Deep Basement Construction Through an Existing Basemement at the Central Business District of Hong Kong

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ABSTRACT

In June 2002, a 32-storey high quality commercial building with a 3-level deep basement, namely Chater House, was completed. The Chater House site was previously occupied by the Swire House and its basement structure and foundations obstructed the construction of the new basement. Temporary pipe pile walls with grout curtain were used to facilitate local trimming/demolition of the existing basement slab and pile caps. Diaphragm walls were constructed through the locally demolished basement to retain the soils for the 15m deep excavation and the new basement was constructed by top-down construction method. In addition, the diaphragm walls and large diameter bored piles were constructed to support the vertical loads and wind shear from the superstructure.

This paper describes the geotechnical design aspects of the new development. The difficulties and special issues during the substructure construction works are also discussed. Instrumentation monitoring results are also reviewed and compared with the predicted movements.

INTRODUCTION

Chater House is a new 32-storey 134m high commercial building located in the centre of the Central Business District of Hong Kong. The new development also includes a 3-level 15m deep basement for underground parking. The site is approximately 50m x 70m and is surrounded by sensitive structures and utilities, including

- a Mass Transit Railway station and tunnel with running tracks at a distance of 4m from the construction works.
- a tall building supported by shallow friction piles at a distance of 4.5m.
- a pedestrian footbridge and a pedestrian passageway at a distance of 7m.

In addition, the site was formerly occupied by Swire House (built in 1960's), which had a one level basement and was supported on Franki piles. The existing basement and foundations imposed major obstructions to construction of the earth support wall, foundations and basement of the new development.

These site constraints were major challenges to both the design and the construction of substructure works. This paper describes the geotechnical design aspects of the new development. The difficulties and special issues during the substructure construction works are also discussed. Instrumentation monitoring results are also reviewed and compared with the predicted movements.

GROUND CONDITIONS

Twenty-eight vertical boreholes were sunk using rotary drilling method to identify the ground condition at the site. Trial pits were also excavated to locate the existing utilities and underground structures. The typical geological profile under the site consists of 8-10m of Fill, overlying 6-8m of Alluvium/Marine Deposits. Below these strata is varying thicknesses of the Completely and Highly Decomposed Granite layers. The ground surface of the site is at approximately elevation +4mPD.

The rockhead, defined as Grade III or better rock, dips rapidly across the site, varying from a depth of 30m on the east to 70m on the west. Where the rockhead is deep, a thick layer of core stones and grade III/IV materials are apparent. The groundwater table is at approximately +2mPD.

MAJOR CONSTRAINTS AND CONSIDERATIONS

Existing Foundations and Basement Structures

The site was occupied by the former Swire House, which was a 22-storey concrete building with one level of basement supported by 1130 nos. Franki Piles. These piles extended into the decomposed granite and beared approximately at elevations –13mPD to –15mPD (18m below ground surface). As indicated in Figure 1, the building occupied the entire limit of the site and was originally constructed in two concurrent phases during the sixties. The structure had a one level basement which occupied 60% of the plan area. The Phase I structure was supported on isolated pile caps and the Phase II structure was supported by a piled raft foundation. The Phase I pile caps ranged from 1.5m to 3.6m in thickness and the elevation of the base of the caps ranged from +1.2mPD to –2.0mPD. The Phase II raft was 2.6m thick with a soffit level at approximately –2.3mPD. These existing pile caps and raft of Swire House obstructed the construction of the new earth support wall and foundations.

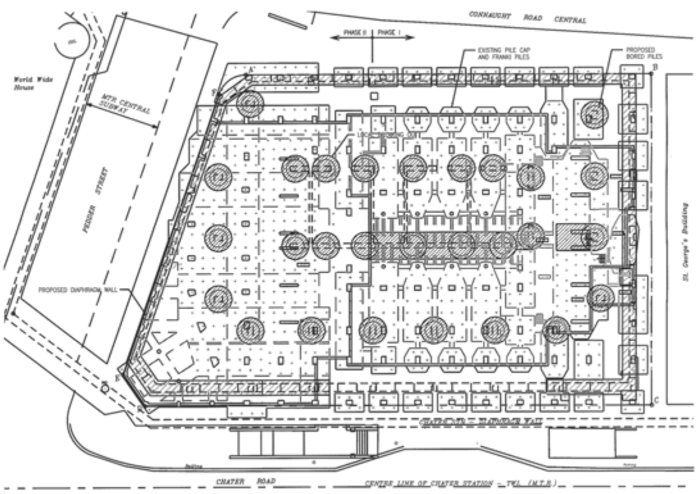

Fig. 1 : Site Layout, Existing Foundation and Proposed Works

Adjacent Structures

The adjacent structures requiring particular attention include :

1. St. George's Building along St. George's Lane: A 26-storey high building supported by Franki piles, which extended into CDG. The building is located 2.2m from the site boundary and 4.5m from the new basement.
2. MTR Central Station along Chater Road. The station box is supported by 1.2m thick diaphragm walls bearing on rock. The depth of the Station is approximately 26m. The clearance between the station and the site boundary is 2m.
3. MTR Central Subway along Pedder Street. The subway is a floating structure located 7m from site boundary with a bottom level at -10mPD. The slabs are connected to Worldwide House by 125mm key-in with dowel bars at the intermediate slab level.

4. Footbridge on friction piles and Pedder Street Underpass at Connaught Road.

The new basement of Chater House is 15m deep and during construction of the basement, movement of adjacent ground is inevitable. Therefore it is important that the design of the retaining structures, the supporting system and the method of construction to consider the effects to these adjacent structures and not to cause distress to these structures.

Figure 2 shows a section of the Central Station and the Chater House basement, with the existing Swire House basement and Franki piles.

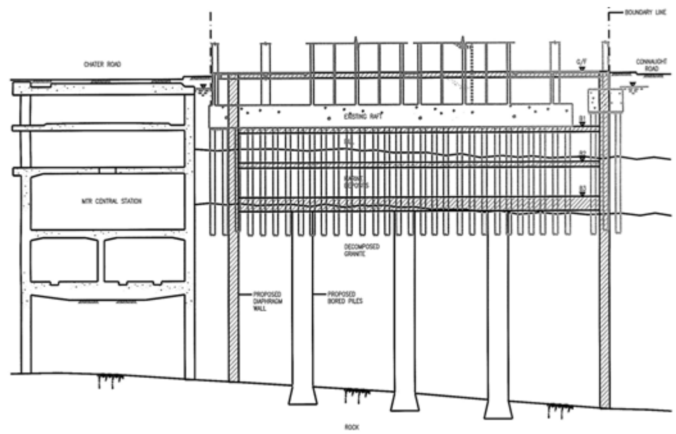

Fig. 2 : North-south Cross-Section

Construction Program

The demolition of the existing Swire House commenced in October 1998 and the new Chater House structure, both basement and the superstructure, was completed at the end of 2001. The design and construction of the basement has to consider this fast track program.

DESIGN

Foundations of Chater House

Large diameter bored piles together with the diaphragm wall were adopted as the foundation system to support the gravity loads of the superstructure. The bored piles ranged from 2.5m to 3.0m shaft diameter with bell-out to a maximum of 4.4m and were founded on Grade III or better rock. The maximum working capacity of the bored pile is 76 MN. To facilitate top down construction method, steel stanchions were installed to each of the bored piles. These stanchions were installed with very strict tolerance and were encased into the concrete core walls and columns of the permanent basement structure. A 16m long temporary steel casing was installed to the top of each bored pile to facilitate the installation of the stanchions.

Peripheral Wall and Construction Sequence of Chater House Basement

In view of the movement constraints of the surrounding structures, the depth of the excavation and to allow for a fast track construction of the superstructure, top-down construction method for the 15m deep basement was adopted. The ground floor slab at +4.0mPD and the B1 slab at -1.7 to –3.0mPD were cast to act as supports to the earth support wall prior to excavation below the slabs. After the base slab was cast, local pits 1.5m deep were dug down below the base slab for lift pit structures. The B2 slab at –6.3mPD was constructed bottom-up after completion of the base slab.

Once the ground floor slab was cast, the design allowed the construction of the superstructure concurrently with the basement excavation up to 10-storey high which was governed by the limitation on the induced horizontal stress onto the adjacent MTR structure due to wind shear. After the B1 slab in the basement was cast, the core wall between the B1 slab and the ground floor slab was also constructed to transfer the wind shear down to B1 level that could resist the wind loading of the superstructure, and the superstructure could be constructed to its final height while the basement was excavating below the B1 slab.

Cast in-situ diaphragm wall was used as earth support wall to support the excavation as well as permanent retaining wall of the basement. A 1.0m thick wall was designed along Pedder Street, Connaught Road and St. George's Lane. Along Chater Road, a 1.2m thick wall was adopted in view of complying with the strict movement criterion of the Central Station. The wall was also offset from the site boundary to create a 4m clearance zone from the Station and to avoid clashing with most of the existing piles. The diaphragm wall was designed using the Oasys program "FREW" (Pappin et al 1986). In this program the wall is represented as elastic beam elements joined at the nodes and the soil is represented as an elastic-plastic continuum with the soil stiffness matrices being developed from pre-stored stiffness matrices calculated using the Oasys geotechnical FE program "SAFE". The program analyses the behavior for each stage of the construction sequence. For general ground settlement around the site, an empirical approach based on the observations made by Humpheson el al. (1986) relating the lateral wall movement and the ground settlement was applied.

In order to support the top down construction slabs and the podium load, the diaphragm wall was also designed as vertical load bearing elements. The panels were founded on various materials, from CDG to Grade III rock, depending on the loading conditions and utilized end bearing to support the vertical loads.

The behavior of the Completely Decomposed Granite during diaphragm wall panel installation has been described by Davies and Henkel (1980). The decomposed granite is both relatively compressible and relatively permeable and this allows rapid swelling to occur in response to the stress relief accompanying trench excavation. This leads to the formation of a compressible zone adjacent to the diaphragm wall panel which recompresses as arching develops during construction of adjacent panels. The resulting horizontal ground movements lead to settlement at the ground. From previous studies by Davies and Henkel (1980) and Humpheson et al (1986), the induced ground movements are strongly influenced by the excess slurry head (i.e. difference between bentonite level and groundwater level) during excavation of the trench. To limit the effects of the adjacent ground and structures due the diaphragm wall installation, the diaphragm wall panel lengths along Pedder Street, St. George's Lane and Chater Road were limited to approximately 3m to reduce the arching loads onto adjacent panels. A 1.7m slurry head above the existing groundwater table was to be maintained.

The effects of diaphragm wall trenching and basement construction on the adjacent sensitive structures like the St. George's Building, the MTR Central Station and the pedestrian subway connecting Hong Kong Station were analyzed using "SAFE". The soils have been modeled as elastic-plastic materials with Mohr-Coulomb strength limits. Two dimensional plane strain analyses were carried out to assess the induced movements and angular distortion onto these structures.

Seepage analysis was carried out using the OASYS finite element program "SEEP" to investigate the piezometric and groundwater drawdown outside the excavation. From the analyses, the amount of drawdown, required pump capacity and the associated ground settlement could be determined. In order to ensure an effective seepage cut-off and limit groundwater drawdown, toe grouting below the diaphragm wall, in the form of chemical grout in soils and fissure grout in rock, was required to a depth of 5m into Grade III or better rock.

CONSTRUCTION

Demolition of the Existing Basement Structures

Local trimming/demolition of the existing basement structures and foundations formed part of the advance work in the Swire House demolition contract to facilitate the construction of the new peripheral diaphragm wall and bored piles construction. Where the existing basement wall could not be used to support the local trimming/demolition, pipe pile wall was installed along the perimeter of the site to enable the trimming works, as shown in Figure 3. The pipe pile wall also acted as the outer guide wall for the subsequent diaphragm wall construction. In some areas, the existing pile caps and raft were located along the pipe pile wall alignment and diamond coring through the reinforced concrete caps was required to permit penetration of the pipe piles. A grout curtain was installed by performing chemical grouting through the slotted pipe piles. The pipe pile wall was supported by raking steel struts prior to trimming of the existing basement wall, piled raft and pile caps (Plate 1). Where pumping of water was required, local sump pumps were used.

Following the removal of the existing pile caps and raft within the limits of the proposed diaphragm wall and bored pile locations, the local openings were then backfilled with a cohesive concrete/bentonite mix. The existing basement was then backfilled to ground surface level to allow access of diaphragm wall and bored pile construction equipments. The remaining existing pile caps and raft were removed during the top-down excavation of the new basement.

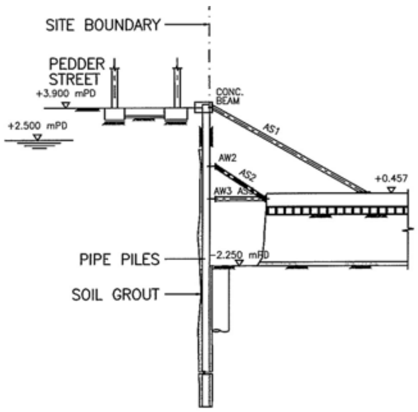

Fig. 3 : Pipe Pile Wall for Trimming Works

Plate 1 : Existing Basement Trimming Works

The installation of pipe pile wall commenced in October 1998 and was completed by March 1999. The local trimming and demolition works of the existing basement structures was carried out from June 1999 to August 1999.

<u>Bored Piles and Diaphragm Walls</u>

Due to the limited site area, the bored pile construction and the diaphragm wall construction were carried out sequentially. The bored pile works commenced in September 1999 and were completed by April 2000. The bored piles were constructed using traditional rotator and oscillator to advance the temporary steel casing in soils. Soils were removed using hammer grab. The shallow obstructions were overcome by chiselling while the deep obstructions and the rock socket for bell-out were penetrated by the Reverse Circulation Drilling (RCD) method. Diaphragm wall and toe grouting works commenced in March 2000 and were completed in September 2000 (Plate 2). In general, diaphragm wall was constructed by the hammer grabbing method. Along Chater Road, a mill type reverse circulation trench cutter "hydromill" was used to excavate the diaphragm wall panels in order to reduce the induced vibration to the existing MTR Central Station.

The existing Franki piles caused various degrees of difficulty for the foundation works especially in controlling the overbreaking and verticality of the diaphragm wall panels. Removal of the Franki piles was carried out by light chiselling, breaking up the piles into smaller pieces and removed using the grabs. Timber piles, which were used to support an old building, known as Union House, before Swire House was built, were also encountered and which obstructed the foundation works as well as the basement excavation.

Plate 2 : Aerial View of Foundation Construction

<u>Pumping Test and Groundwater Drawdown</u>

After the completion of the diaphragm wall, full size pumping tests were carried out to determine the performance of the cut-off system. The pumping tests were carried out in two stages in order to minimize the deflection of the diaphragm wall and the effects to the adjacent structures. The first stage was to dewater to –4mPD after the completion of the diaphragm wall. The second stage was to dewater to below the base slab at –12mPD after the completion of the ground floor slab.

The results of the Stage 2 pumping test revealed excessive drawdown along Chater Road while the targeted dewatering level within the basement construction had been reached. However, only slight ground and building movements were detected during the pumping test due to the excessive drawdown. It was considered that the excessive draw-down was due to confinement of the diaphragm walls surrounding the site and of the existing MTR Central station, which obstructed the natural recharging of the groundwater table.

As reported by Davies & Henkel (1980), the area had been subjected to substantial groundwater drawdown during the construction of the MTR Central Station and caissons of Worldwide House. Since the soils had been preloaded, the measured magnitude of the settlement due to the ground water drawdown was small.

From both the pumping test results and back-analysis, a recharge well system was proven to be an effective way to minimize the groundwater drawdown. New recharge wells were installed along Chater Road and together with the recharge wells installed along St. George's Lane, an active recharge well system was proposed to maintain the water level outside the site. The wells were switched on automatically when the groundwater level measured in the monitoring standpipes dropped below +0.1mPD.

Basement Excavation

During the Chater House basement excavation, demolition of the existing basement structures was carried out using backhoe and hydraulic breaker (Plate 3). Since the majority of the existing Swire House basement structures and piles were to be removed, the Chater House basement excavation program was relatively long compared to normal excavation works. The new basement structure, together with the superstructure, was completed in December 2001. This was followed by the building services work and the occupation permit was obtained in June 2002.

Plate 3 : Basement Excavation

INSTRUMENTATION AND MONTIORING

A comprehensive instrumentation monitoring program outside the site was carried out to monitor the behaviour of the adjacent structures and to ascertain the predicted movements would not be exceeded. Ground, utility and building settlement points, inclinometers, piezometers, and tiltmeters were installed to monitor the ground/utility settlements, building movements, groundwater levels and tilting of adjacent structures. Inclinometers were also installed into the diaphragm wall panels to monitor the deflection of the wall. Observation wells were installed within the site to monitor the water level during the pumping tests and subsequent dewatering. In addition, vibration monitoring around the site was carried out to monitor the degree of vibration due to various construction activities.

Figure 4 shows the trend of ground settlement at different stages of construction. The ground settlement caused by the diaphragm wall installation attributed about 40% of the total ground settlement, while the basement excavation attributed to 50% of the total ground settlement.

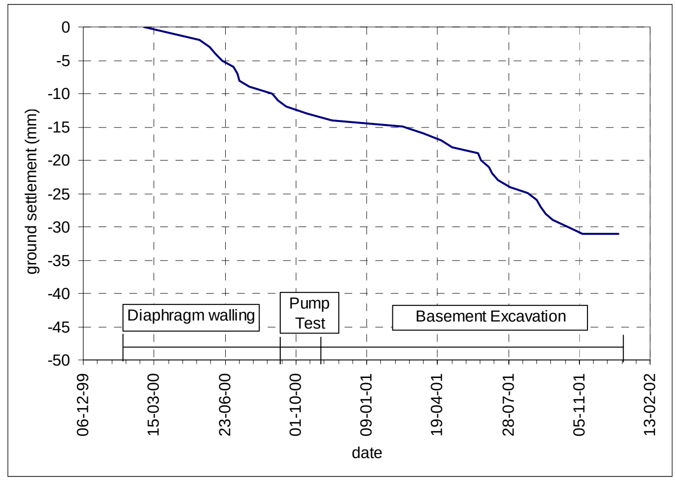

Fig. 4 : Ground Settlement Trend

Table 1 summarizes the ground settlement at different areas caused by the diaphragm wall installation. It is observed that the measured ground settlements are about half of the predicted values which were based on the findings of the trial panels as reported by Davies and Henkel (1980) during the construction of the MTR Central Station. This could be due to the fact that the completely decomposed granite at the site is of less clayey which attributes less swelling and the beneficial effect caused by the existing Franki pile foundations within and around the site.

Area	Maximum panel length (m)	Settlement (mm)	
		Predicted	Measured
Connaught Road	6.2	25	12
Other areas	3.0	12	6

Table 1 : Summary of ground settlement induced by diaphragm wall installation

It is also noted that the settlement due to dewatering (pumping test) is negligible. This can be explained by the site and the surrounding areas are pre-loaded and experienced significant groundwater drawdown due to the construction activities nearby, including the construction of MTR Central Station (Davies and Henkel (1980)), basement construction of the St.

George's Building, Pedder Street Underpass and MTR Central Subway.

The predicted and measured diaphragm wall lateral movement at Pedder Street during basement excavation is shown in Figure 5. The predicted and measured displacements at the adjacent ground and structures are compared and summarized in Table 2.

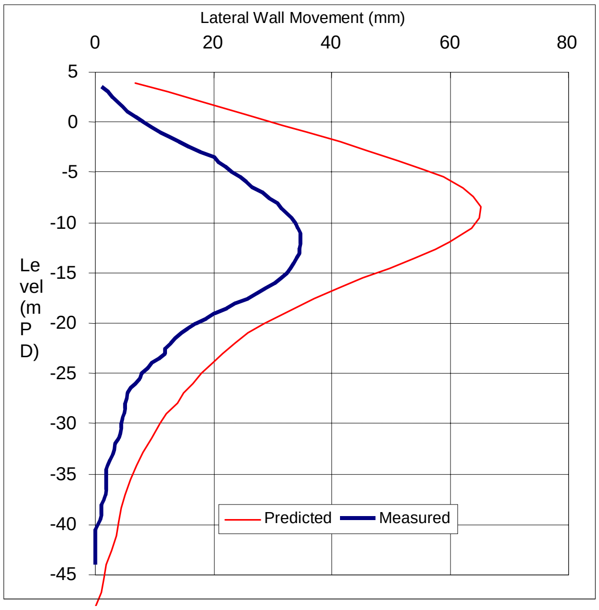

Fig. 5 : Diaphragm Wall Movement at Pedder Street

Area/Structure	Settlement (mm)	
	Predicted	Measured
Adjacent Ground	60	32
Connaught Road Footbridge	18	10
St. George's Building	21	8
MTR Central Subway	6	5
MTR Central Station Transfer Level	7 (lateral)	4 (lateral)

Table 2 : Summary of Movements

The measured movements are well within the predicted values. There are several reasons attribute to the differences :-

- Heaving of ground occurred during demolition of Swire House and offset part of the settlement;
- Only 2-D analyses were carried out and the 3-dimensional effect was ignored;
- Soil small strain stiffness has not been considered;
- Soils at the site and the surrounding areas are well pre-loaded due to substantial groundwater drawdown in the past, and due to loading of Swire House;
- No account has made for the influence of existing Franki piles within and around the site.

CONCLUSION

The foundations and the new basement structure of Chater House had been designed using various soil/structure interaction and finite element analyses. Although encountering some difficulties during construction, the works were carried out and completed without exceeding the acceptable movement of the adjacent ground and structures. The top down construction technique allowed a fast track construction program of the basement construction concurrently with the superstructure construction. The local trimming/demolition of the existing basement slab and pile caps at the diaphragm wall and bore pile locations allowed construction of the foundation works prior to removal of the entire existing basement and was a cost effective way to construct the new basement.

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