A Review of Micropiles Beneficial Aspects through a Case History near False Creek, Canada

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Micropiles, also known as minipiles are a type of deep foundations composed of placed or injected grout and steel reinforcement with diameters of typically smaller than 300 mm. Micropiles have recently gained higher acceptance in geotechnical engineering practice and have been utilized as a foundation solution in numerous applications such as seismic retrofitting, resisting uplift loads, control of settlements and underpinning of existing foundations. This paper presents a case history where micropiles were used as supporting elements for underpinning and controlling settlements of an existing foundation system adjacent to a 15 m shored cut for a residential tower development, located in close proximity to False Creek, in Vancouver, Canada. The existing foundation system, supporting each pier of an elevated viaduct, included a pilecap and a group of cast-in-place reinforced concrete piles with pile tips located significantly above the final excavation grades. The 15 m shored excavation was proposed to be completed directly adjacent to the existing pilecaps. The advantages of using micropiles in controlling the movements of the existing foundations of a sensitive structure (bridge viaduct) will be demonstrated. Laser displacement meters (LDM's) and tilt meters (TM's) were used to monitor the 3-dimensional displacements and rotation of the existing pilecaps during the excavation and shoring. In addition, traditional precision surveys were carried out to verify the data of the automated monitoring system. Monitoring results showed excellent performance for the micropile supported piers in a congested construction area to control the displacement/rotation of the existing viaduct structure adjacent to the shoring walls.

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INTRODUCTION

Micropiles were first introduced to the geotechnical engineering practice in early 1950's in Italy and mainly used for underpinning the historic structures with settling foundations (Shong and Chung, 2003). Micropiles have recently gained increased acceptance in geotechnical engineering practice and have been utilized for seismic retrofitting, resisting uplift loads, control of settlements and underpinning of existing foundations. This paper presents a construction case history of the application of micropiles in controlling settlement of an existing highly sensitive foundation system supporting a viaduct. The project included a residential tower (South Tower) with five levels of underground parking, located about 150 m to the north of False Creek, in Vancouver, Canada. Figure 1 shows the construction site area in relation to the surrounding structures and features.

Figure 1. Site area in relation to surrounding developments/features (Google Image, 2014)

The high significance of this project was mainly due to the presence of sensitive structures such as the Georgia Viaduct and the Rogers Arena building (Vancouver's Ice Hockey Stadium) in the vicinity of the 15 m deep shored cut. The north side of the shoring line was located immediately adjacent to the Rogers Arena building and two pilecaps supporting the existing Georgia viaduct. The performance of both of the noted public structures are of high importance for the City of Vancouver and the safety of its residents that utilize the viaduct as a major commute to downtown Vancouver. Figure 2 displays a partial site plan showing the excavation area with respect to the adjacent sensitive structures.

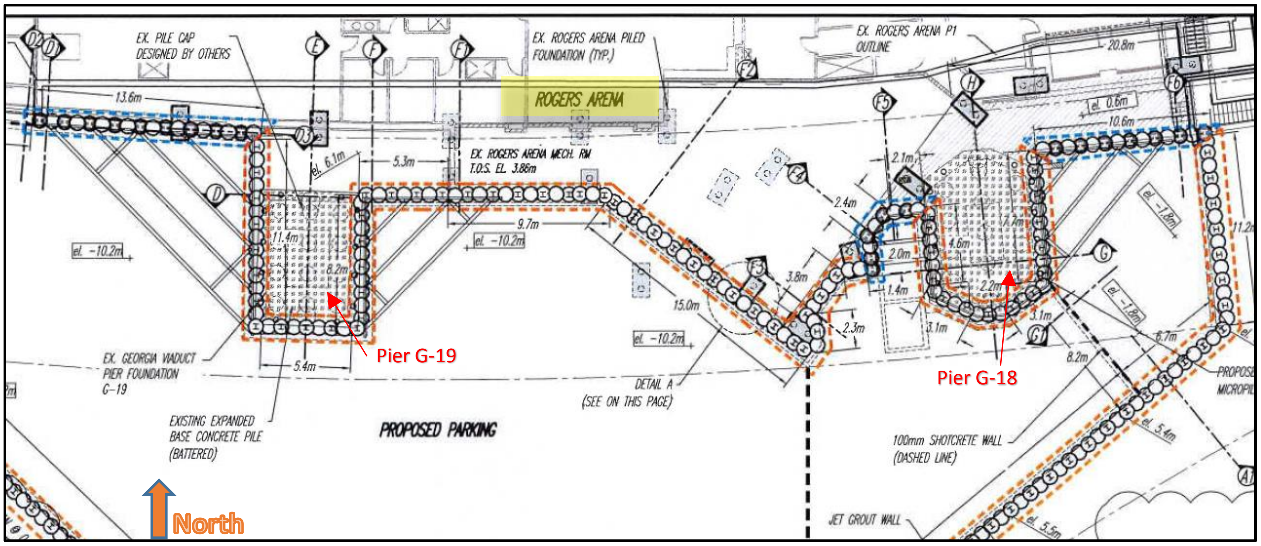

Figure 2. Partial site plan showing the viaduct pilecaps and Roger Arena in the vicinity of shoring area (GeoPacific's Drawing)

SITE CONDITIONS

The approximately 2,000 m^2 site area is bounded by the Rogers Arena building and the Georgia Viaduct piers to the north and City roads to the south, west and east. Prior to the construction, the site was generally level with an average geodetic elevation of about 4.5 metres. Based on the results of a geotechnical investigation program, completed by GeoPacific Consultants Ltd., the subsurface soils onsite were identified as 7 to 9 m of fills, overlying 2 to 3 m of a native deposit of firm to stiff silty clay with sand, underlain by dense to very dense silty sand with some gravel (glacial till). The dense glacial till was noted to be encountered at about 9 to 12 m depth.

Historically, the shoreline of False Creek was located northwest of the subject site and subsequently large amounts of fill materials were used to reclaim portions of False Creek. The fills can be separated into two different units due to differences in consistency and relative density of soils, observed during the geotechnical investigation. 'Recent fill' can generally be classified as compact and was noted to contain a smaller fraction of refuse materials and/or organics s compared to the originally deposited fills. The underlying historic fill is a heterogeneous unit, placed during the original reclamation of False Creek. The static groundwater level was identified at about 5 m depth over the site area. Each of the two viaduct piers, present within the construction area were supported on a group of cast-in-place piles. These piers are shown as G-18 and G-19 on the site plan (Figure 2).

SHORING AND UNDERPINNING DESIGN

The foundation system of the two viaduct piers that were adjacent to the construction area included concrete pilecaps, supported on reinforced cast-in-place concrete piles. A review of as-built drawings showed that a total of twelve and thirteen cast-in-place concrete piles supported the pilecaps of piers G-19 and G-18, respectively. Pile tips were located at about 7 to 8 m below original site grades. Figure 3 shows a plan view of the pilecaps with the arrangement of the original concrete piles. The width and length of the pilecaps were in the range of 4 to 5 m and 6.5 to 8 m, and as shown in Figure 3, the 15-m deep shoring line was proposed to be adjacent to the pilecaps (within less than 1 m distance from the edge of pilecaps).

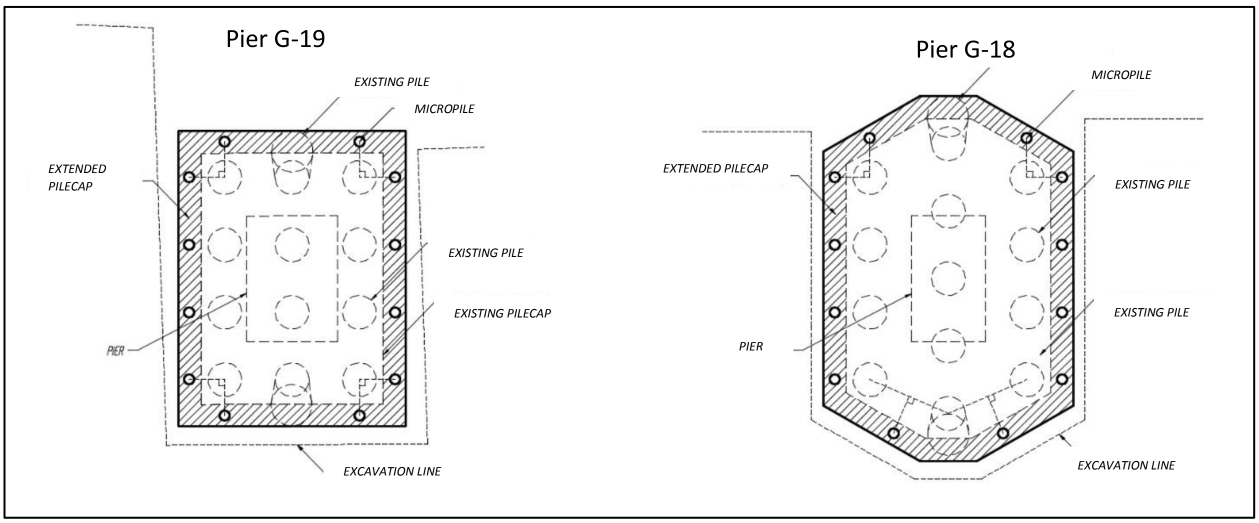

Figure 3. Plan view of the pilecaps supporting Georgia viaduct piers in the subject site area (GeoPacific's Drawing)

The shoring system, designed by GeoPacific Consultants for this project included a combination of anchored jet-grout walls, within the upper portions, and conventional anchored shotcrete walls, for the lower portion of shoring (below the level of glacial till layer). Details of the jet-grout shoring system is not included in the scope of this paper and was presented in a separate paper (Gazzarrini et al. 2016). A typical section view, showing the designed shoring system, and the position of the shoring walls in relation to the foundation system of the viaduct piers is presented in Figure 4.

Given the final grades of excavation and the line of shoring in relation to the existing piles and pilecaps, as schematically illustrated in Figure 5, the interaction between the existing concrete piles and surrounding soils was anticipated to be influenced due to the expected movements of the underlying soils (re-arrangement of soil particles) under the effect of excavation and ground relaxation. This could result in excessive settlements of the entire foundation system, including the pilecaps, piles and their surrounding soils within the shoring walls around the pilecaps.

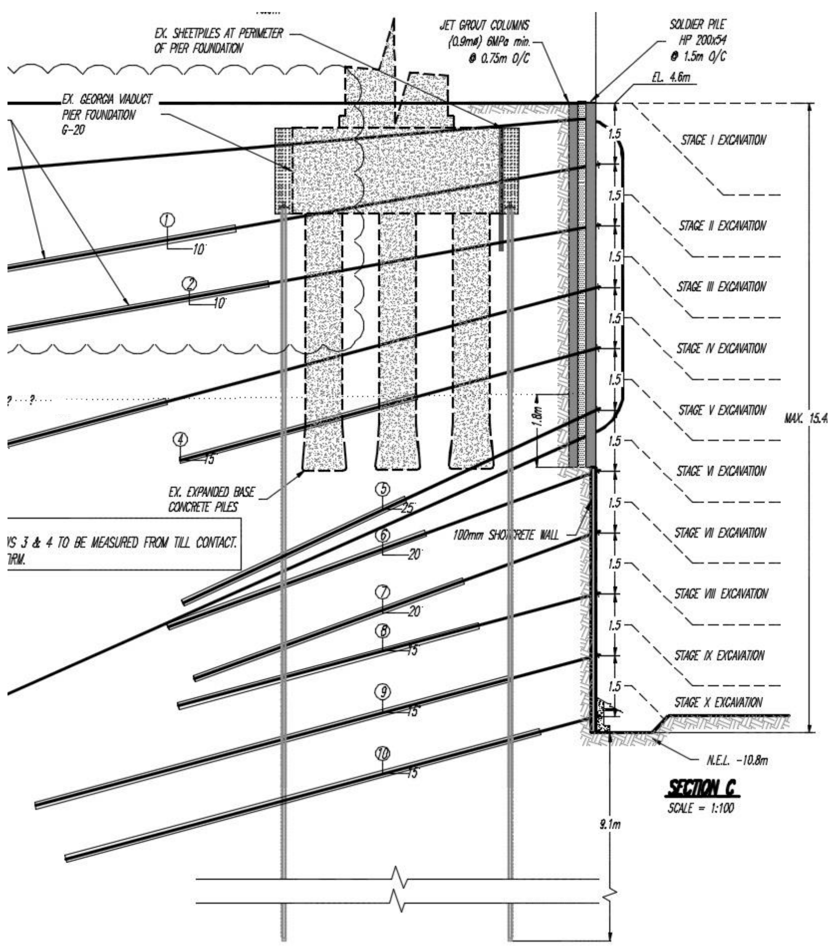

Figure 4. A typical section view of the shoring and underpinning system at the location of pier G-19 (GeoPacific’s Drawing)

The anticipated settlements are proportional to the elevation difference between the pile tips and the final excavation grades such that the significant elevation difference between the toe of original piles and the final excavation depth would result in larger settlements in the foundation system, since the viaduct is well above the foundation level.

One of the key aspects of the excavation work in this project was controlling the possible movements in the foundation system of the Georgia Viaduct which was of extreme importance to the City of Vancouver.

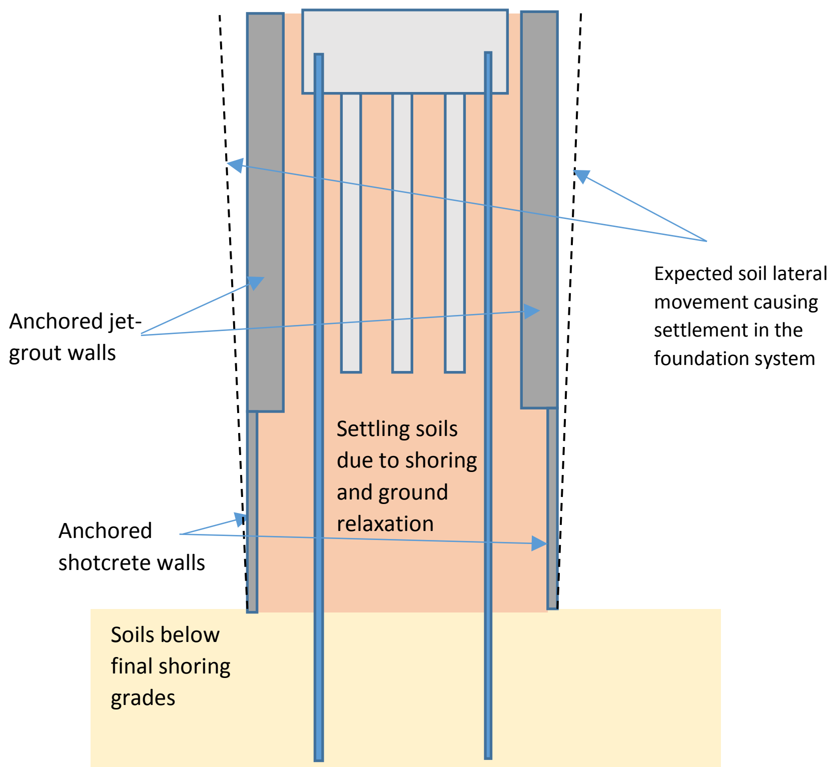

Figure 5: Schematic representation of underpinning micropiles, shoring system and the existing foundation system of viaduct piers

Based on the analysis of the existing viaduct structure by the bridge engineer of the project, threshold values for the 3-dimensional displacement and rotation of the viaduct foundations (G-18 and G-19), for the safe performance of the structure, were determined. Based on the results of the structural analysis of the bridge, the following thresholds of displacements and rotation were prescribed:

1) Threshold for rotation: 0.04°
2) Threshold for longitudinal (horizontal) displacement: 10 mm
3) Threshold for transversal (horizontal) displacement: 5 mm
4) Threshold for vertical displacement (settlement): 10 mm

Level A and Level B of thresholds were accordingly defined as 50% and 80% of the prescribed limits. Horizontal displacements of the pilescaps were successfully maintained within the prescribed threshold limits by means of internal steel bracing, as a part of shoring system, installed at the corners of shoring walls (see Figure 2 and 6). Details of controlling the horizontal displacements of the pilecaps are not included in the scope of this paper.


(a) (b)

Figure 6. Internal bracing to control lateral movements (a) pilecap of pier G-19 and (b) pilecap of pier G-18

In order to control the settlements of the pilecaps, an underpinning system, using drilled micropiles was designed to directly transfer the pilecap loads to the deep glacial till layer, considerably below the excavation depth. Since the construction space under the viaduct structure was congested and a distance of less than 1 m between the proposed excavation lines and the edge of existing pilecaps was available (see Figure 3), mciropiles were suggested to provide an underpinning system to transfer the pilecap loads directly to the deep competent glacial till stratum which allowed for substantial elimination of the original concrete piles and their surrounding soils such that the possible soil/CIP pile settlement could not influence the pilecaps. A group of twelve micropiles were designed around each existing pilecap to underpin the viaduct pier foundations (Figure 3). These micropiles were then structurally engaged to the existing pilecaps by expanding the existing concrete pilecaps.

A typical section view of the micropiles, designed for underpinning the viaduct pier foundations is shown in Figure 7 and a view of an installed micropile in the field (prior to pilecap expansion) is shown in Figure 8. Each micropile was designed for a service load of 850 kN. The bonded length of the micropile, in contact with glacial till, was computed using a bond strength of 150 kPa, in both tension and compression. Given the maximum service load of 850 kN and the micropile diameter of 200 mm, a minimum bonded length of 9.1 m was considered in the design. Each micropile included a high-grade steel thread bar with a bar nominal diameter of 66 mm and a steel casing, HSS 168 x 6.4 mm, ASTM 500 (in the upper portion), as shown in Figure 7. The bearing capacity of the micropiles was achieved using 35 MPa grout, injected into the 200 mm drilled holes as shown in Figure 7.

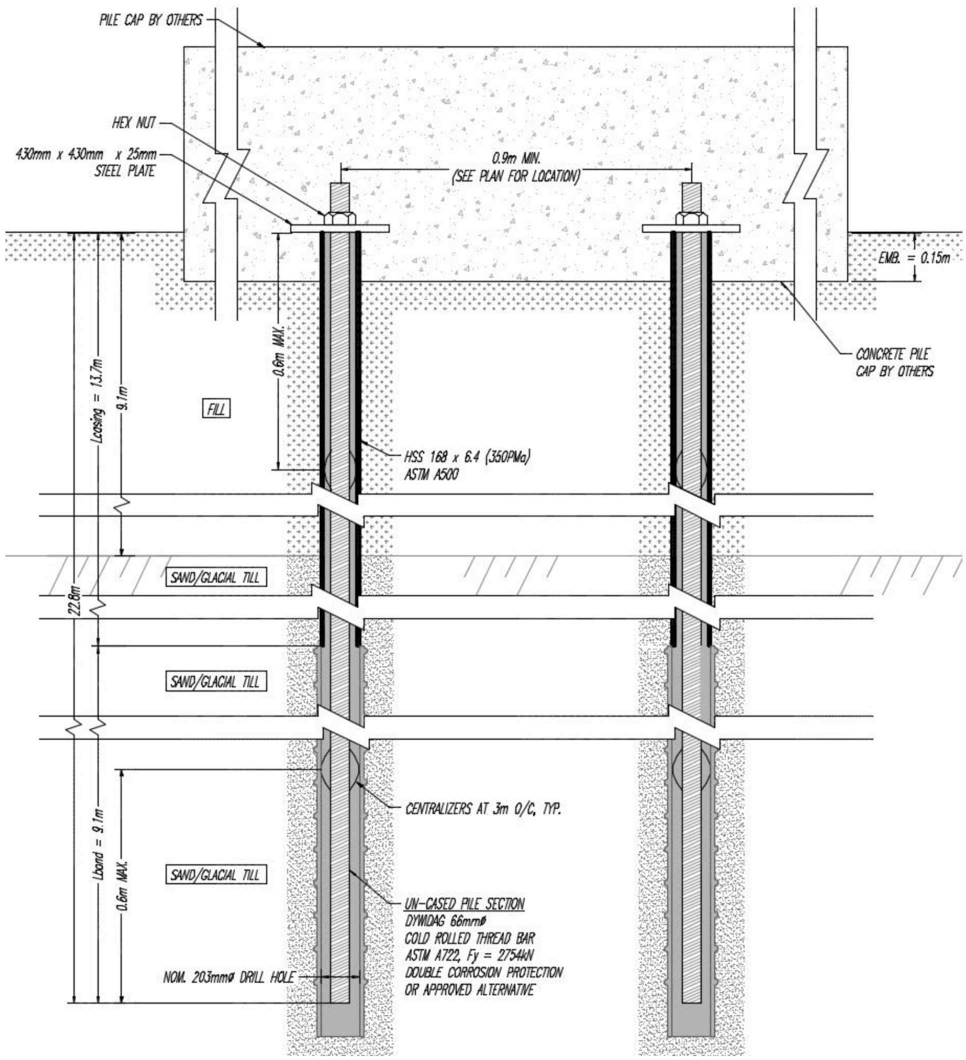

Figure 7. A typical profile of the micopiles designed for underpining the viaduct pier foundations

Despite the cast-in-place piles that may provide a relatively small tensile capacity, the designed micropile system worked in both compression and tension with a relatively similar capacity which is one of the advantages of these types of foundation/underpinning systems in controlling the rotations of the pilecaps as the group of micropiles can work in compression-tension mechanism and provide a coupled force system to control the pilecap rotations.

Figure 8. A view of an installed underpinning micropile on the north side of pier G-18 prior to pilecap expansion

The performance of the designed micropiles in controlling the settlements and rotation of the viaduct pier foundations was thoroughly monitored using an automated monitoring system as well as conventional survey. The results of the conventional survey and the automated monitoring system are presented and discussed in the following section. It should be noted that prior to excavation and shoring construction, all of the installed micropiles were successfully tested in general accordance with FHWA (2005) guidelines, which is typically used in the standard geotechnical engineering practice. All tested piles satisfied the referenced guideline criteria for performance testing.

MONITORING RESULTS AND DISCUSSION

In order to verify that the displacements and rotation of the subject pilecaps would be maintained within the referenced acceptable ranges, prescribed by the bridge engineer, an automated monitoring system was designed to continuously record the 3-dimensional displacements and rotation of the pilecaps for the full duration of excavation and shoring construction. The monitoring system for viaduct pilecap G-19 included two tilt meters (TM's), with the accuracy of 0.001°, and a Laser Displacement Meter (LDM), capable of measuring 3-dimensional displacements with the accuracy of 0.01 mm. For viaduct pilecap G-18 one TM and one LDM were used to measure the movements continuously. In order to validate the performance of the automated monitoring system, and also to investigate the influence of temperature variations and traffic noise on the monitoring data, a 2-week trial monitoring period was conducted prior to the commencement of the shoring construction and bulk excavation. Upon the completion of the trial period, the effects of temperature variations and also direct sunlight on the results of the automated monitoring data were investigated and the sources of possible errors were either removed (e.g., direct sunlight) or quantified (e.g., temperature effects) and a baseline was established for all sets of the monitoring data.

In addition to the automated monitoring system, a conventional monitoring program via manual survey was conducted and a baseline for the coordinates of the selected monitoring points was established. The intent of considering a conventional survey in the monitoring program was to periodically validate the recorded data of the automated monitoring system.

The shoring and excavation operations and construction of the permanent structure to the level of the original ground were completed in about 12 months. During this period the automated monitoring system continuously recorded the displacement and rotation data of the pilecaps. The recorded monitoring results were available online to the design and construction team for the duration of the project. In addition, conventional survey was conducted on a bi-weekly basis (monthly at later stages of the project) to validate the automated data. It should be noted that the threshold limits were adjusted over the 12-month period of temporary shoring to account for the influence of seasonal temperature variations on the electronic output, generated by the automated instrumentation, installed on the viaduct pier foundations. These adjustments were carried out based on the correlations between the recorded movement data of the pier foundations and temperature variations during the trial period of the automated monitoring system. These correlations were established by the structural (bridge) and geotechnical teams of the project. Typical sample results of the automated monitoring data, at different time intervals during this project, are presented in the graphs of Figure 9. The prescribed threshold limits with their variations based on seasonal temperature levels are also included in these graphs. Comparison of the displacement and rotation data against the prescribed threshold limits is indicative of the excellent performance of the micropile underpinning system to control the movements of a highly sensitive structure in close proximity of the shored cuts.

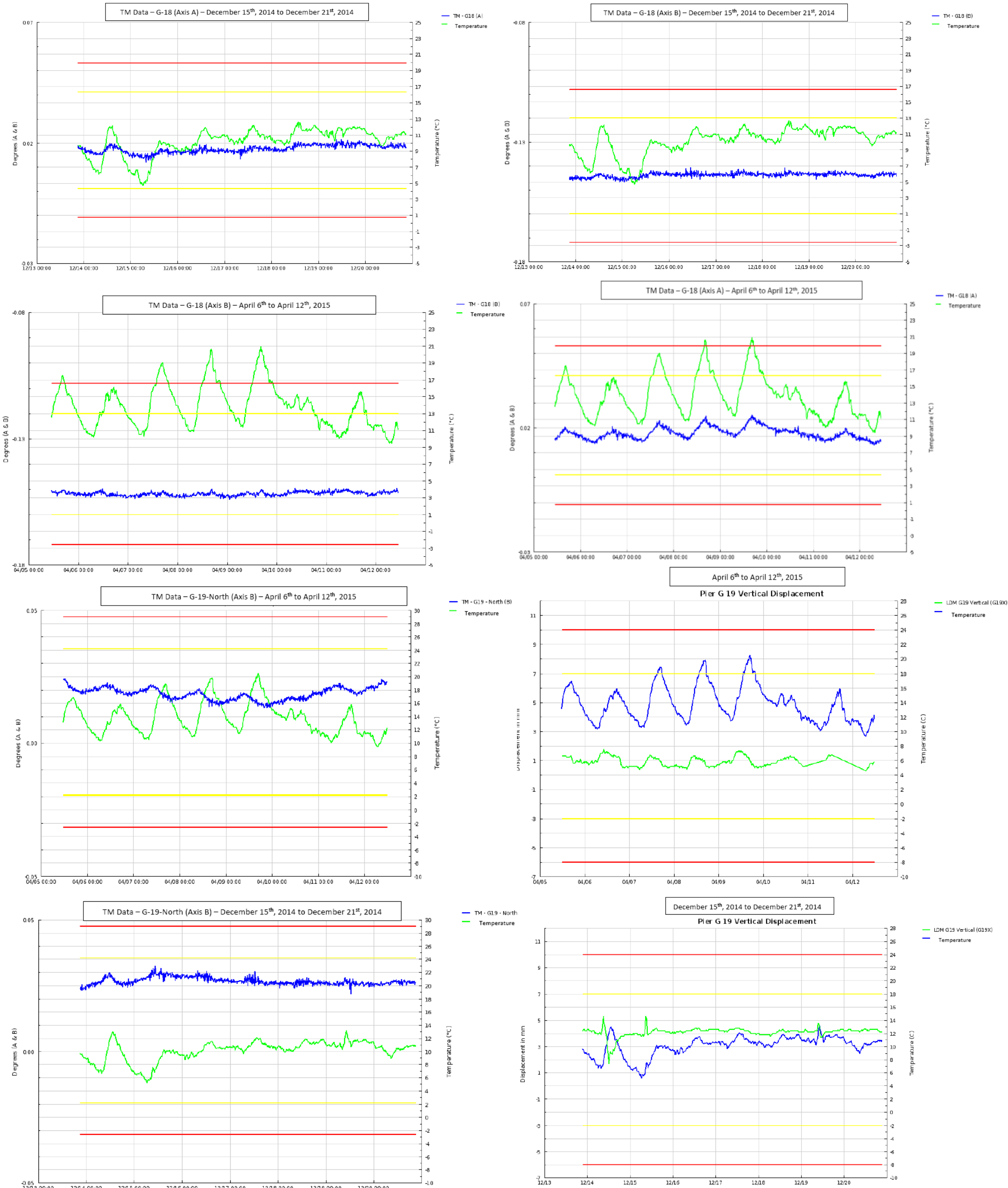

Figure 9. Typical graphs of the automated monitoring system for piers G-18 and G-19 at different time frames

Based on our experience in a number of shoring projects in downtown Vancouver for relatively similar subsurface conditions, excessive foundation settlements and rotation would be anticipated for the shoring system without the micropile underpinning system, indicating that properly designed micropiles can be considered as an excellent solution for controlling movements in the vicinity of deep excavations.

CONCLUSIONS

The South Tower project, demonstrated excellent performance of micropiles for underpinning and controlling foundation movements of a highly sensitive structure (Georgia Viaduct) in the vicinity of a deep shoring wall. Monitoring results confirmed that all foundation displacements and rotation were maintained within the prescribed limits for the safe performance of the viaduct structure. In spite of a limited construction space around the subject pilecaps, micropiles showed to be an excellent option for underpinning, particularly in congested construction areas, to control settlements and rotation of the existing footings. The capability of micropile systems in providing resistance against foundation rotations based on developing a coupled compressive-tensile force system is another advantage of micropiles which can safely secure the control of both vertical and rotational movements of pilecaps.

REFERENCES

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