Remedial Piling and Settlement

Twin Residential Towers

Scenario Overview and Data Compilation

Introduction

The redevelopment of a major inner city riverbank included the construction of several residential towers and a number of other structures. The proposed construction site consisted of several metres of fill material overlying approximately 15 m of highly compressible silty clay (Unit 1). Directly below the compressible silty clay layer, a layer of stiff, overconsolidated silty clay material (Unit 2) extends for approximately 10 m. Layers of gravel (Unit 3), stiff clayey silt (Unit 4) and clayey silts with some sand (Unit 5) then overly the siltstone bedrock (Unit 7).

Initial geotechnical foundation design for the towers recommended bored piles founded in the siltstone (Unit 7). An alternate bid for driven piles for two of the towers, Towers 2 and 3, was proposed by the piling company to reduce the project cost. There was concern that driven piles may not penetrate through the gravel material (Unit 3) to the siltstone (Unit 7) as required in the foundation design. The alternate bid was accepted in place of bored piles after a test pile was successfully driven to refusal in the siltstone (Unit 7).

However, a significant number (most) of the working piles refused at various depths within the gravel layer (Unit 3), rather than in the siltstone (Unit 7) as required by the design. Concerns were raised with respect to total and differential settlement of the footing system caused by the additional load placed on the more compressible (Unit 4) clayey silt. After further ground investigation and analysis, it was decided that the settlement of Tower 2 was likely to be acceptable, but unacceptable for Tower 3.

To reduce the estimated settlement of Tower 3, additional steel H-piles were integrated into the footing system for this tower. These H-piles, driven to refusal in the siltstone (Unit 7), were used to supplement the driven piles in the more heavily loaded footings.

The settlements of both Towers 2 and 3 were monitored at regular intervals during construction with over a hundred individual settlement points at each of the towers.

Initial Site investigation

An initial site investigation for Towers 2, 3 and the adjoining podium construction included 12 boreholes drilled to the level of, or below, the Siltstone formation (Unit 7). The borehole logs from boreholes 1, 2, 5 (Tower 2), 8, 10 and 11 (Tower 3) are attached in Appendix A. All borelogs end at the top of the siltstone.

Appendix B shows a plan view of the site, marking the locations of the logged boreholes in relation to the proposed construction. Two inferred cross sections across the site are included based on information obtained in the borelog data.

In addition to the drilled boreholes, a series of 9 electric friction cone penetrometer soundings were obtained at various locations across the proposed site. The results from the penetrometer test are attached in Appendix C.

Since the heavily loaded towers were designed to be founded in the Siltstone formation (Unit 7), no samples were obtained in the lower, stiff clayey silt (Unit 4) material during the initial investigation.

The groundwater table was assumed to be at an approximate elevation of 0.0m, compared to the natural surface level with an elevation of about 1.5 to 2m.

Subsequent site evaluation

To obtain data on the compressibility properties of the clayey silt (Unit 4), an additional 4 boreholes were drilled adjacent to the proposed tower sites. Samples from these bores were used for laboratory testing to assess the consolidation and creep characteristics of the clayey silt (Unit 4) material. The borehole logs are attached in Appendix D.

Site Geology and subsurface condition

The general area of the site is located on Quaternary age sediments of a river delta. These were deposited during phases of sedimentation and erosion associated with Quaternary age sea level changes. At this site sediments rest on uneven, Pre-quaternary terrain formed by Tertiary age sediments or volcanics, in turn overlying Silurian age siltstone and sandstone (Unit 7). The silty clay (Unit 4) underlying the gravel (Unit 3) is of Tertiary age. The results of classification tests performed on selected samples recovered in the investigation are attached in Appendix E.

Fill

The fill material at the site consists of recently (<100 years) placed clean sandy clays and sands. Generally the fill is less than 2m in depth.

Quaternary Age sequence

Unit 1: Silty clay

This dark grey silty clay is present across the entire site with an observed thickness between 12 and 20m. This highly compressible material is susceptible to both primary consolidation and secondary compression under loading. Regional creep settlement of about 5 to 10mm per year has been measured at nearby sites. The consistency of the material increases with depth from soft to firm.

Unit 2: Silty clay

This silty clay comprises a combination of silty clay, sandy clay and occasional clayey sand, which appears grey or yellow brown in colour. Found across the entire site directly beneath the Unit 1 silty clay, the Unit 2 silty clay varies in thickness between 4 and 13m and has a consistency from firm to very stiff.

This material is overconsolidated and is generally considered to experience low levels of settlement under modest applied stresses. This material was assessed to have an undrained shear strength of between 50 kPa and 200kPa.

Unit 3: Gravel

Comprising sands and gravels with some clay, the gravels are 1 to 6m thick. Based on SPT results, this unit is considered to be medium dense to very dense in consistency and of generally low compressibility.

Tertiary Age sequence

Unit 4: Clayey silt

This clayey silt material typically comprises silts, clayey silts and fine sandy silts, including minor ligneous silts. This unit was observed in the boreholes to be up to 5m thick beneath the towers and of stiff to very stiff consistency.

Unit 5: clayey silts with some sands and gravels

Unit 5 material was found to be a dense to very dense combination of clayey sands, clayey silts and gravels, including some non-marine clayey sands and clean quartz sands. This unit was found to be up to 8m thick. SPT 'N' values ranged from approximately 20 to 50 within this material. The unit was found both above and below the local volcanic basalt (Unit 6) and is generally of low compressibility.

Unit 6: Local basalt

Local deposits of Unit 6 type basalt were found in a few of the investigation boreholes. No significant basalt deposits were encountered in the vicinity of the tower footprint for Towers 2 or 3.

Silurian Age sequence

Unit 7: Siltstone baserock

The basement rock at the site consists of Silurian age interbedded siltstone with lesser interbedded fine sandstone. The depth of the basement rock varies between approximately 35 and 42 metres below the ground surface (RL -33.5 and RL -40). The rock was found to be highly to slightly weathered and of low to medium strength.

Laboratory investigation

Potential settlement of the driven piles was considered likely to occur within the clayey silts (Unit 4) below the gravels (Unit 3). Soil samples from subsequent boreholes 1, 2 and 3 were tested to establish their consolidation and creep characteristics of the Unit 4 material. The oedometer test results are attached in Appendix F.

History of footing construction

The initial foundation design for the structure prescribed the use of bored piles founded in the siltstone (Unit 7). An alternate bid, proposed by the piling company to utilise driven piles instead of bored piles, was later accepted. Following installation of the precast piles for the towers, excavation of lift overrun pits was carried out at both Towers 2 and 3. The unsupported excavation in the fill and Unit 1 type material resulted in significant lateral movements of the piles, in excess of 400mm at some locations. As a result, it was considered there was an unacceptable risk that the moment capacity of the piles may have been exceeded and the durability of a significant number of installed piles may have been compromised. Additional precast piles were installed to replace the piles that had been assessed to be unsatisfactory.

Towards the completion of installation of the additional piles it was reported that most of the piles for both Towers 2 and 3 had not penetrated through the Unit 3 and Unit 5 material as required by the design. The load from the towers would therefore be directly applied to the Unit 4 material underlying the toe of the piles, resulting in an increase in settlement. Preliminary estimates of total and differential settlements of the installed piled footings indicated that the estimated settlement of Tower 2 was considered acceptable to the structural designers. Tower 3 was considered to be unacceptable.

Steel H-piles were therefore adopted as a remedial solution to support the Tower 3 footings. The H-piles were founded in the Siltstone (Unit 7) and were installed only for selected, highly loaded columns. Appendix G sets out the locations of the precast concrete piles and H-piles.

Loadings

The layout of the columns for each of the two towers and surrounding structures are attached in Appendix G. For each column, the pile locations and pile numbers are indicated. For Tower 3 the column specifications are tabulated to indicate number of H-piles per footing. Appendix H outlines the serviceability loads associated with each column and the number of H-piles assigned to each column footing.