Geotechnical Challenges in Construction of an Underground Stormwater Storage Scheme in Happy Valley

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ABSTRACT

Happy Valley Underground Stormwater Storage Scheme (HVUSSS) is under construction by Chun Wo Construction and Engineering Company Limited and supervised by the Drainage Projects Division of the Drainage Services Department, the Government of the HKSAR, supported by an Independent Geotechnical Engineer. The Scheme includes construction of a storage tank, which is located below the existing football pitches at Happy Valley. Phase One work including the southern portion of the scheme was constructed to a very tight programme. As a part of this work, temporary excavations supported by strutted sheet pile wall have been carried out in close proximity to sensitive structures. Soil-Structure Interaction modelling was conducted as a part of the design of temporary support for sheet pile wall. The project requires extensive geotechnical instruments monitoring with daily feedback to the Project Manager, Contractor, temporary works designer and the IGE. This paper presents the geotechnical challenges of the Excavation and Lateral Support works of the Phase One project (include 30,000 m³ storage tank, pump house, box culvert, etc.) together with description of notable events during construction.

1 INTRODUCTION

Happy Valley was first developed as a race-course in 1846 on a piece of ‘swampy land in a valley’ and was ‘often affected by floodwater.’ The area around Happy Valley has long been prone to flooding problems. During the major rainstorms in August 2000, April 2006 and June 2008, severe flooding occurred in Happy Valley and adjacent areas including Sing Woo Road, Wong Nai Chung Road, Morrison Hill Road, Lap Tak Lane and the Happy Valley Racecourse and the Recreation Ground.

In this area drainage improvement by upgrading the existing major stormwater drains is disruptive and very difficult. It would involve open trenching in the busy main roads. To avoid serious disruption to the public and to minimize complicated diversion of the underground utilities, an underground storage tank was proposed.

The underground storage tank will temporarily store part of the stormwater collected from the upstream catchment. The addition of the storage tank would enable the drainage system to handle major rainstorm events effectively, thus minimizing flooding problems in the area. The stormwater will subsequently be discharged via pumps and gravity drains to the outfall once the stormwater flow volume in the existing drains has subsided.

The Contract was awarded to Chun Wo Construction & Engineering Co., Ltd. (Chun Wo) in September 2012 who submitted, and obtained approval for a cost-saving design with raft foundations and under-drainage system. The permanent and temporary works design is by Black & Veatch Hong Kong Limited (BV HK). This contract is one in the initial batch of Government contracts to use New Engineering Contract (NEC) instead of the traditional General Conditions of Contract (GCC). As a part of this contract, an Independent Geotechnical Engineer (IGE), ONLYgeotechnics Ltd, was appointed to provide advice and assistance to the Client, DSD, in their supervision and control with regard to geotechnical aspects of the contractor’s work. To
ensure timely control and minimizing any damages during Excavation and Lateral Support works, geotechnical instruments monitoring was carried out with daily feedback to the Project Manager (the Engineer as referred in GCC), Contractor, temporary works designer and the IGE.

2 SITE LOCATION

The site is situated on the estuary area downstream of the Wong Nai Chung Valley (ERM, 2010). An old map, Figure 1, indicated that villages including Wong Nai Chung Village had been established on the valley upstream of the estuary area. The original swampy ground was infilled over 150 years ago to form the race course with filling probably sourced from the surrounding hills. The infield area of the race course was mainly used as a resting area for recreation and leisure, up to the present. As revealed in old maps and aerial photographs, there have been no significant earthworks within the infield area since then. Happy Valley Underground Stormwater Storage Scheme (HVUSSS) is located beneath the infield area (football pitches) in the centre of the Hong Kong Jockey Club’s Happy Valley Racecourse – Figure 2.

![Figure 1: Old map of Happy Valley Area](image)

3 THE SCHEME

The project (two phases) involves the construction of a 60,000 m$^3$ stormwater storage tank, an inlet structure, a twin cell box culvert and a movable crest overflow side-weir system, see Figure 2. It also includes the construction of a pump house with a discharge rate of 5,400m$^3$ per hour. At the southern end of the scheme, towards the hills, at the stilling basin, is a short length of hand-excavated tunnel which carries the new culvert. The culvert then passes under the race-course and through the centre of the football pitches area, and exits at the north western end of the race-course. The catchment area served by this scheme is about 130 hectares. The infield area of the Happy Valley Racecourse is the lowest spot in the area, therefore it provides an ideal location for the scheme from the hydraulic point of view.

The design calls for the use of a movable crest overflow side weir system incorporating supervisory control and data acquisition (SCADA) for real time monitoring of water levels at the existing drainage system and the
tidal levels at the outfall to control up and down movement of the weir automatically. This innovative and intelligent design would reduce the volume of the storage tank by 30% and save electricity consumption up to 60%. The pumping station will be remotely monitored and controlled, with outgoing data stream of water levels, status of pumps and penstocks, any equipment failure etc.

Figure 2: Key features of the HVUSS

4 DESIGN SCHEME

The original design for foundations of the scheme indicated that pre-bored H-piles socketed into bed rock would be required. Due to the lighter unit weight of the storage tank than that of the existing ground, the foundation was designed to be capable of resisting the buoyant force. The Contractor proposed a cost saving design using a raft foundation with subsoil drainage system including a cut-off wall (BV, 2012). The system would maintain groundwater level to below a limit by conveying any excess groundwater through a drainage blanket to be discharged or re-used. A series of groundwater monitoring points was installed along the perimeter of the storage tank within the groundwater cut-off wall. An array of pressure relief wells was constructed at the base slab of the storage tank as a part of emergency relief of any high groundwater pressure within the groundwater cut-off wall. This alternative design was agreed and adopted.

The storage tank itself is a large concrete structure, L-shaped in the overall layout plan as viewed from above, see Figure 3. The structure is some 7 metres deep. It is built in two phases according to the layout of the existing football pitches in order to maintain the use of some of the football pitches throughout the construction duration. The design allowed for soil cover of up to 800 mm thick on top of the storage tank for re-turfing works, which would enhance the resistance to the uplifting force.

The alignment for the stormwater culvert (Figure 3) runs parallel to the storage tank and lies between the “LCSD building” and the main excavation. The building is 2-storey LCSD changing rooms building for the users of the infield’s sports facilities, with the large Diamond Vision Screen mounted on its roof. In order to minimize disturbances to nearby sensitive structures, the construction sequence required early completion of the stormwater culvert, before the start of the excavation for the adjacent storage tank. This would minimise the effect of the main excavation on ground movements at the LCSD building.

5 GROUND CONDITIONS

Ground investigations were conducted in the 1990’s associated with development of the Hong Kong Jockey Club. Later, a two phased ground investigation was carried out in 2010 for USSS by DRILTECH comprising 36 drillholes, 1 trial pit, 30 inspection pits and 6 trial trenches and 8 GCO probes. A third phase of
investigation was undertaken following award of the contract to verify the design parameters for the cost saving design. This included an additional 10 boreholes and 10 Cone Penetration Tests (CPTs).

Overall the investigation showed the ground conditions comprise several metres of sandy clayey Fill underlain locally by Pond/Marine Deposits (soft clays) up to 5 metres thick. Below the soft clays is Alluvium of predominantly sandy silty CLAY but locally clayey silty SAND up to 17m thick. The underlying bedrock is Granite. Figure 4 is a summary of soil strata, and a section through the site is shown in Figure 5. Geotechnical properties of the strata are summarized in Figure 6.
Alluvium is found in all drillholes with a maximum thickness of 16.20m in drillhole BH1, locally interbedded with pond deposit in BH3 and IBH2, interbedded with estuary deposit in BH6 to BH8, BH11 and IBH2 and interbedded with marine deposit in BH10 and IBH2, which composed mainly of sandy silty clay and clayey silty sand with gravel materials. Colluvium is found in drillhole BH4 only with a thickness of approximately 9.20m, which composed mainly of clayey silty sand with gravel materials. The distribution of subsoil strata is rather complex, hence in model simulation a large number of different strata has to be included and their thicknesses vary greatly in different vertical sections.

Groundwater monitoring records show the highest level of groundwater to be close to ground level ~ +5mPD with a lower level at around +2.9mPD. The water table generally follows the ground profile which falls gently towards the north west.

6 SOIL-STRUCTURE INTERACTION MODELLING

As a part of the design for the Excavation and Lateral Support system, extensive Soil-Structure Interaction modelling was carried out. Two dimensional finite element analyses were conducted using the BD approved program PLAXIS version 9.02. Plane strain conditions are assumed. The analyses’ results were used to assess the ground movements at and around the excavation face, the sheet pile and the nearby sensitive structures. Initial analyses were conducted from early 2013. Five vertical sections within the area under construction were analysed, see Table 1. The analysis for each of the sections was performed through all the construction stages (phases) relevant to section from start to finish in a step by step procedure. The number of
ground strata included in the analysis varied from 24 to 10 depending on the section considered. Additionally, relevant structural elements were also included, such as sheet pile wall, concrete walls and slabs of storage tank, box culvert and LCSD Building. The total numbers of construction stages, time steps, ground strata and structural elements for each of the sections analysed are presented in Table 1. Examples of the finite element grid used for Section 10-10 are shown in Figure 7 for the initial ground condition before construction work and in Figure 8 for near completion stage with strutted support to the sheet pile wall.

Table 1 Summary of the Sections for PLAXIS Analyses Carried Out Initially

<table>
<thead>
<tr>
<th>Section No.</th>
<th>Total Construction Stages</th>
<th>Total time steps</th>
<th>Ground Strata</th>
<th>Structural Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-8</td>
<td>37</td>
<td>717</td>
<td>24</td>
<td>14</td>
</tr>
<tr>
<td>10-10</td>
<td>23</td>
<td>343</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>11-11</td>
<td>25</td>
<td>304</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>12-12</td>
<td>24</td>
<td>634</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>X</td>
<td>15</td>
<td>303</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

Note 1. Ground strata such as Marine Clay, Alluvial Clay, CDG each has assigned engineering properties such as unit weight, permeability, Young’s Modulus, etc.
Note 2. Structural elements such as sheet pile wall, concrete walls and slabs of storage tank, box culvert, LCSD Building, etc and elements acting as anchors.

For finite element analysis, the important values of Young Modulus for soils were derived from relevant considerations including initial values from early studies (Figure 6) and those estimated from later investigation as a part of the design including CPT results for soil layers above CDG and SPT “N” values from the tests on CDG and HDG layers. It is generally recognized that the Young’s Modulus for unloading and reloading could be much higher than that for the virgin loading. In the ground movement analysis, the Young’s Moduli for soil within the excavated area of the storage tank, where effective stress would be reduced, were taken to be 2 times the respective virgin moduli (unloading & reloading $E' = 2 \times$ virgin $E$). However, for determination of member forces and moments for structural design (under ULS) the virgin values were used.

Supplementary PLAXIS simulation was carried out and reported in early 2014 after initial part of the work has been done. This is to take account of the agreed change in the strut support arrangement in view of the much smaller measured ground movements than expected. This included further analyses on Sections 10-10, 11-11 and 12-12.
The total ground settlement around an excavation comprises two parts, settlement due to wall deflection and that due to groundwater drawdown. PLAXIS analysis was able to simulate the wall deflection and the associated ground settlement as well as the groundwater drawdown and the related settlement. For the area around the LCSD Building the results from PLAXIS for the maximum total ground settlement is 26 mm. The maximum estimated at the most critical high mast for lighting (out of the 10 masts) is about 22 mm. The range of possible maximum settlements at the edge of race track was estimated to be from 5 to 14 mm. Part of the jogging path and part of paved area at the east of the LCSD Building are in this zone and could be affected. It is considered that the impact to the race track and the area east of LCSD Building are much less critical than the impact to LCSD Building itself and the high masts.

![Figure 8: The PLAXIS Finite Element Grid for the Excavated Ground with Strutted Support (Stage 21)](image)

It is considered that the results from PLAXIS simulation are within the settlement limit generally adopted for settlement control at or near structures. Therefore the Action Level was set at 25 mm, with Alarm and Alert Levels set at 20 and 10 mm respectively.

7 GEOTECHNICAL CHALLENGES

The construction works started from September 2012, and reached substantial completion of Phase One by March 2015. The works commenced with construction of the pump house followed by excavation for the storage tank. As the excavation progressed, temporary support is provided by installation of sheet piles using a “silent piler” to minimize any noise impact to the public in the vicinity. Thickness of the soft layer is critical in the control of movements during the work, and the thickness contour is shown in Figure 9. The progress of work up to May 2014 is illustrated in Figure 10.

The cost saving design requires the sheetpile wall around the storage tank to act as groundwater cut-off wall as a part of permanent work to minimize the water pressure under the tank. The sheetpile wall has to perform this function well or else there could be a high uplift force, nevertheless there is a contingency measure for such an event by activating the relief wells. Pumping test for demonstrating water tightness of the sheetpile wall was conducted. Although some seepage was observed from the sheetpile wall, the amount is considered small and well below the limit allowed for in the design.

The design also requires excavation of about 7 metres of the superficial deposits, with much of it below the level of the ground water table. The LCSD building with Diamond Vision Screen on top, and the high mast supporting the flood lighting (> 20 m high) are both quite close to the excavation. According to ArchSD as-built drawings, the building is founded on a raft footing, a hollow box structure embedded about 1.6m below ground (BV, 2012). The hollow box reduced the load on the soil strata below. The high mast (visible in...
Figure 12) poses a particular challenge. It is founded on shallow spread footing, size 4.3 m x 4.3 m at about 1.6 m depth, and only a few metres from the excavation. Local softening due to heavy rain exacerbated the potential movement and will be discussed later. The challenge for the construction was to have adequate excavation support system, with control on construction sequence, and continuous monitoring / alert system for on-going detection of any excessive movement and timely remedial action.

The design of the Excavation and Lateral Support is a typical arrangement with multiple struts required as excavation proceeds. One of the particular challenges arose at the sheet pile wall immediately in front of the LCSD building. This is the most sensitive area but made more complex because of the location of the box culvert between the storage tank and the building. Programme requirements dictated early construction of the box culvert between the pair of sheet piles shown in Figure 11. The design indicated that some movement of the LCSD building and area to the east of the building would occur during trenching and installation of the box culvert and this movement would be further developed during excavation for the adjacent stormwater storage tank. As a cost-effective alternative for extensive ground treatment works, pre-loading of the struts was introduced to mitigate the predicted movement of the building. The lateral support work in progress is shown in Figure 10.
8 INSTRUMENTATION AND MONITORING

Assessment of the results from the finite element modelling could be made by comparing the results with the measured movements from instrument monitoring including those on sensitive facilities located close to the race course compound. This was done based on the monitoring report of cumulative readings of all instruments up to the end of February 2015. For ground settlement, it is mostly below Action Level of 25 mm, with only about 10% of ground settlement markers (19/189) having settlement readings exceeded the level. The percentage is also relatively low, about 18%, for building settlement markers (12/68), and 5% for tilt markers (4/83). Most other readings show little movements. Apart from SSI modelling, other factors during construction have to be taken account of, such as the mis-match in the sequences of excavation work and lateral support work, and heavy rainfall at vulnerable stages of work. For the exceedance cases, all parties were aware and take appropriate actions since after Alert Level has been reached. Some minor damages such as cracked paving and surface drainage channels did occur and were immediately rectified but no major damages were observed. Two cases of exceedance are presented below to show the geotechnical challenges encountered in actual construction work.

Figure 12: Excavation and Lateral Support Woks in Progress

The contour plan in Figure 9 shows the clay is up to 3 metres thick below the building. The LCSD building is on a spread raft foundation with the existence of soft clay layer below it. Geotechnical instruments installed around LCSD Building are summarized in Table 2.

In the area near LCSD Building, up to 4mm of ground settlement was recorded on by October 2013 due to nearby excavation for the box culvert. Settlement continued but gradually reduced, stabilizing from end of 2013 to June 2014, see Figure 15(a) for ground settlement marker GS34, the location of which is shown in Figures 3 & 13. This marker is located near a surface u-channel in the area east of LCSD Building. Starting from July 2014 substantial settlement occurred and progressed at a high rate concurrent with the rapid excavation in the area, while strutting support work was not yet catching up. The settlement also appeared to be accelerated at times of heavy rainfall. High ground settlement (26mm) in this area is anticipated according to PLAXIS results discussed earlier. During this period, the building settlement markers at LCSD Buildings recorded fairly uniform settlements along the edge parallel to the excavation indicating very small tilting and distortion of the building. Immediate response to readings included increasing the monitoring rate, reviewing the construction sequence and immediately repairing gaps between the LCSD building and the adjacent ground to avoid water ingress. It became apparent during the review that the building itself was not subject to significant movement but that adjacent channels at ground level had moved during excavation. This movement was not critical to the building and was resolved by an adjustment to the construction sequence.
Table 2 Summary of Instrumentation around LCSD Building

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Purpose</th>
<th>Ground Level, mPD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground Settlement Marker</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS33 – GS41 (10 Nos.)</td>
<td>To monitor the ground settlement around LCSD Building</td>
<td>+4.371 - +4.796</td>
</tr>
<tr>
<td><strong>Building Settlement Marker</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS1 – BS15A (15 Nos.)</td>
<td>To monitor the building deformation/tilting</td>
<td>+4.862 - +6.530</td>
</tr>
<tr>
<td><strong>Inclinometer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN8 - IN9</td>
<td>To monitor the deformation profile inside soils</td>
<td>+4.362 - +4.450</td>
</tr>
<tr>
<td><strong>Piezometer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP4</td>
<td>To monitor the ground water level and pore water pressure around the LCSD building</td>
<td>+4.45</td>
</tr>
<tr>
<td><strong>Extensometer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1 - E2</td>
<td>To monitor the deformation between soil layers</td>
<td>+4.473 - +4.535</td>
</tr>
<tr>
<td><strong>Tilt Marker</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T9 – T20</td>
<td>To monitor LCSD light mast</td>
<td>-</td>
</tr>
</tbody>
</table>

The teams involved were alerted to the situation and the increased observation and rectification of existing facilities and newly built structures (e.g. box culvert) were carried out. No significant damage was observed on the newly built structures and the LCSD building while there was localised damage to the drainage channel near the building. The settlement stabilized by the end of August and during September 2014, as the full strut supporting work was completed. There have been no significant settlements since September 2014. The progress and magnitude of ground settlements around the LCSD Building (see also Figure 14) at three settlement markers can be seen in Figure 15(a).

![Figure 13: Instruments around LCSD Building](image)

![Figure 14: The Diamond Visual Screen on top of LCSD Changing Rooms Building](image)
Close attention was paid to the high mast for lighting T15 as it is located near the construction area as shown in Figure 3. The data from the reading of tilt marker T15 are shown in Figure 15(b). The tilt marker T15 is of the type recommended by GEO (2012) with a vertical distance of 5 m between the two marker-points. The location of T15 is indicated in Figure 3. The first significant movement of about 12 mm occurred in August 2013, related to the excavation for underground storage tank, possibly also included unknown measurement anomaly due to the change in monitoring team at the time. Responses to rainfall events similar to that at GS34 were also observed for T15. The most significant movement of up to 20 mm was observed in April 2014 during the construction work of the storage tank in the vicinity. The relevant teams were alerted and prompt attention and collaboration was initiated. The movements were quickly stabilized within about a month (Figure 15 (b)) at the completion of base slab of the tank and the lateral support system nearby.

The construction of HVUSSS is well on the way to completion on schedule for both Phases One and Two.

9 CONCLUSIONS

An innovative project to alleviate the serious flooding problems in Wan Chai – Happy Valley area is in progress with Phase One substantially completed. Temporary excavations had been carried out in close proximity to existing sensitive structures. A plan of continuous monitoring and construction control has been implemented from the start within the frame work of the newly introduced NEC Conditions of Contract. The monitoring and control work has been well conducted with effective co-operation among the Project Manager, Contractor, Temporary Works Designer and the Independent Geotechnical Engineer (IGE). Analyses to determine ground movement, using PLAXIS finite element simulation as a Soil-Structure Interaction modelling, was carried out from the design stage and well into the construction stage so that adjustments can be made for the modelling to be more representative of the actual conditions. The simulation results compared with the actual measured movements showed that only 5% to 18% of all instrumented locations have readings exceeding the maximum limit specified. Two exceedance cases are described. They showed that compliance with the designed construction sequences in all stages is important in reducing any potential problems during the work. The presented cases illustrate the vital role and effectiveness of continuous instrument monitoring and reporting in the control and management of geotechnical works, so that any possible problems are detected early and prompt co-ordination of actions can be carried out to prevent more serious problems from occurring.

ACKNOWLEDGEMENTS

This paper is published with the permission of Drainage Services Department, the Government of the Hong Kong Special Administrative Region (HKSAR).
REFERENCES

