Foundation Works for a Sewage Treatment Plant using Ground Improvement Methods in Malaysia

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The largest Sewage Treatment Plant in Malaysia was recently completed in 2008, which caters to an ultimate capacity of 1.2 million population equivalent. The project successfully improved Georgetown’s (in Penang) sewage disposal system and rehabilitated an unsanitary site. The sub-soils at the site are primarily soft marine clay deposits up to 10m deep. One third of the site was covered by a former garbage dump site. The original proposed foundation was conventional piled foundation but this was later found to present a few undesirable construction limitations such as noise pollution during pile driving; and transportation and storage of pre-cast piles on a congested site. Alternative ground improvement technology comprising of Vibro Concrete Columns, Cement Columns and Vibro Stone Columns were introduced to support the process tanks and ancillary structures. The construction methods are considered environmental friendly as they produced minimum spoil and consumed relatively low energy. This paper describes the design and construction of the alternative ground improvement methods including quality control measures and insitu tests. Hydrotest and settlement monitoring results, proving tank performance, are also presented.

Keywords: Ground Improvement; Vibro Stone Columns; Vibro Concrete Columns; Cement Columns; Sewage Treatment Plant.
1.0 Introduction

The old sewage treatment system for Georgetown (Capital of Penang Island, Malaysia) was more than two decades old. Sewage was treated to a less than desirable extent before sludge was channeled 2 km offshore. The area surrounding the sewage treatment plant has been a domestic dumping site and although no longer in use, was a major source of environmental pollution for more than 20 years. Further, squatters lived around the rubbish dump. The polluted and smelly environment was a health hazard.

A modernized sewage system for the inhabitants of Georgetown, Penang was deemed necessary by the Government of Malaysia. The Jelutong Sewage Treatment Plant (JSTP) commenced construction in 2005 and was completed in 2008. Besides delivering a modern STP, the project allowed the rehabilitation of the surrounding area. The treatment plant comprises of 12 nos. of Sequential Batch Reactor (SBR) tanks and associated process tanks to cater for an ultimate capacity of 1.2 million population equivalent (PE).

The foundation work for the tank structures was not a straightforward task given the presence of thick marine clay deposit and heterogeneous dumped waste materials. Ground improvement technology comprising of Vibro Stone Columns, Vibro Concrete Columns and Cement Columns were utilized as the foundation system. This paper presents the experience for using these Ground Improvement schemes as alternative to conventional piling system.

2.0 Site Development and Subsoil Conditions

Prior to construction of the structural works, site preparations works were done between 2000 and 2004. Chen and Tan (2002) described clearly the history of these preliminary works.

The subsoil conditions primarily consist of about 5m thick reclaimed fill underlain by about 5m thick soft to firm silty clay deposit. Stiff silt can be found at a depth of about 10m. Dense and hard stratum was encountered at a depth of more than 40m. Figure 1 shows that the extent of waste (domestic garbage) dump demarcated from trial pits carried out at site covering approximately one third of the site. Table 1 presents the general soil profile from boreholes.

Laboratory tests such as Atterberg limits, sulphate content, chloride content and pH value were conducted on samples recovered from marine clay deposits, waste dumps and landfill leachate (contaminated water). Laboratory results indicated that plasticity index ranges between 20% to 40%; very low sulphate and chloride content (< 0.2%) and average pH value to be around 8. Based on the recommendation in Concrete in Aggressive Ground (BRE Special Digest 1 (SD1:2005)), the project site requires no additional protective measures for the proposed concrete/cement based foundation systems.

3.0 Treatment Plant Structures

The treatment plant has 12 nos of Sequential Batch Reactor (SBR) tanks and associated process tanks as shown in Figure 1. The SBR tanks are major process tanks in the entire plant and were designed as twin tanks made up of reinforced concrete (total 6 nos. of twin tanks separated by 25mm gap). The dimension of each twin tank is approximately 90m x 60m x 7m high. One of the twin tank (SBR 1&2) has additional 2 floors on top of the tank to accommodate administration offices and storage area for process equipment.

Other associated process tanks and ancillaries structures include Pump Station, Sludge Holding Tanks, Anaerobic Digester, Gas Storage Tanks, Centralized Sludge Storage, Effluent Disinfection
Area, Sub-station and Utilities trenches. A permanent retaining RC wall up to 4m high along the perimeter of the plant was also part of the development.

**Figure 1: Foundation schemes and extent of waste dump**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Average depth (m)</th>
<th>Average SPT ‘N’</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reclaimed fill/Domestic waste dump</td>
<td>0 – 5</td>
<td>6 – 10</td>
</tr>
<tr>
<td>2</td>
<td>Soft Clay</td>
<td>5 – 12</td>
<td>2 – 4</td>
</tr>
<tr>
<td>3</td>
<td>Medium stiff to stiff sandy Silt</td>
<td>12 – 15</td>
<td>6 – 15</td>
</tr>
<tr>
<td>4</td>
<td>Very stiff sandy Silt</td>
<td>15 – 40</td>
<td>15 – 30</td>
</tr>
<tr>
<td>5</td>
<td>Dense/Hard silty Sand</td>
<td>&gt; 40</td>
<td>&gt; 30</td>
</tr>
</tbody>
</table>

**Table 1: General subsoil profile from soil investigation works**

### 4.0 Foundation System using Ground Improvement

#### 4.1 Conforming Foundation System

The conforming foundation system specified precast RC spun piles driven to over 30m depth; but this was later found to present a few undesirable construction limitations such as noise pollution during pile driving; and transportation and storage of pre-cast piles on a congested site; relatively long construction time; as well as relatively high cost. Pile wastage was also needed to be properly taken care of.
4.2 Performance Criteria
The foundation system was required to carry SBR tank loads from 96 kPa to 126 kPa with the total settlement of the structure required to be less than 75mm and differential settlement to be less than 1:360. Other lighter structures had similar settlement criteria.

4.3 Alternative Foundation System
As an alternative design and build proposal by the Specialist Contractor, various ground improvement techniques i.e. Vibro Concrete Column (VCC), Cement Columns (CC) and Vibro Stone Columns (VSC) were instituted to support tank structures and ancillary structures. The design concept of ground treatment requires the weak superficial deposits to be treated such that the structures are founded on raft sitting on improved soil. The design intention was to found all the heavier structures on CC and lighter structures on VSC. Within the garbage area, VCC was utilised since soil mixing will be inappropriate. The raft ensures that the superstructure loadings are distributed evenly onto the soil and column matrix. Details of distribution layer and concrete raft (e.g. SBR tanks) are presented in Figure 2.

4.4 Design of Ground Improvement Foundation System
4.4.1 Design of Vibro Concrete Columns
The diameter of Vibro Concrete Columns (VCC) was about 0.6m with working loads of 35tons. Typical spacing of columns ranged between 1.8m c/c and 1.6m c/c to support foundation loads between 96kPa and 126kPa, respectively. The depth of columns was up to 14m. The VCC was designed to achieve an insitu Unconfined Compressive Strength (UCS) of around 10MPa.

4.4.2 Design of Cement Columns
Cement Columns (CC) consists of mechanically mixed cement grout with in-situ soil forming a “column-like” element of 0.8m diameter. The columns were designed to carry working loads of 30 tons. Typical spacing of columns ranged between 1.7m c/c and 1.5m c/c to support foundation loads of 90kPa and 110kPa, respectively. The depth of columns was up to 9m. The CC was designed to achieve 1MPa UCS strength.

4.4.3 Design of Vibro Stone Columns
Vibro Stone Columns (VSC) were designed to support lighter structures; e.g. Gas Storage Tanks and Sludge Holding Tanks, Utility Trench as well as RC retaining wall along the perimeter of sewage plant. The diameter of Vibro Stone Columns was 1.0m. The foundation loads of the structures varied between 40kPa and 70kPa and the typical spacing under these loadings ranged between 2.2m c/c and 1.8m c/c. The Vibro Stone Columns under the perimeter RC retaining wall were designed as settlement reducing elements. The column spacing varied between 1.4m c/c and 1.8m c/c and the area was surcharged prior to construction of the RC wall.
4.5 Execution

Vibro Stone Columns and Vibro Concrete Columns were constructed using Vibro Replacement method (BS EN 14731:2005; Yee & Raju (2007)). Cement Columns were executed in the same manner as Deep Soil Mixing method (BS EN 14679:2005).

4.5.1 Execution of Vibro Concrete Columns

Vibro Concrete Columns were installed using custom-built Vibro Replacement machines where no water jetting is required. Concrete was fed using a skip to the top of vibrator and transferred through a special delivery tube attached to the vibrator directly into the ground. This method uses a pure displacement process where no soil or garbage was removed. After reaching the desired depth, the vibrator was pulled up slightly and the concrete was discharged to fill the cavity. During re-penetration the concrete was compacted. The method successfully installed the columns without removal of the existing garbage.

4.5.2 Execution of Cement Columns

Cement Columns were constructed using hydraulic boring rig mounted with high revolution turn-table. The mixing process used 3 level mixing blades, rotating at 60 to 70 revolution/minutes. Cement grout was injected into the soil during penetration at a pressure of 60 bars which also assisted the penetration of the mixing blades. When the designed depth was reached, mixing blades were maintained at the termination level for a few minutes to ensure homogeneity of column was achieved. Then the mixing blades were lifted at a fixed speed. The penetration and the withdrawal speed were controlled to achieve the required cement content and blade rotation number more than 400/m. (M. Topolnicki, 2004).

4.5.3 Execution of Vibro Stone Columns

Vibro Stone Columns were formed using Top-Feed Wet Method. The method is extensively used in Malaysia as described in Yee & Raju (2007) and will not be repeated here.
5.0 Quality Assurance and Quality Control

To ensure quality, the installation works were monitored in real time by computers to ensure that the columns were consistently formed.

Selected VCC and CC columns were excavated for examination. It was proven that domestic waste material was displaced sideways during installation of VCC and did not contaminate the concrete. For CC columns, it was demonstrated that the mixing was uniformed.

Some working columns selected by the supervising consultant were tested up to 1.5 times the working load using plate load tests over 3-cycles. A total 48 nos (13 nos VCC; 13 nos CC and 22 nos VSC) single column and 13 nos (7 nos VCC and 6 nos CC) four-column group load tests were carried out to prove the performance of the constructed columns. All the load tests were successfully carried out which proved adequate bearing capacity with acceptable settlement (<25mm).

Concrete samples for VCC and backflow samples for CC were collected for unconfined compression tests. Further, coring was carried out on selected working columns to retrieve samples of 50mm to 100mm diameter. The retrieved samples were subjected to unconfined compressive strength (UCS). Results of tests on VCC samples showed UCS in the acceptable range of 10MPa to 40MPa. For CC samples, the achieved UCS strength was in the acceptable range of 2.5 MPa to 11.0 MPa.

6.0 Settlement Monitoring During HydroTest

Hydro tests were carried out on every SBR tank. The main objective of the Hydro test was to prove the water tightness of the structure prior to actual operation. The rate of water filling was about 0.5m per day and the maximum load was maintained for minimum 2 weeks (rest period) after reaching to full water height. Upon completion of the rest period, half of the twin tank was emptied, whilst maintaining the full water load in the other half to prove water tightness of the central wall as well as to ascertain foundation performance for loading and unloading sequences during operational stage.

Settlements were monitored using precise survey instruments during and after Hydro tests. The Hydro tests for 3 nos. of twin tanks (SBR 1&2, SBR 3&4 and SBR 7&8) supported on VCC foundation and remaining 3 nos. of twin tanks (SBR 5&6, SBR 9&10 and SBR 11& 12) supported on CC foundation were successfully completed. Settlement monitoring data over a 10 month period indicated good performance with maximum settlements in the range of 5mm to 20mm. The typical results of settlement monitoring for SBR 7&8 are shown in Figure 3.
7.0 Conclusion

The largest sewage treatment plant in Malaysia was completed in 2008 (Figure 4). Besides providing a modern facility for the inhabitants of Penang, the project also rehabilitated an environmentally undesirable site. An optimised foundation system using ground improvement technology i.e. Vibro Stone Columns, Vibro Concrete Columns and Cement Columns were used to replace conventional driven precast RC spun piles to support the process tanks and ancillary structures. The design of the Ground Improvement System in the challenging ground, comprising soft marine clay and garbage landfill has been presented. The installation works were completed on time using customized machines. The construction methods are considered environmentally friendly as they produced minimum spoil and consumed relatively low energy. The performance of the foundation has been proven by a series of load tests, hydrotests and subsequent, operation.

Figure 3: Typical results of settlement monitoring (SBR 7&8)
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