A CASE STUDY: DESIGN AND CONSTRUCTION OF FOUNDATION AND BRACED EXCAVATION AT A RECLAIMED SITE AT WATERFRONT

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Abstract: *The Sheung Wan Stormwater Pumping Station is located on reclaimed land at the waterfront of Victoria Harbour. It comprises a pump house and an underground storage tank measuring 45.6m by 43m on plan and 11m deep as temporary stormwater storage for alleviating the flooding problem of Sheung Wan Area. The presence of heterogenous marine deposits and dumped fill, the proximity to the vertical seawall and sensitive structures, and the recharge from the sea has posed particular difficulties to the design and construction of the temporary excavation. Also, an alternative foundation design using a combination of prebored socketed H-piles, minipiles and raft foundation has been adopted to replace the large diameter bored piles in the conforming design. This paper presents the challenges faced in the design of the foundation and the temporary excavation and how they are addressed. It also describes the difficulties encountered in the construction of foundation and braced excavation and the solutions adopted to overcome them.*

INTRODUCTION

The lowlying Sheung Wan areas at the western side of Hong Kong Island has long been plagued by flooding during heavy rainstorms coincided with high tide. The situation would be worst during extreme high tides, when the sea level is higher than the ground level in Sheung Wan, causing seawater to flow back and overflow from manholes and gully gratings. A stormwater pumping station was proposed by the Drainage Services Department of the Hong Kong SAR Government at the waterfront of Sheung Wan. The construction was commenced in mid 2006 and is to be completed in 2009. It serves to collect stormwater from a network of drains and discharge the water into the harbour through high-powered submersible pumps, at the same time stopping the backward flow of seawater into the drainage system by a penstock.

One key element of the project was the foundation construction for the Sheung Wan Stormwater Pumping Station (the "SWSPS"). The pile caps of the pumping station are found at various depths, with the lowest one – the pile cap for the underground storage tank, which serves also as the base slab of the tank – founding at some 11m below the existing ground surface. To construct the pile caps, it was necessary to first install an excavation and lateral support (ELS) system.

The pumping station is located on reclaimed land and is just 11m from the harbour. The heterogenous nature of the dumped fill forming the reclamation, the proximity to the vertical seawall – part of the pumping station is located above the foundation of the seawall, the constant recharge from the sea, the proximity of Water Supplies Department's Sheung Wan Salt Water Pumping Station – a structure on raft foundation, all posed challenges to the design and construction of foundation and excavation for the pumping station.

The authors of this paper were involved in the design of the foundation, the design of the ELS and the supervision of the construction works.

SITE LOCATION

The proposed SWSPS is located along Chung Kong Road, Sheung Wan, Hong Kong. The footprint area of the pumping station structures measured approximately 56m long and 43m wide, whereas the ground level is approximately +4mPD. The SWSPS is surrounded by various structures, which are sensitive to ground movement. To the north is a vertical seawall, which was completed around 1976. The seawall, constructed of modular mass concrete blocks, was founded on a submerged bund formed by sand fill and rock fill. To the west of the SWSPS is the existing Sheung Wan Salt Water Pumping Station. The Salt Water Pumping Station is founded on raft footing and has a deep open culvert (founded at -3.8mPD) on the side abutting the proposed SWSPS. At the nearest point, this culvert is only approximately 1.5m from the site boundary (4m from the SWSPS structure). On the southern boundary is Chung Kong Road where several major utilities pipes are present. On the opposite side of Chung Kong Road is the Sheung Wan Waterfront Police Station, which is founded on piles. The Police Station is approximately 20m from the site boundary of the SWSPS. The eastern side is an open space for temporary site offices and material storage.

Immediately prior to construction, the Site was an open bazaar and was also used as parking area.

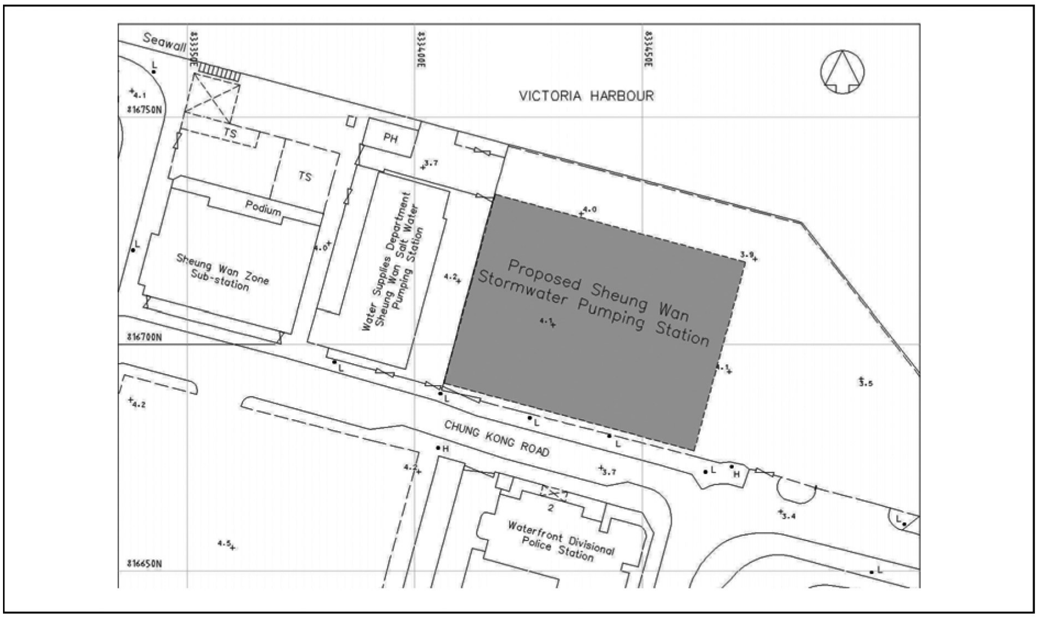

Figure 1: Location Plan of Sheung Wan Stormwater Pumping Station

GROUND CONDITIONS

According to the geological survey map published by the Geotechnical Control Office, the site is underlain by fill material generally reclaimed in 1982 which possibly overlies medium grained granite formed in the Jurassic-Cretaceous period of the Mesozoic era. The ground investigations for this project revealed that superficial deposits comprising fill, marine deposits and alluvium are overlying weathered granite with saprolitic zone before reaching the rockhead of strong moderately to slightly decomposed granite. Figure 2 presents a typical geological section across the site.

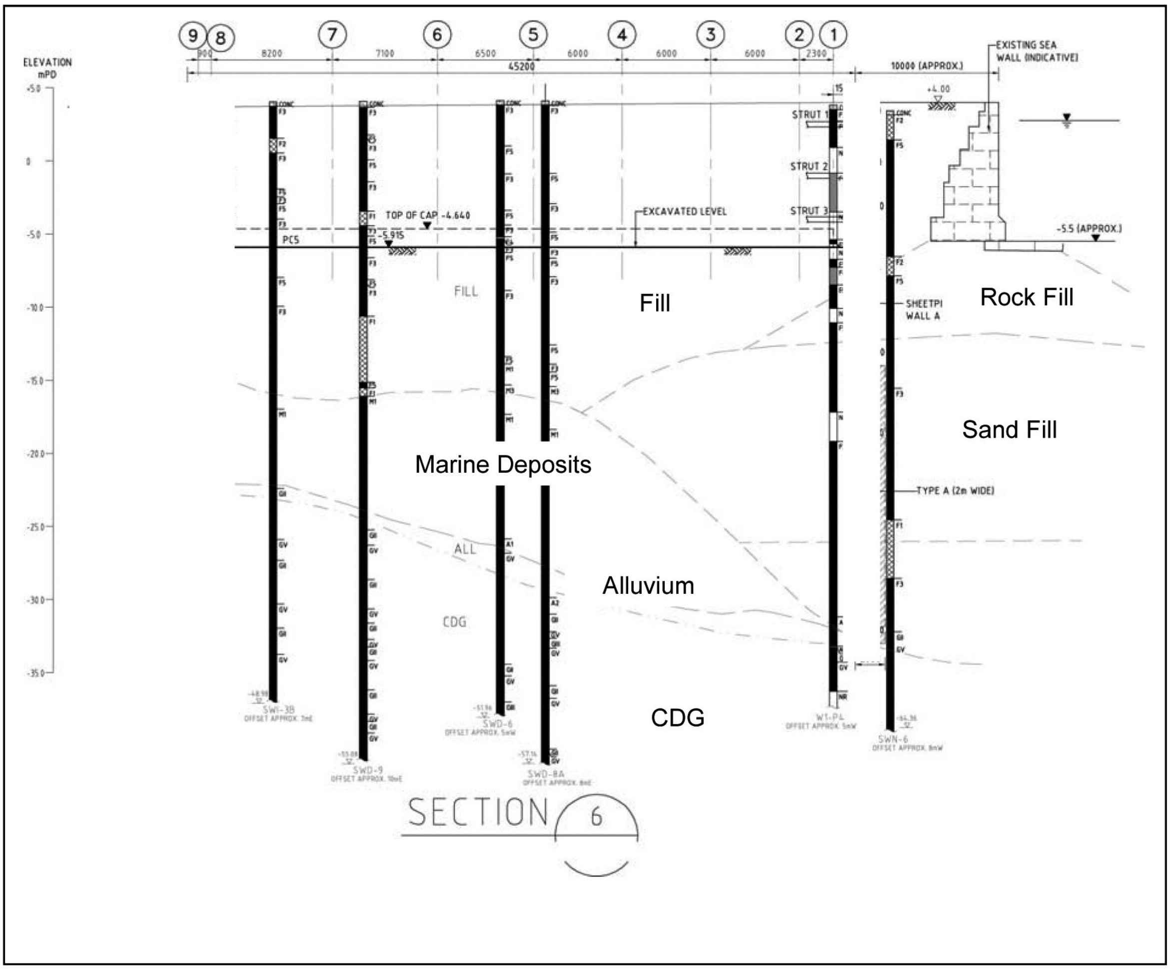

Figure 2: Typical North-South Geological Section across the Site

Series of ground investigations have been carried out at different periods, between May-July 2002 (6 holes), between February-March 2006 (26 holes) and during the early part of the contract in July and August 2006 as pre-drilling for the foundation piles (63 holes). Although the latest series of holes were excavated by wash boring, the drillholes were useful in understanding the rockhead profile at the site.

A summary of the strata as encountered during ground investigations is presented in Table 1.

Table 1 : Summary of Geological Strata at the Site

Geological Stratum	**Description**
Fill	Various types of Fill material including general fill, sand fill and rock fill, varying widely in composition in the forms of layers of sandy clayey SILT, sandy silty CLAY, silty CLAY, silty/clayey fine to coarse SAND, coarse GRAVEL and COBBLES and BOULDERS. The thickness of the Fill encountered varied between 13.5m and 35.8m, with the base elevation of the it ranging from -11mPD to -28mPD. Relatively large cobbles or boulders were encountered by the drillhole series closest to the existing seawall on the SWSPS northern boundary, interpreted to be the foundation materials for the seawall based on review of the as-built records of the seawall.
Marine Deposits	Comprising soft to firm, sandy silty CLAY with occasional gravel and shell fragment was encountered underneath the fill at the portion of site surrounded by existing seawall. Locally, thin layers of anthropogenic mud are present within the deposits. The revealed thickness of the deposits ranges from 0m (for drillholes closest to the seawall) to 14m. It is believed that the presence/ absence of the Marine deposits has been influenced by the recent past construction in the vicinity. From the as-built records of the seawall (see latter discussion), it is noted that the soft Marine deposits were required to be dredged before the backfill with rockfill and sand fill.
Alluvium	Encountered only in some drillholes underneath the Marine deposits. When encountered, it comprises firm, slightly sandy clayey SILT with occasional gravel. Alluvium was found to a depth of 24.5m (-20.41mPD) at the deepest location.
Saprolite and Corestone	Saprolitic soil derived from the in-situ weathering of medium to coarse grained Granite. The material recovered comprises slightly sandy/sandy clayey SILT, silty SAND or fine to coarse SAND with fine gravel. The thickness of the saprolite encountered varies between 17.4m and 27.0m, with the base elevation ranging from -41.36mPD to -59.24mPD. Corestones were encountered at some drillhole locations immediately beneath Alluvium at depths between 25m (-20.7mPD) and 59m (-55mPD). The corestones comprise weak to very strong, highly to slightly decomposed Granite.
Bedrock	Moderately or slightly decomposed predominantly medium to coarse grained Granite. The strength of rock encountered varies from moderately strong to very strong. Occasional pegmatitic dykes were encountered within the granitic rock mass. Drillholes were terminated at depths between 55m and 65m, with proven rock thickness varies from 5m to 9m.

GROUNDWATER CONDITIONS

Standpipe and piezometers were installed in some of the drillholes at depths ranged from 19m to 23m below ground for groundwater level monitoring. As the site is close to the shoreline, the measured groundwater levels are found corresponded generally to the active seawater level which varies from +0.5mPD to +2.5mPD. Piezometers were not installed at deeper depth closer to the rockhead level and there was no information to evaluate whether an artesian pore pressure are present.

ENGINEERING PROPERTIES OF SOILS

Engineering properties of various soil materials encountered by drillholes within the site have been determined using both field and laboratory test data where available, and are summarised in Table 2.

Table 2: Design Engineering Properties of Soil Materials

Soil Type	Bulk Unit Weight (kN/m^3)	Effective Cohesion c' (kPa)	Effective Friction Angle ϕ' (deg)	Elastic Modulus E' (MPa)
Fill (Sand)	19	0	36	10 (above +0mPD) 15 (0 to -5mPD) 20 (below -5mPD)
Fill (Rock)	20	0	40	25
Marine Deposits (Drained)	18	0	30	Eu = 15 + 1.5z (where z > -20mPD)
Marine Deposits (Undrained)	18	Cu = 55 + 4z (where z > -20mPD)	na	E' = 15 + 1.5z (where z > -20mPD)
Alluvium	19	0	35	30
CDG / HDG	19	0	37	E' = 30 + 2.5z (where z > -30mPD)

In situ falling and constant head permeability tests were carried out in selected drillholes during the 2006 ground investigation. The results of the soil's permeability are typical of those commonly encountered in Hong Kong and are summarized in Table 3.

Table 3: Summary of Soil Permeability Test Results

Soil	Permeability Range (m/s)
Fill (Sand)	1.01×10^{-5} to 6.11×10^{-6}
Fill (Gravel / Cobble)	1.34×10^{-1} to 5.07×10^{-6}
Marine Deposits	No test
Alluvium	No test
Completely Decomposed Granite	6.55×10^{-7} to 1.39×10^{-4}

It will be relevant to note that the permeability of the gravel and cobble fill is of the order 1×10^{-1} m/s. Considering the proximity of the site to the harbour, it is practically impossible to dewater the excavation without a groundwater water cut-off to a depth below this layer provided.

EXCAVATION & LATERAL SUPPORT SYSTEM

At the outset of the design of the excavation and lateral support (ELS) structures, the complex ground conditions of the site, which had major influences on the selection of the retaining wall system, was fully recognised. The proposed ELS had to be simple and economical, and be able to

- facilitate a stable excavation with minimal obstruction
- provide an efficient groundwater inflow cut-off
- contain ground movement to within acceptable limits

The options of bored pile retaining wall and diaphragm wall had been considered but discarded. Apart from cost consideration, for the diaphragm wall option, it was envisaged that the trenching phase alone of the wall construction through the rubble rockfill of the seawall might induce ground settlement in the order of 60mm (Cowland et al, 1984). Whereas for contiguous bored piled retaining walls, it was considered that the risk of water leaking through piles would be high. Hence, a ELS system comprising FSP IV sheetpiles was finally selected. Layout of the sheetpile cofferdam is shown in Figure 3.

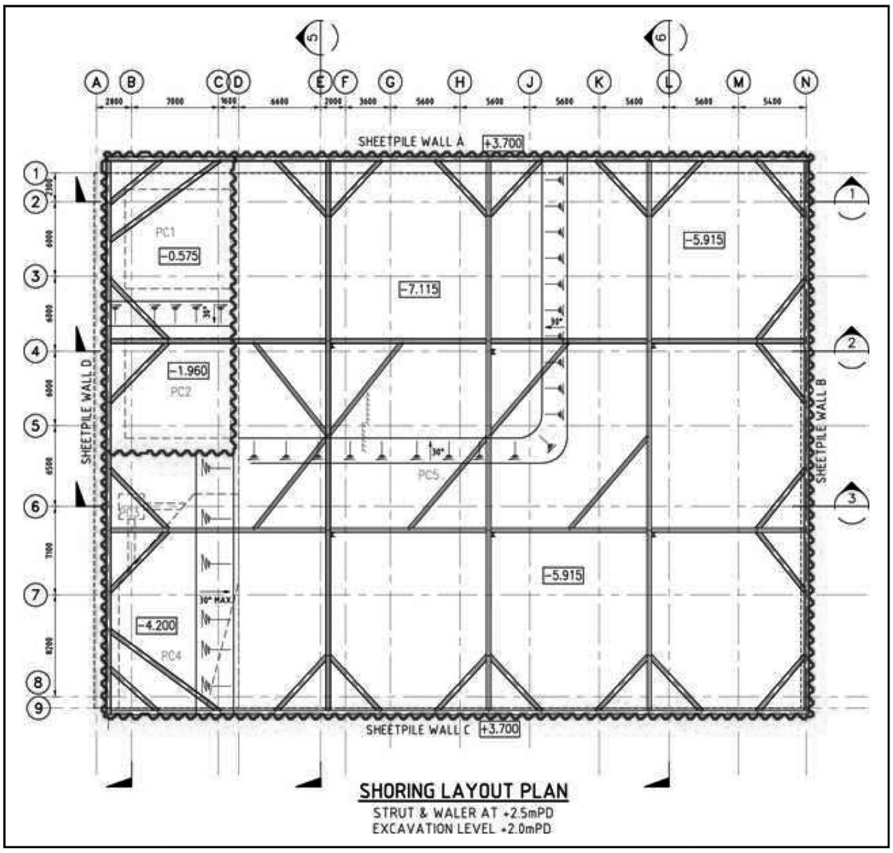

Figure 3: Shoring Layout Plan

As discussed in earlier section, seawall located to the north of the pumping station is founded on permeable rubble rock fill to a depth of approximately -18mPD. Hence, the sheetpile wall (Wall A) was designed to have a toe elevation of -19.5m (total wall length of 24m). The sand fill beneath the sheetpile was made less permeable by toe penetration grout curtain to a depth of minimum 1m into the completely decomposed granite (CDG).

On the western side, the ground investigation drillholes revealed that the majority of the original marine deposit had been left un-dredged in the previous constructions. Groundwater inflow was not the key consideration in this location. However, as discussed in previous section, immediately outside the excavation is a deep box culvert structure founded on-grade. To limit the ground movement, the retaining wall was designed to terminate at -19.5mPD. In addtion, ground improvement in the form of penetration grouting of a 6m zone behind the sheetpile wall and jet grouting of a 4m wide zone below the toe of the sheetpiles were implemented.

For the remaining two sides of the excavation, the walls were generally able to comply with the stability requirements with the toe level at -13.5mPD (total wall length of 18m). However, despite the wall being stable, it was estimated that ground movement behind the walls would be excessive when groundwater level was lowered below the excavation level. Hence, grouting of a 2m wide zone down to CDG stratum was implemented to serve as cut-off to groundwater flow.

Sections across the sheetpile cofferdam showing the sheetpile and grouting arrangement are given in Figure 4 and Figure 5. Penetration grouting is denoted as Type A and jet grouting as Type B in the figures.

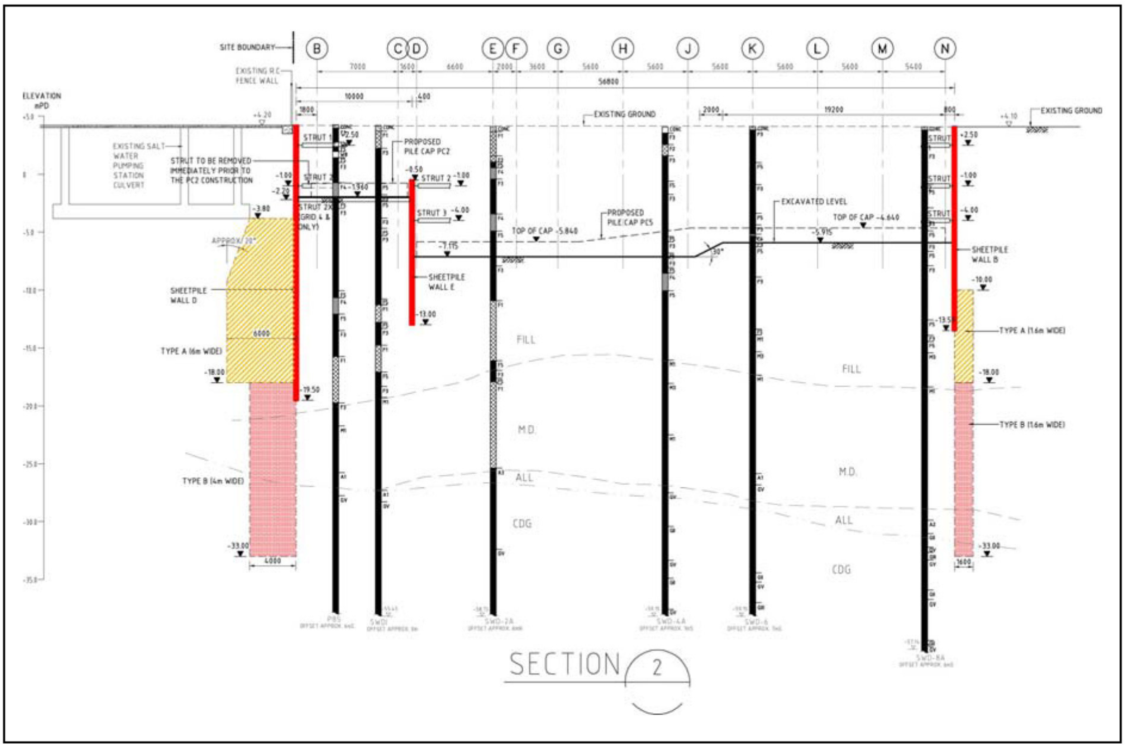

Figure 4: East-West Cross-section of the Sheetpile Cofferdam

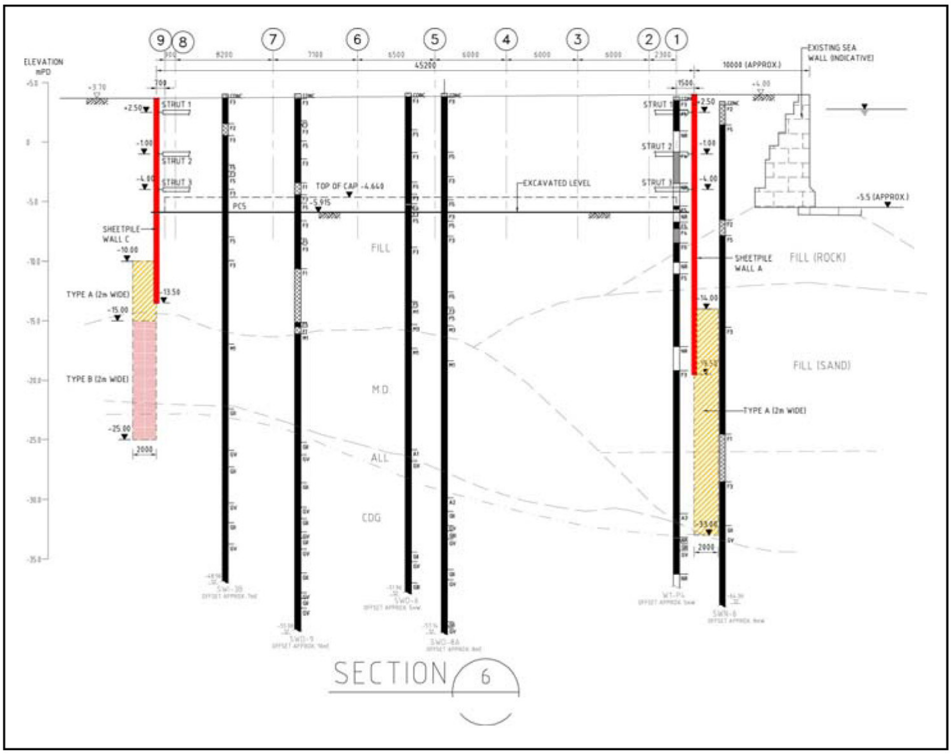

Figure 5: North-South Cross-section of the Sheetpile Cofferdam

FOUNDATION SYSTEM

The original foundation scheme of the pumping station, on the basis of which the foundation and drainage works contract was awarded, comprised 60 nos. of 1.2m to 1.5m diameter large diameter bored piles. Layout plan of the piling scheme is shown on Figure 6.

After award of the contract, the contractor proposed an alternative design of the foundation as a cost-saving solution, which was subsequently approved for construction. The proposal involved one-to-one replacement of the large diameter bored piles by rock socketted H-piles, which is formed by grouting a steel pile section inside a 550mm dia. hole drilled into bedrock. Typical detail of the rocketted H-piles is shown in Figure 7. For achieving the required pile capacity of 6900kN, apart from a 305x305x223 kg/m Grade 55C steel H-pile section, the pile is further reinforced with 4 nos. of T50 steel bars.

As construction proceeded, the foundation design was further reviewed with an aim to minimize the effects of piling on adjoining ground and structures. Ultimately, the foundation scheme evolved to be a combination of rock socketted H-piles, mini-piles and raft foundation, with only pile cap PC5, the pile cap of the underground stormwater tank, remained to be supported by rock socketted H-piles.

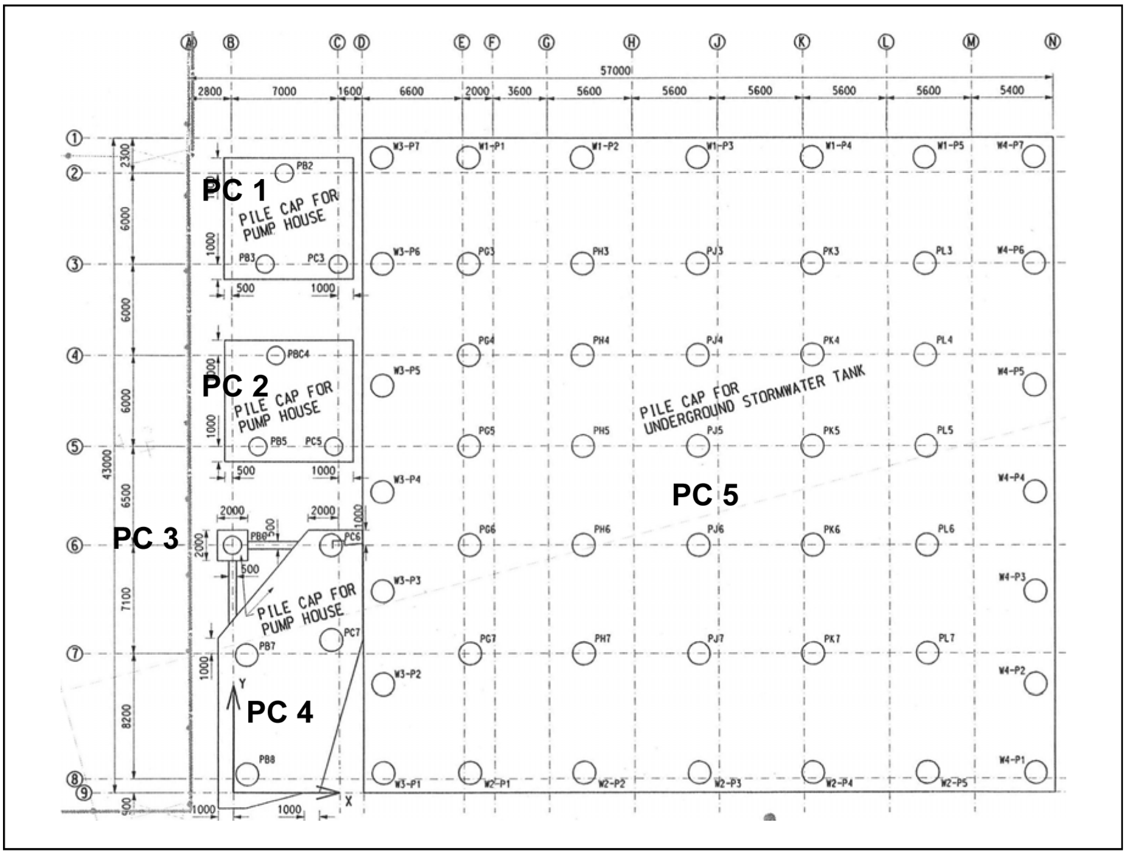

Figure 6: Bored Pile Layout Plan of Conforming Foundation Scheme

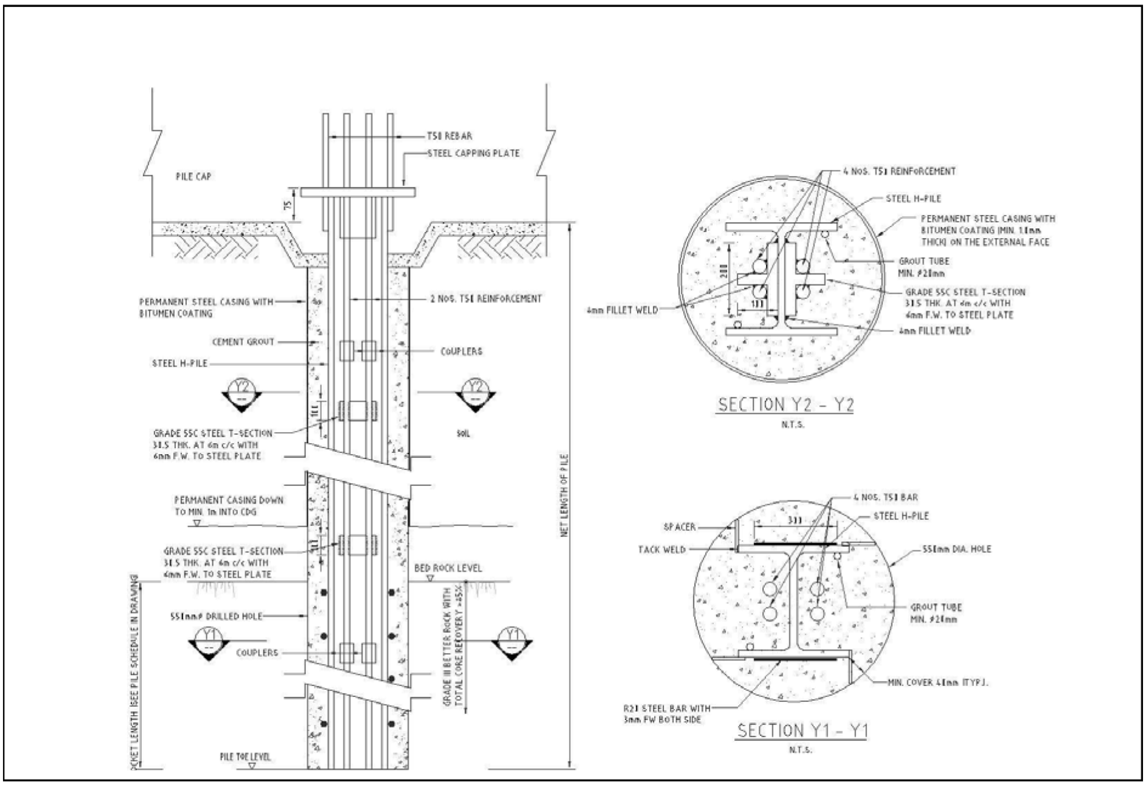

Figure 7: Typical Detail of Rock Socketted H-piles of Alternative Design

Pile caps PC1 and PC2 were revised to be founded on mini-piles, formed by grouting 4 nos. of T50 bars in a 190mm dia. hole drilled into bedrock. The pile has a capacity of 1374kN. Typical detail of the mini-piles and piling layout of pile caps PC1 and PC2 are shown in Figure 8 and Figure 9 respectively. The alternative piling design also achieved cost saving by reducing the bending moment and thus the reinforcement required in the pile caps.

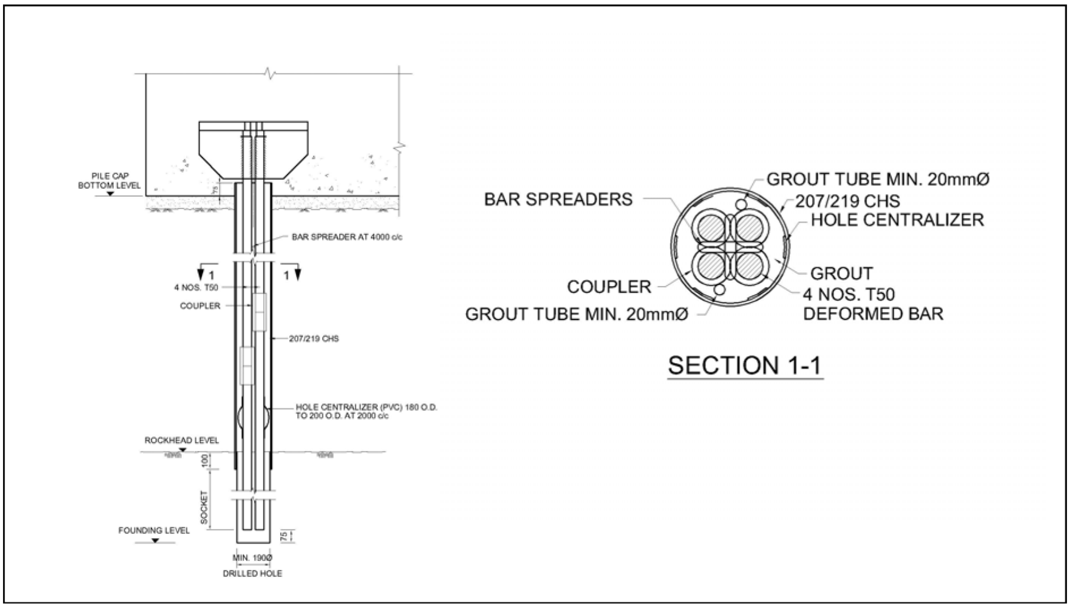

Figure 8: Typical Detail of Mini-piles

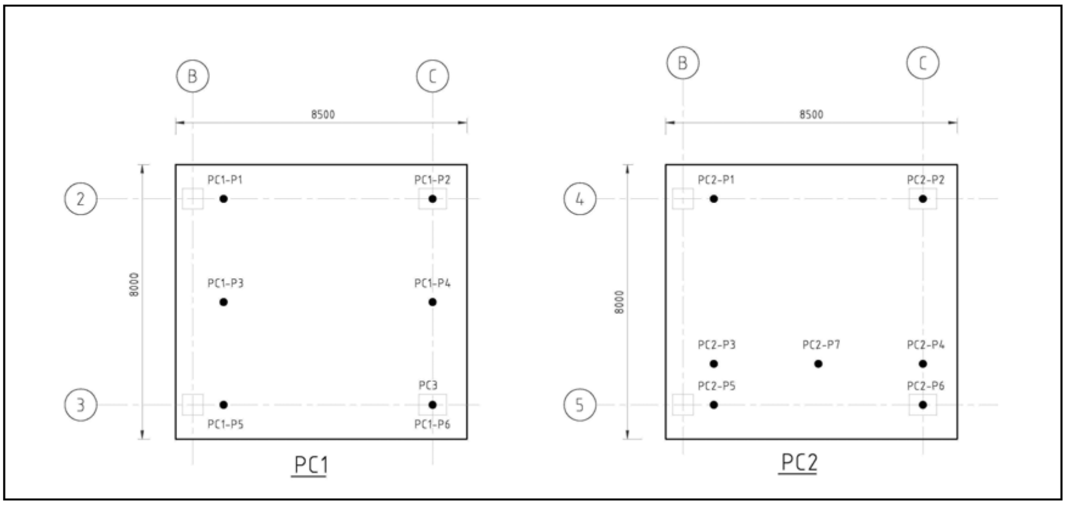

Figure 9: Piling Layout of Pile Caps PC1 and PC2

Pile cap PC4 supports a culvert leading the stormwater into the underground stormwater tank. As such, the net loading on the pile cap makes it feasible to design the cap as a raft foundaton as it results in a bearing pressure not significantly higher than the existing overburden pressure at the founding level of the raft, at about –3.1mPD. The prime consideration would thuse be controlling differential settlement between the raft and the adjoining pile caps. Pile caps PC3 and PC4 were hence replaced by a single raft foundation, with a larger combined footprint. Ground treatment by penetration grouting was designed for soil strata below the raft down to the bottom of the aluvium layer for improving the deformation property of the soils, thus reducing settlement of the raft. Layout of the raft and grouting pattern are shown on Figure 10. The grouting was targeted to achieve an improvement of the soil elastic modulus to 50MPa.

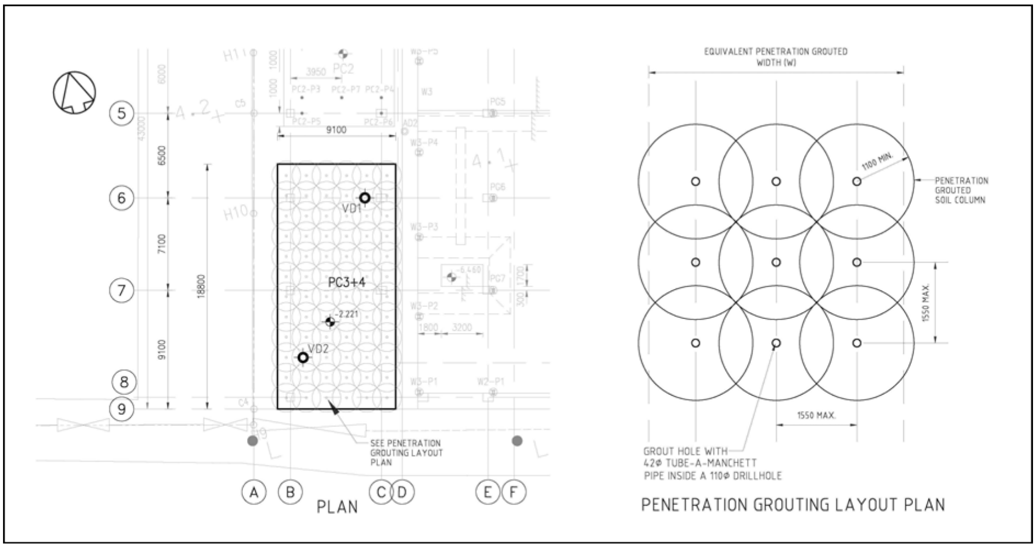

Figure 10: Layout Plan of Raft Foundation PC3+4 and Grouting Pattern

CONSTRUCTION

Sheetpile Installation

To limit the vibration effect from sheetpiling works, the contractor of the works had chosen to use press-in method for sheetpile installation. As ground investigations revealed the presence of cobbles and boulders in the superficial fill stratum, Giken's Super Crush System, which was equiped with an integral auger for overcoming obstruction, was adopted. It was understood this system was deployed for the first time in Hong Kong. Photo 1 shows the Crush Piler with the auger head. The system had been found to be capable of installing the sheetpiles to a high quality standard in the difficult ground condition, as revealed by the amount boulders found in the course of excavation (Photo 2).

Photo 1: Crush Piler in Operation

Photo 2: Boulders Exposed in Excavation

Foundation Pile Installation

The rock socketted H-piles were installed by a concentric overburden drilling system with air flushing, the commonly adopted installation method for the pile type at the time of construction. The system uses a rotary-percussive action for drilling and uses air flushing for removal of debris. After installation of some piles, it had become apparent that in the ground conditions of the site, the pile drilling operation was liable to over-excavation and thus causing ground loss.

As mitigation measures and to control the effects on adjoining ground and existing structures, apart from better control of the piling operation, the following measures were implemented:

- Drilling for a pile was only allowed when sheetpiling and toe grouting within a 15m radius from the pile had been completed;
- Replacing the piled foundation PC3 and PC4 by a combined raft foundation (PC3+4) in order to minimize the effect on the adjoining WSD Salt Water Pumping Station.

Ground Improvement

Jet grouting in clayey soils was carried out with the following parameters:

Target grouted dia.:	1500 – 2000 mm
Jetting pressure:	300 – 400 bars
Withdraw rate:	13 to 15 min/m
Rotation rate:	6 – 7 rev/step

The target was to achieve an unconfined compressive strength of 600kPa and an elastic modulus of 150MPa. Core samples were retrieved for testing (Photo 3). Test results showed that UCS of 7 to 10MPa were generally achieved, with some samples having a strength exceeding 40MPa.

Pentration grouting for the more granular soils were carried out using tube-a-manchette technique. For the grout curtain associated with the sheetpile wall, a two-staged grouting operation was adopted. Stage 1 involved the used of bentonite-cement grout and Stage 2 the use of silcate-based chemical grout for achieving water-tightness. For the ground improvement under raft foundation PC3+4, bentonite cement grout was adopted. Performance of the grouting was verified by inspection of retrieved cores (Photo 4) and also by in situ pressuremeter tests.

Photo 3: Core Sample of Jet-grouted Soil

Photo 4: Core Sample of TAM-grouted Soil

Instrumentation and Monitoring

An extensive instrumentation and monitoring scheme has been put in place during construction. Monitoring instruments included:

- Ground settlement monitoring points around the excavation;
- Inclination and settlement monitoring points on the seawall;
- Movement monitoring points, tell-tales, building settlement markers, crack monitoring points on existing structures, including WSD's Sheung Wan Salt Water Pumping Station, the associated culvert, and Waterfront Police Station;
- Utility settlement monitoring points;
- Inclinometers behind the sheetpile walls;
- Piezometers outside and within the sheetpile cofferdam.

Monitoring results indicated significant ground settlement occurred during initial pile installation, in particular at the side adjoining the existing seawall. The settlement is considered attributable to a combination of over-excavation, an intrinsic feature of the piling method adopted, and the compaction of the fill material and the rock fill foundation of the seawall by vibration from the construction. It is also considered this effect has been aggravated by the presence of voids within the gravelly material within the fill layer.

Movements during excavation were predicted by analysis using the finite element software PLAXIS. Figure 11 compares the monitored ground movement during excavation behind the eastern wall and the western wall with the predicted. It shows that for the eastern sheetpile wall, both the wall deflection and ground settlement have reasonable agreement with the prediction. For the western sheetpile wall, the wall deflection was much less than predicted. This is because the finite element analysis had not taken into account the ground improvement at the excavation side under raft PC3+4, which was decided subsequent to the ELS design.

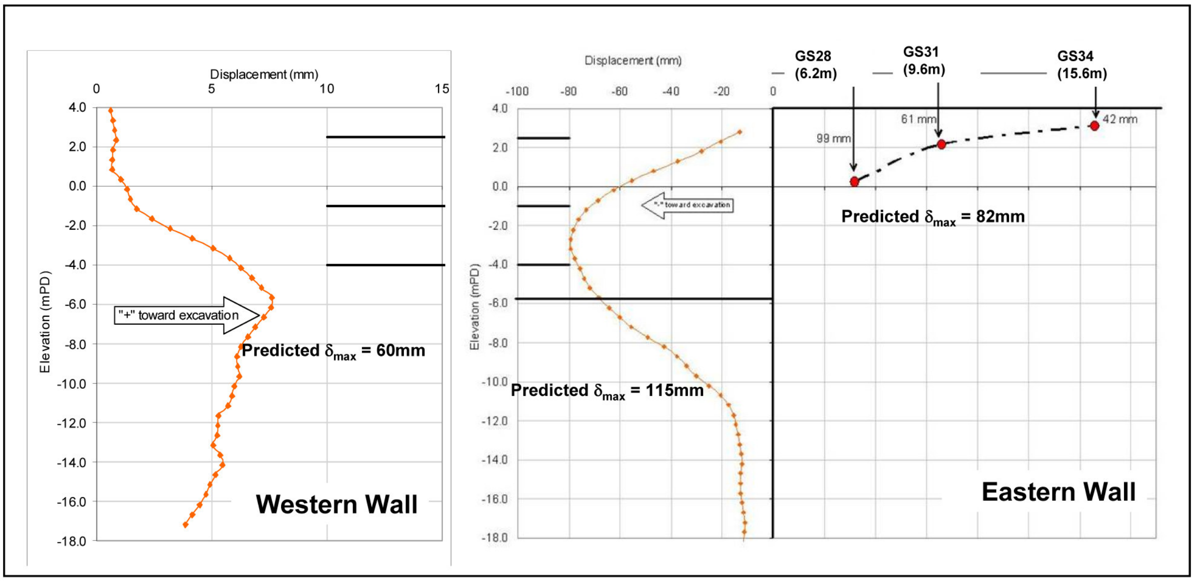

Figure 11: Ground Deformation behind Sheetpile Walls due to Excavation

DISCUSSION AND CONCLUSION

This project highlights the importance of a good understanding of site history. In this case, record drawings of the existing seawall and knowledge of the reclamation operation adopted at the time have provided valuable information in complementing the ground investigation data for arriving at a full picture of the geological profile under the site and the properties of the soil materials to be encountered.

The ground conditions of the site, though complex, are fairly common in old reclamation sites in Hong Kong. With the presence of existing sensitive structures in the vicinity, a careful consideration and selection of construction method and equipment would become essential for controlling disturbance to the ground and hence the existing structures. These objectives shall be established at the outset of the design process. Input from professionals well experienced in construction would be beneficial.

This foundation construction of SWSPS has seen the successful application of Giken's Super Crush Press-in method for installing sheetpiles through obstruction with minimal vibration and of penetration and jet grouting technique in ground improvement. The latter also offers an alternative to piled foundation when loose or soft ground is encountered. It has also seen the limitation of conventional method for rock socketted H-pile installation in the ground conditions of the site. The successful application of this pile type will merit from a thorough understanding of how different installation methods behave in different ground conditions, with a view to selecting the most appropriate installation method to suit the particular ground conditions and providing necessary precautionary and mitigation measures.

This case also highlights that ground movement due to pile installation, which sometimes may be ignored by designers, can be significant. Sometimes, advance stabilization or underpinning of existing structures and utility diversion may help shorten the construction programme.

The foundation construction of SWSPS has also seen the sincere collaboration of the various government departments, the contractors and the engineering consultants involved for achieving the common goal of delivering the project. The result is shown in Photo 5 below.

Photo 5: Completed Foundation of Sheung Wan Stormwater Pumping Station

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