheet pile
- Soldier pile
- Hand-dug caisson
- Bore pile
  - continual pile
  - lagged pile
- Mini-pile or pipe pile
- Diaphragm wall
Excavation to start later within the area line-up with sheet pile wall
Close-up detail showing the sheet pile section

Using sheet pile as side support
Steel H-pile as vertical main support

Lagging material to kind the soil behind from collapsing

Lagging material is to seal up the gap between two H-pile. It can be of steel plate, steel channel, timber or precast concrete plank

Soldier-pile wall
Addition support to sheet pile using raking shore that rested onto a firm temporary pile

Addition support to sheet pile using ground anchor
Cut-off walling provision using sheet pile (above) and soldier pile (below)

**Sheet Pile**

**Soldier Wall**

Wood Plank, precast concrete planks or steel channel etc.
Cut-off walling provision using various forms of bore pile

In-situ concrete piles, grouted tube or other mini pipe systems

CONTIGUOUS PILES

Protective concrete rings

CONTIGUOUS CAISSONS

CAISSONS WITH IN-FILLING WALL
Using bore-pile as side support
Using bore pile as side support

- Hand-dug Caisson wall
- Large-diameter bore-pile wall
- Lagged bore-pile wall
Using pipe-pile as side support

After the driving in of the steel piles/tubes, steel bars will be inserted into the pile and then grouted. It will become a relatively cheap but strong support suitable for use in excavation support up to 12m deep.
Grouted sub-soil to improve its stability when exposed during excavation
A cut-off wall cannot stand alone stably without a lateral support system. This lateral support can be provided in the form of ground anchor, using a steel stud frame or rows of steel tubes.
Lateral support using steel tube

Using steel strut

Lateral support using steel tube
Typical composition of a lateral support system

1. Diagonal bracing
2. Strut member
3. King post
4. Work platform
5. Waling
Other large-scale basement excavation/support example – Ho Man tin Residential development
Excavation arrangement –

To plan how to carry out the excavation using carefully sectioning, phasing and scheduling of works

Excavation in section as in congested site

Excavation in benched arrangement for open site
Dewatering

Ground water exists usually within a few metres down from the ground surface in Hong Kong depending on which season it is.

An imaginary line called water table usually referred to indicate the level of the underground water. Soil above the water table is with water under a non-saturated condition. Below which water is over-saturated. That means, when there is a void exists below the water table, water will leak out toward the void for the soil cannot hold any extra water.

This is the principle of dewatering, a process to remove the over-saturated water in ground and keep the subsoil within a non-saturated condition.
Dewatering arrangement using well point
Active dewatering method using suction type well point
Dewatering arrangement

Active dewatering method using suction type well point

Passive dewatering method using sump pit

Water rush-in from gap of sheet pile wall – water is drained to a sump pit and pumped out using a submersible pump
Soil removal arrangement

Removing the excavated material from the basement pit is not an easy joy because of the quantity and mass of soil to be removed. We are talking sometimes about a few 10,000 m³ of soil to be handled having a density of about 2 tons per m³.

Removal of excavated spoil using grab mounted on gantry crane

Removal of spoil using excavating machine placed on staged platform
Mobile crane for the handling of heavy material and equipment including the hoisting up of excavated soil.

Lift Bucket to take up excavated spoil from the basement pit.
Methods for basement construction

Basement or similar underground structures can be constructed using the following approaches:

1. Open cut arrangement
2. Bottom-up arrangement
3. Top-down arrangement
Construction of basement using open-cut approach
- suitable for site with abandon of unobstructed working space

Example of open-cut arrangement for the construction of the Kowloon Station of the Airport Railway
Construction of basement using bottom-up approach
- Redevelopment of TST Hyatt Hotel
The 12th month

The 15th month
Example of a semi open-cut arrangement method for the construction of a residential project at To Kwa Wan.
Close-up look of the complicated shoring system with the integrating detail with the approaching basement structure
Close-up look of the complicated shoring system with the integrating detail with the approaching basement structure.
Construction of basement using Bottom-up approach
- suitable for basement of small to medium size

Case example: The Witness of the Christ Church project in Kowloon Tong
Construction of basement using Bottom-up approach
- A much complicated case (Langham Place)
Provision of a work platform for the stationing of equipment and handling of spoil to facilitate the excavation process
Constructing the basement from bottom up
Construction of basement using Top-down approach
- suitable for basement of very large size, deep and with complex environment

Steel column (stanchion) erected in advance and rest on bore-pile below as support to the top-down basement

Typical Top-down arrangement as in Pioneer Center (left) and Cheung Kong Center projects
Typical Top-down construction arrangement as in Langham Place project
Construction of basement using Bottom-up approach
- A much complicated case for large area site with multi-phases to speed-up works

July 2010
Construction of basement using Bottom-up approach
- A much complicated case for large area site with multi-phases to speed-up works

December 2010
Construction of basement using Bottom-up approach
- Extension for St Paul Hospital
Construction of basement using Bottom-up approach
- Extension for St Paul Hospital
Compare the features of various basement construction methods

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Conclusion

1. The construction of basement bears a very spectacular status in the entire construction process. It often marks the success of a project in terms of:
   - profitability,
   - effective use of valuable resources,
   - ensurance of contract time,
   - quality and safety considerations.

2. Various professions would have their own involvement in the basement construction process and each of them has their own concerns. It is not easy to formulate a simple yet straightforward solution to get everything right.

3. Better understanding of the variety of possible methods and practices, as well as knowing the constraints when handling basement works, there is higher chance to complete the work with a more acceptable result.
Conclusion (Cont.)

4. Single-issued methodology or managerial system can hardly serve the targets of completing a relatively large-scaled yet complex basement project.

5. A highly dynamic, tailor-made and quick-responded approach may be the most workable way in solving problems in basement construction.

6. The competency and practical experience of the key players work in accordance to the unique physical environments and other confining conditions inherited in each project is very helpful.

7. Abundant supply of resources, strong support in IT and computer facilities, or even with plentiful funding backup, may not be a guarantee to the success of basement projects.
Project Case 1 – Urban Renewal Authority’s Redevelopment project at Wanchai Road, H K

- Site area 7500 m² (divided into 2 sites by the Wanchai Road)
- the site was previous occupied by a series of pre-war buildings or buildings that was built in the early 1960’s
- There is a 3-level basement to be built in one sites
- Foundation was carried out before the construction of the basement
- A bottom-up method is employed for the basement construction, with sides supported by pipe-pile/sheet pile, and strutted by modulated strut sections.
URA’s Redevelopment at Wanchai Road, H K

Pipe-pile as cut-off walling

Bored-pile being exposed at formation level

Modulated strut members
URA’s Redevelopment at Wanchai Road, H K

Working platform is set up to facilitate the basement construction works
Baseline structure constructed using traditional formwork from the formation level upward.
Construct the basement structure inside the congested basement pit
URA’s Redevelopment at Wanchai Road, H K

Inside the properly supported basement pit before the construction of the main basement structure.

Construct the basement structure inside the congested basement pit with layers of strut frame and open area for material delivery.
URA's Redevelopment at Wanchai Road, H K

Working inside the congested basement pit
URA’s Redevelopment at Wanchai Road, H K

- Basement floor support by traditional prop system
- Obstruction caused by the lateral supporting shore work need careful planning for the phasing and sectioning of the formwork layout
- Basement wall after erecting formwork
URA’s Redevelopment project at Wanchai Road, H K

Basement close to its topping out at ground level
Project Case 2 – Redevelopment of Lee Garden’s Hotel

• Site area 5,750 m²
• the project required to demolish the 22-storey Lee Garden Hotel, with a 2-level basement structure in it. A new 50-storey office building together with a 4-level basement will be built.
• All the new foundations and the required ground strengthening and permanent basement supporting works had to be carried out in the old basement before it was demolished.
• The old basement could only be demolished in small sections to allow for room and to cope with other associated works.
• When part of the basement was demolished and cleared, temporary or sometime permanent supporting structures have to be built as soon as possible to infill the void until the old basement was completely replaced by the new.
• Provisions were made for the construction of the future building including the central core in RC and part of the new basement constructed in top-down manner.
Demolish the central part of the old basement and excavate further down to form a pit to construct the raft for the core wall of the new building.
Demolition extended to the outer portion of the old basement and raft foundation in the centre for the core wall proceeded.
80% of the old basement structure being demolished, cut-off wall being completed, and steel columns for the new tower erected in position.
Close up view seeing the construction of the new core wall from the completed raft foundation. Demolition to the remaining portion of the basement in progress.
Shoring arrangement at the central pit where the new raft foundation was located
Forming the new ground floor slab and the demolition of the remaining portion of old basement took place at the same time.
Construction of the new basement slab to replace the old basement structure in phases
Superstructure and basement construction at the same time
Excavation inside the top-down basement

Forming the ground beams at the formation level of the lowest basement level
Project Case 3 – Festival Walk (Commercial Complex)

- Site area 21,000 sq m.
- Two major railway systems running nearby:
  - Kowloon Canton Railway (KCR) running on one side
  - Mass Transit Railway (MTR) tunnel tube running across the site almost in the middle
- works sub-divided into two contracts
  - site formation (including cut-off walling and foundation)
  - basement and superstructure
- 4-level basement and 3-level semi-basement was built.
- Very shallow rockhead exists on several spots that involved a lot of underpinning work when constructing the basement
Stages 1 – forming of diaphragm wall
Stages 2 – forming of bored piles and early stage of site
Stages 3 – construct the first slab and commence top-down basement
Stages 4 – construct the superstructure and basement in extending phases.
Stages 5 – completing the superstructure and basement
Stages 6 – Final completion of the superstructure and basement

Atrium space
Early stage of site formation – by the time excavation to form the site, diaphragm wall construction and foundation works were carried out at the same time under carefully phased manner
Forming the site and with diaphragm wall as the side support

Protecting the MTR tunnel by forming a cut-off bored-pile wall on the sides
Site formation to the formation level where the basement work would be commenced
Provision to protect the servicing MTR pedestrian access shaft using part of the completed structure
Works around the MTR pedestrian access shaft

Bore-pile wall formed in advance to protect the pedestrian access shaft
Underpinning work at the base of the diaphragm wall along the Tat Chee Avenue side.

Rock cutting and excavation along the toe of diaphragm wall under TC Avenue carried out at a later phase due to shallow rock level.
Early stage of the basement construction and the forming of an access route into the basement to facilitate excavation.
Entrance arrangement to facilitate the basement excavation/construction
Forming of vehicular ramp (using top-down arrangement) as a means for access for spoil removal purpose during the basement excavation process at a later stage.
Construction of the superstructure and the top-down basement at its peak
Project Case 4 –
International Finance Center Phase II

- Overall site area: about 20000 sq m
- 5-level basement constructed using top-down arrangement
- basement works involved
  - portion under the Main Tower
  - portium under the retail podium
- a 71m diameter cofferdam down to – 35m was constructed to form the raft foundation for the building core of the Main Tower
- portion under the retail podium was constructed using top-down approach
- breaking through into the existing station concourse of the MTR lines took place inside the basement
Overall foundation and excavation layout
Stages of the top-down basement construction

Footnote: This drawing shows the process of building the basement in the IFC 2. The method of building this basement is using the top-down method. Firstly, workers will put the 72 bored pile to the soil, which is the foundation of the basement. Then, the workers will remove the top soil in the site to make the upper slab of the basement. After making the upper slab, workers will start to excavate the soil. Then they will excavate two floor level soil firstly. And then, they will make the floor of the level 3. Then, they will continue excavating the soil. The worker also excavates two floor level soil and building the lower level floor slab. After this, the worker will build the level 2 and level 4 floor slab at the same time. This method is called the double-bit method. It can save much construction time. This basement is used about 18 months to build.
THE CONSTRUCTION OF LINKING THREE BASEMENTS
(in CROSS -SECTION)

1. Firstly, assumed that the basement of carpark and 88-storey IFC II tower were finished, and it was started to construct the basement of the podium together with connection of three basements.

2. The podium was constructed using a top-down approach. And the construction of the basement was the breaking through between the podium and the main tower portions II. The diaphragm wall panels that formed the cut-off wall of the cofferdam were demolished by pneumatic breakers as the excavation proceeded in a top-down sequence.

3. The structure of the podium consists of a number of long-span beams with some up to 30m, as well as some atrium spaces with headroom up to 25.

4. All diaphragm wall panels that formed the cut-off wall of the cofferdam were demolished, and the basement can be linked.

Stage of basement construction – longitudinal section
The ground slab as the separating plate

Forming the ground floor slab as the first separating plate before the top-down excavation process
Forming the remaining portion of the ground slab after a suspension of about 2 years as seen in early 2000
Muck opening provided on the ground slab for the removal of spoil
Excavation inside the basement
Excavation down to the formation level with pile head exposed
The use of a material hoist for the removal of spoil from the basement interior
Constructing the basement structure

Construct the basement in a “double Bit” manner
Forming the basement slab and encasing the stanchion to form the column
Basement structure around the muck opening soon to complete, slab will be reinstated afterward
The forming of the vehicular ramp

The shaft lined by diaphragm wall forming the vehicular ramp into the basement carpark. The ramp serves also as an dump access during the basement excavation process.
Forming the circular ramp
Completing the ramp for temporary spoil removal purposes
End of Presentation