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The Foundation Design for Two Super High-Rise Buildings in Hong Kong

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Abstract

Over the past 5 years foundations for two super high-rise buildings have been constructed in Hong Kong. The first of these, the IFC Tower II located on the reclamation on Hong Kong Island is currently the 5th tallest in the world at 420 metres high and obtained its occupation permit in 2003. The second, Union Square is a 480m high tower currently under construction immediate opposite IFC Tower II across the harbour in Kowloon. This will be the second tallest building in the world albeit for a short period of time

Introduction

The development of Hong Kong's underground rail network has been traditionally financed by the award to the Mass Transit Railway Corporation (MTRC) property development rights over or adjacent to the stations on the proposed railway.

The construction of the rail link to the new airport at Chep Lap Kok presented opportunities for development at two key stations in Hong Kong and Kowloon.

The development at the MTRC Hong Kong Station consists of the station with in town check-in facilities, shopping mall, an office tower block (IFC Tower I), a six star hotel as well as IFC Tower II.

The Union Square is part of the comprehensive development associated with the MTRC Kowloon Station, which provides check-in facilities on the Kowloon side of the Victoria Harbour. This is a mix of residential and commercial development of which the Union Square is a key element.

The relative locations of the two developments are shown in Figure 1.

Foundation And Basement Design In Hong Kong

Foundations

The foundations for the high-rise developments in Hong Kong have traditionally been piles or caissons bearing on the unweathered rock normally at depths of up to 40 or 50 metres. With the extension of land reclamation into the harbour the depth to the rock has generally increased and it is not uncommon for rock head to be at depths in excess of 70 or 80metres.With such depths more powerful and innovative foundation equipment has been introduced into Hong Kong to provide the deep foundations required to support the tall buildings of Hong Kong.

Fig. 1 Site Location Plan

The two tower blocks described in this paper represent almost the extremes with IFC Tower II founded on relatively shallow rock at about 35 metres whilst at Union Square the rock is at depths

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of over 100 metres.

The norm in Hong Kong is large diameter piles to up to 3.5m in diameter drilled with powerful Reverse circulation Drills (RCD's) with, if necessary under reams founded on the granite bedrock Bearing Stresses are in the range of 500t/m² for standard designs increasing to up to 1,000t/m² for good quality rock. As an alternative rock sockets are adopted where the load capacity is derived both in end bearing but also socket friction.

Basements

Basements particularly in reclamations areas of Hong Kong are normally constructed within diaphragm (slurry) walls. For the support of the excavations either the permanent slabs in a top down construction sequence provide the propping or for open out temporary steel strutting or ground anchors.

As with any excavations in an urban environment the ground movements outside of the site need to be minimised. By adopting a stiff propping system together with a stiff retaining wall the movements are normally small. This is usually achieved with a top down constructed basement within a perimeter diaphragm wall. However the construction period will normally be longer with a top down sequence compared with an open excavation.

One option is a circular perimeter diaphragm wall for the basement providing both a stiff wall and the hoop effect ensure movements outside the basement are small. In addition it is an attractive option in providing an open excavation for rapid construction of the basement.

Hong Kong Station (IFC Tower II)

IFC International Finance Centre II presented a fairly unique opportunity to adopt a raft foundation on rock for the tower. The conforming solution for the foundation of the 88 storey tower required 72 no. 3m diameter end bearing bored piles with 4.2m diameter bell outs in rock. A cofferdam was also required around these to enable pile caps to be constructed some 30m below ground level, the details of this being left to the contractor's choice.

The alternative proposal consisted of a large diameter circular diaphragm wall shaft, within which the excavation was carried down to rock. The piles and pile caps were thus eliminated, with the tower founded on a reinforced concrete base slab founded directly on rock. Where the rock was lower than the underside of this base, mass concrete was used to fill up to the base level. The cofferdam, required for the base construction, became an integral part of the design and construction. The conforming and alternative foundation options are shown in Figure 2.

The diaphragm wall shaft had an internal diameter of 61.5m, a thickness of 1.5m and was designed to resist soil and water pressure by hoop compressive stress. The hoop stress can only be mobilised if the effective wall thickness is maintained, which is a function of the accuracy with which the diaphragm wall panels can be constructed. The use of hydraulic cutters with built in inclinometers enabled the required verticality tolerance of 1/500 to be achieved. The diaphragm wall was toe grouted to control seepage.

Figures 3 shows the particularly excavated cofferdam whilst Figure 4 shows the completed structure.

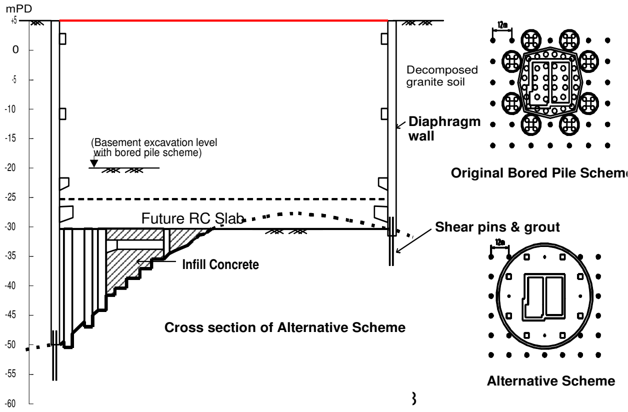

Fig.2. IFC Tower II

Fig.3. Excavation within the temporary cofferdam

Fig.4. Two International Finance Centre

The lateral movements of the circular diaphragm wall were extremely small. Inclinometers recorded inward movements of less than 25 mm. Further details are given in Davies (2003), Sutherland (1999) and Gibbons (2004).

Kowloon Station (Union Square)

Introduction

Union Square development consists of a 108-storey office tower with hotels and 4 levels of basement (Figure 5). Arup were commissioned by Sun Hung Kai Properties Ltd to design and supervise construction works and Bachy Intrafor Joint Venture was responsible for constructing the foundation system.

Union Square is located at the Southwest corner of the Comprehensive Development Area of MTRCL Kowloon Station, Figure 5. The tunnel of the MTRCL is located approximately 3m to the east and the Station approximately 15m of the proposed development. The Highways viaduct is located at 15m to the west of the site. The basement and foundations therefore needed to be built in a manner that ground movements outside the site were small to ensure no damage to the surrounding structures.

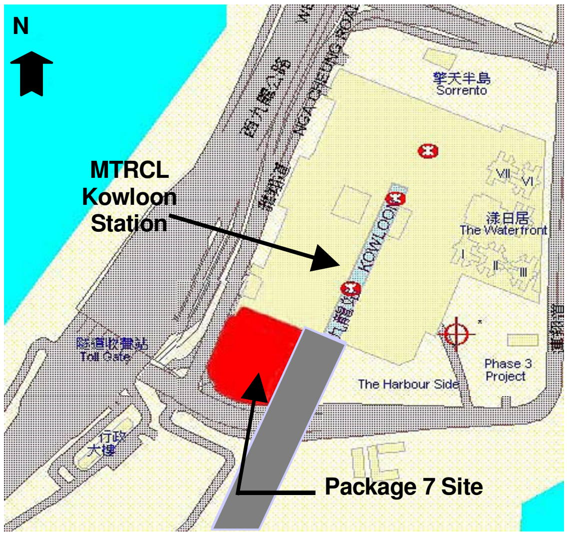

Fig.5. Block Plan

Site geology and ground conditions

The proposed development involved a comprehensive ground investigation work to establish the geological profile across the site.

The geology determined from investigation is summarised below:

STRATUM	TOP LEVEL OF STRATUM (MPD)	AVERAGE THICKNESS (M)
Sand fill	+6	26
Alluvium	-20	10
Decomposed Granite	-30	45
Bedrock	-80	N/A

The superficial geology is mainly governed by the previous reclamation work. The West Kowloon Reclamation is a ‘fully dredged’ reclamation. Soft Marine Clay beneath the original seabed was generally been removed prior to placing of sand fill.

The thickness of sand fill is about 26m and is underlain by Alluvium with a thickness about 10m. Beneath the Alluvium is the traditional weathered profile of Decomposed Granite. The surface of the Decomposed Granite is at an approximate level of –30mPD.

The main trend of the faults and photo lineaments in the area is in a NE-SW and NW-SE direction.

The rock head profile below the site suggests that a deep weathering feature existed extending to depths in excess of 110m.

The trend of the weathered feature is in a similar orientation to the main faults suggesting it is the location of a fault or shear zone (Figure 6).

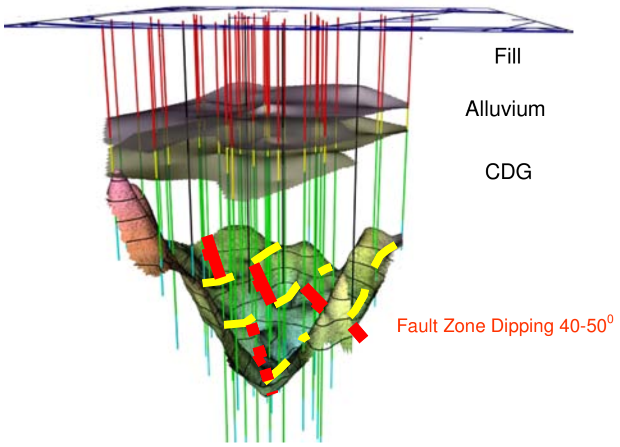

Fig.6. The 3D inferred rockhead contour

Foundation Scheme

Since the footprint of the proposed tower is located above a major fault zone, the conventional end-bearing bored concrete piles would have been difficult to construct and the quality of the piles, especially the interface between the concrete and the end-bearing medium was likely to be contaminated with debris arising from sedimentation as well as segregation of concrete in such deep piles. Moreover, the inferred bedrock profile varies significantly across this site, thus making the end-bearing option extremely difficult both in terms of founding the piles and the extremely lengthy construction time with the extreme depths. In view of this, frictional shaft grouted barrettes, although relatively new in Hong Kong, were considered the most feasible and viable option.

The proposed foundation scheme adopted for Union Square was shaft grouted barrette piles of size in general 2.8m x 1.5m with 2m clear spacing between pile edges within the footprint of a 76m diameter cofferdam, Figure 7. The cofferdam is also constructed of shaft grouted diaphragm wall panels. The diaphragm wall is 1,500mm thick and was constructed using a hydrofreise. The tolerance achieved on the wall positioning both at ground level and formation level was better than 50mm. well within the required tolerance. Figure 8 shows the cofferdam when excavated to formation level.

Shaft grouting for barrettes has been used extensively around the world, providing a significant increase in capacity, when compared to plain piles and barrettes, as well as savings in cost and time.

There was no precedent for the use of shaft grouting on a building project in Hong Kong until the full-scale pile test programme undertaken for the Kowloon-Canton Railway Corporation (KCRC). Plumbridge et al (2000) reported the results from this test programme and that a two to three fold enhancement of the frictional capacity of a deep foundation could be achieved by shaft grouting.

The mechanisms for the increase in shaft resistance due to grouting were described by Stocker (1983) and Troughton & Stocker (1994) i.e.

- The concrete on the perimeter pile is cracked and pushed out against the surrounding soil with the grout bracing the pile against the soil;
- The increased lateral pressure causes a local increase in soil density in the interface zone of the pile bore which has become softened or loosened by the pile construction process;
- In granular soils, cementation of the soil particles in the interface zone may occur due to the infiltration of grout into the pores of the soil;
- Voids, fissures, cavities or wash outs may be filled with grout providing an improved contact between the pile and the soil.

In order to demonstrate the performance and establish the construction procedure of shaft grouted barrettes in this site; five fully instrumented trial barrettes were installed for testing prior to constructing the working piles. Following the success of the trial pile testing, the construction method, procedure, workmanship and materials of the working shaft grouted barrettes were the same as the trial shaft grouted barrette.

The Hong Kong Building (Construction) Regulations, states that centres of all piles deriving their resistance mainly from friction shall be placed.

a. Not less than the length of the perimeter of the pile or 1m, whichever is the greater, from the centres of adjacent piles; and
b. Not less than half the length of the perimeter of the pile or 500mm, whichever is the greater, from the site boundary.

In addition the commonly accepted group reduction factor of .85 is normally required for pile groups of 5 or more piles unless the piles are widely spaced or founded on the bedrock.

For Union Square in order to provide sufficient capacity, a total of 240 number shaft grouted barrettes with a spacing less than the perimeter of the piles and group reduction factor equal to 1.0 was proposed. To justify the behaviour of the closely spaced pile group was analysed adopting a soil mechanics approach with the aid of the finite element program “Oasys SAFE”. The results indicated that the group efficiency (or ‘group reduction factor’) is greater than 1, i.e. the pile group capacity will be greater than the sum of capacities of individual piles in the group. The result is consistent with the conclusions drawn by Poulos and Davis (1980), W.G.K. Fleming (1992) and M.F. Randolph (1994).

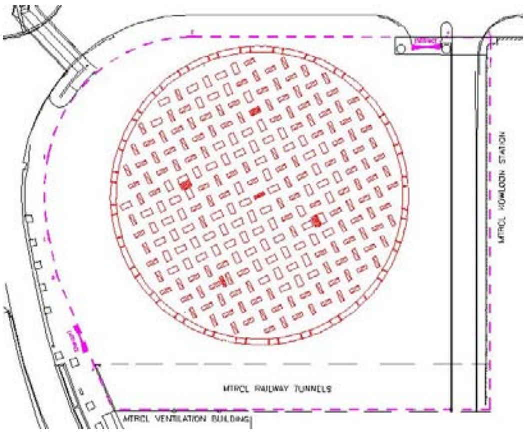

Fig.7. The Piling Layout Plan

Fig.8. Pile Layout within Cofferdam

The pile capacity in resistance to downward loading is derived mainly from shaft friction enhanced by shaft grouting, combined with a minor contribution from end bearing resistance. The capacity in resistance to uplift is derived from the pile self weight plus the uplift shaft resistance.

The vertical loads from columns and walls of superstructure including the pile cap self-weight and the basement structure are transferred through the pile cap to the shaft grouted barrettes. Moment and lateral shear forces due to wind on superstructure are resisted by the pile group by means of push and pull action of the piles and passive resistance of subsoil around the piles respectively.

Design methodology

The design methodology adopted for the closely spaced pile group in soil was:

- Assess the load shed behaviour of the pile group;
- Assess the load distribution among the piles in the group;
- Assess the reduction factor on shaft friction due to basement excavation;
- Assess the geotechnical and structural capacity of individual pile;
- Assess the pile group capacity; and
- Assess the pile group settlement.

A fuller description of the approach is described elsewhere (Chan G et al 2004).

Current situation

The current situation is that the piles have been installed, the circular cofferdam excavated and the pile cap constructed. The construction of the tower is due to start in the near future. Figure 9 shows the tower when completed.

Fig. 9 Union Square, Hong Kong

Conclusions

The paper describes the foundations for two super tall buildings in Hong Kong.
The solutions adopted provide almost the extremes of current foundation design in Hong Kong.
IFC Tower II is built on a conventional raft on the bedrock whilst Union Square adopts a solution, which for Hong Kong is “state of the art”.

IFC Tower II is complete and has performed to expectations and over the next few years the performance of the Union Square foundations will be the subject of keen interest to geotechnical and structural engineers.

References

1) Buildings Ordinance, Cap 123, Government of the Hong Kong Special Administrative Region
2) Chan G Lui J, Lam K, Yin KK, Law CW, Lau R, and Hasle R (2004) Shaft Grouted Friction Barrette Piles For A Super High-Rise Building. Joint Structural Division Annual Seminar 2004. New Perspectives in the Design & Construction of Foundation
3) Davies J A (2003) Geotechnical Aspects in the Design of

Foundations and Basements for High-rise Developments
4) Fleming, W.G.K. & Thorburn, S. (1983). Recent piling advances. Proceeding of the Conference on Advances in Piling and Ground Treatment for Foundations, London, pp 1-16
5) Fleming, W.G.K., Weltman, A.J., Randolph, M.F. & Elson, W.K. (1992). Piling Engineering. (Second Edition). Surrey University Press, London
6) Geo Publication No. 1/96 (1996) Pile Design and Construction, Geotechnical Engineering Office, Civil Engineering Department, Hong Kong
7) Gibbons C el al (2004) IFC Tower II CTBUH Seoul
8) Hill S J, Littlechild B, D Plumbridge G D & Lee S C (2000) End Bearing and Socket Design for Foundations in Hong Kong. Proceedings of the 10th Annual Seminar of the Geotechnical Divi-sion of the Hong Kong Institution of Engineers Hong Kong pp 169-177)
9) Littlechild B D, Hill S J, Statham I, Plumbridge G D & Soon Chop L (2000) Stiffness of Hong Kong Rocks for Foundations. Proc., Foundations, Hong Kong Institution of Engineers Geo-technical Division Annual Seminar, London
10) Plumbridge, G.D., Littlechild, B.D., Hill, S.J. and Pratt, M (2000). Full Scale Shaft Grouted Piles and Barrettes in Hong Kong – A First. Proceeding of the Nineteen Annual Seminar of the Geotech. Div. of the Hong Kong Instn. Engrs, Hong Kong, 157-166
11) Poulos H and Davis EH (1980) Pile Foundation Analysis and Design John Wiley
12) Stocker M (1983) The Influence of Post-grouting on the Load Bearing Capacity of Bored Piles. Eighth European Conference on Soil Mechanics and Foundation Engineering. 167-170 Helsinki
13) Sunderland P, Chan K M & Lau C P (1999) The Big Hole in Central. Hong Kong Institution of Engineers Civil Division Web Site
14) Troughton V & Stocker M (1996) Base and Shaft Grouted Piles. Proceedings of Institution of Civil Engineers. Geotechnical Engineering 119, 186-192