Instrumentation Monitoring of TBM Tunnelling Effects to Adjacent Pile Foundation for HATS 2A Project

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ABSTRACT

The rapid development and redevelopment of the urban area usually demand the use of deep foundation. With the need of infrastructure being planned underground and constructed in the form of tunnelling method, there is a high possibility that the tunnel alignment may become very close to these adjacent existing foundation. Prediction of adjacent pile responses and ground deformations caused by tunnelling is therefore important as part of the design. This Paper presents the instrumentation and assessment of the impact on adjacent rock socketted pre-bored H-pile and ground movements arising from a tunnel construction in the Harbour Area Treatment Scheme Stage 2A project. Field data in comparison with predictions under theoretical methods is also included. Back-analysis of volume loss is given and it is suggested that 2% of volume loss shall be used for design under similar geological condition of reclaimed land area.

1 INTRODUCTION

The Harbour Area Treatment Scheme Stage 2A (HATS 2A) is a major government infrastructure project in Hong Kong aiming to upgrade the existing facilities to treat the sewage caused by urban development around Victoria Harbour, improve the water quality and maintain a healthy and sustainable marine environment. Under HATS 2A, an Interconnection Tunnel was to be constructed linking the existing and the new main pumping station inside Stonecutters Island Sewage Treatment Works (SCISTW). The tunnel was aligned across the future Northern Sludge Cake Silos and Sludge Dewatering Building which the foundation for the two new buildings had been constructed prior to TBM construction. A 10m width protection zone was reserved for the TBM construction as well as to minimize the TBM effect to the adjacent piles.

Tunnel construction invariably causes ground movements and changes in the field stress conditions. Many attempts had been made to simulate the tunnelling effect in centrifuge model tests but few papers discussed the real tunnelling-induced responses and compared the real responses with the theoretical prediction especially in Hong Kong. This Paper presents: (i) the details of instrumentations and monitoring on the newly constructed piles and adjacent areas during the tunnel construction, (ii) tunnelling-induced responses of single pile from the monitoring and comparisons with theoretical methods, (iii) ground deformation patterns obtained from the monitoring and comparisons with theoretical predictions, (iv) analysis on the field data and comparison with the theoretical data and predictions adopted in the design stage, and (v) suggestions for future geotechnical assessment of similar construction effects.

2 BACKGROUND INFORMATION

The site has a typical offshore geology in Hong Kong which is generally underlain by Fill, Marine Deposits, Alluvium and Completely Decomposed Granite (CDG). The bedrock level is between 50m and 70m deep. The new piled foundation adjacent to the tunnel comprises more than 240 numbers of 610mm rock socketted pre-bored H-piles and were installed prior to the tunnel construction (Figure 1). The pre-bored H-piles were socketted into bedrock with maximum socket length of 4.5m with pile capacity up to 5,500kN.

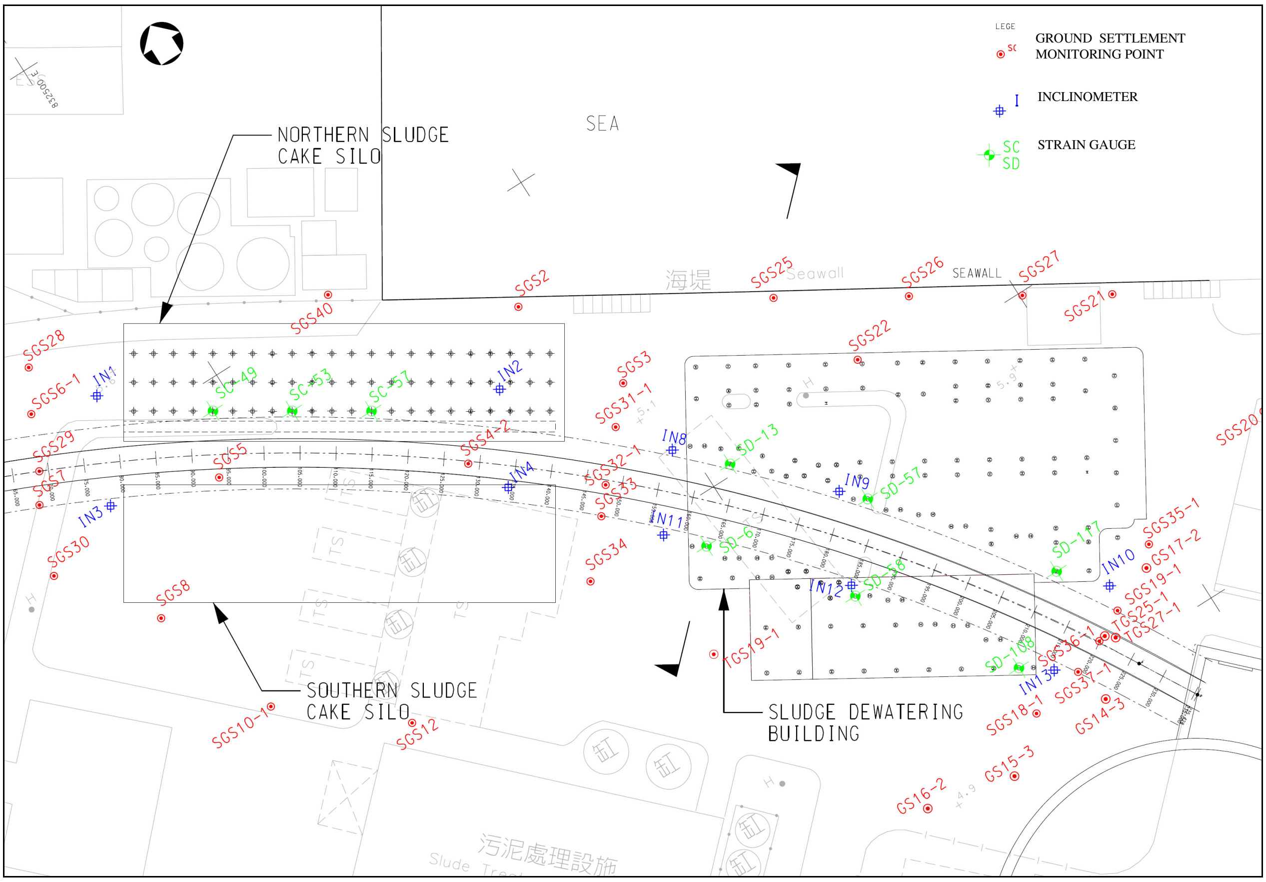


Figure 1: Tunnel Layout Plan

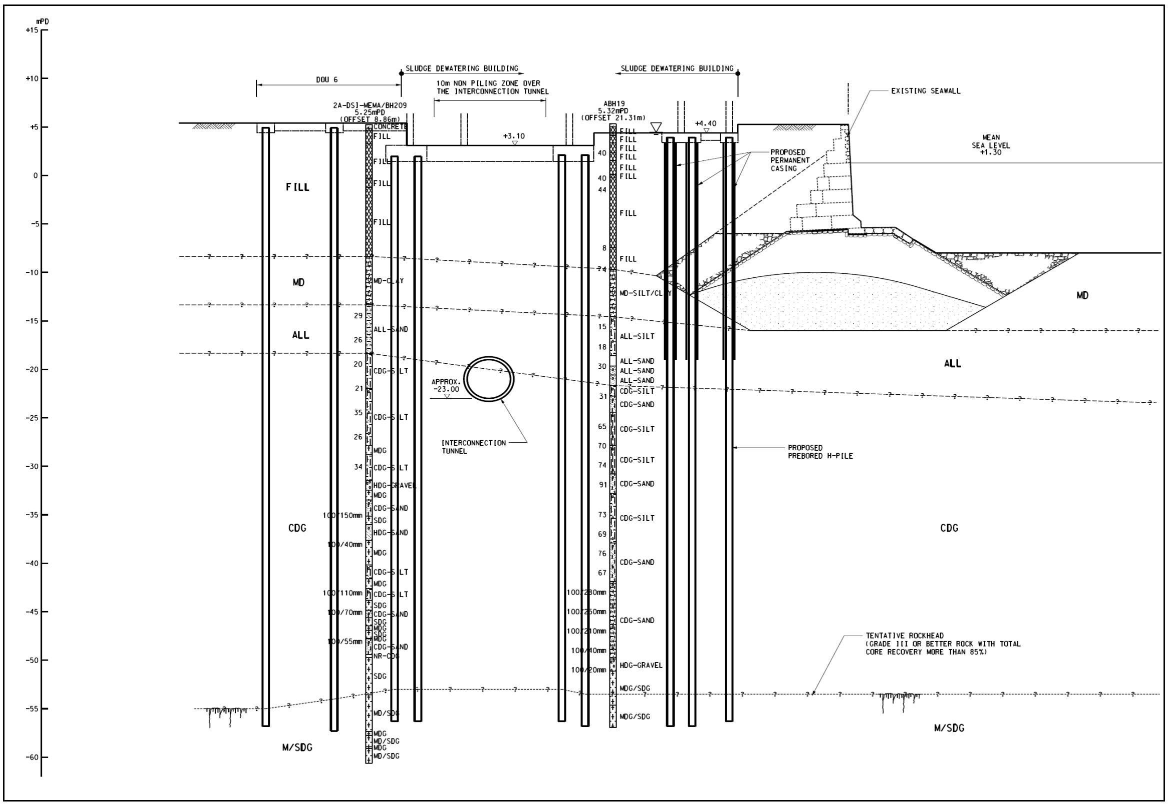


Figure 2 : Cross Section showing the Tunnel and the adjacent Pile Foundation

The proposed tunnel has an invert level of about 28m below the current ground level and having an internal diameter of 4m and around 240m in length. The ground stratigraphy revealed that the tunnel is located within the alluvium layer and occasionally CDG (Figure 2). The tunnel was to be built by Earth Pressure Balanced type Tunnel Boring Machine (TBM). The typical advance rate for this TBM was around 4m per day. The volume loss was estimated to be within 4% at the design stage.

In order to monitor the ground condition and the effect of the TBM construction, there were various instruments installed around the pile foundation locations. It consisted of ground settlements, building settlements, standpipes/piezometers, strain gauges installed along newly constructed piles and inclinometers. In addition, the TBM face pressure, excavated material, measured grout volume were also recorded and reviewed during the construction stage. However, only the monitoring of the induced pile responses and the adjacent soil movement will be presented in this Paper for the sake of readability.

3 MONITORING OF INDUCED PILE RESPONSES

Vibrating wire type strain gauges were installed to the 9 numbers of steel H sections prior to installation which were used to measure the induced strains (Figure 3). 5 sets of strain gauges were installed along each selected pile at prescribed levels -11, -16, -21, -26 and -31mPD and each set consisted of 4 strain gauges installed on the inner face of the H-pile flange at each prescribed level (Figure 3).

The strain gauge produces the strain of the pile at the prescribed level and the stresses can be obtained by the stress-strain relationship. The axial force at the prescribed level is then calculated by the average measured stresses from the 4 strain gauges at the same level times the steel sectional area. Besides, the bending stress developed in the pile is the net value of the average stresses from the strain gauges A/B and C/D (Figure 3). The bending moment will be determined by the following simple equation:

$$M = \frac{\sigma I_x}{y}$$

where M = the bending moment, σ = bending stress, I_x = the second moment of area about the neutral axis x, y = the perpendicular distance of strain gauge to the neutral axis

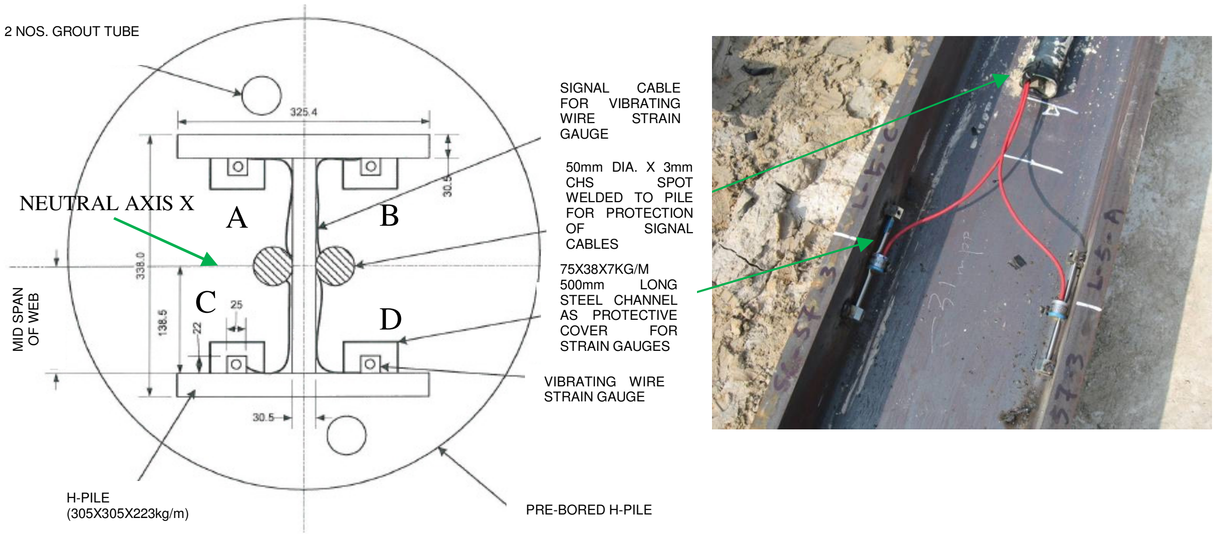
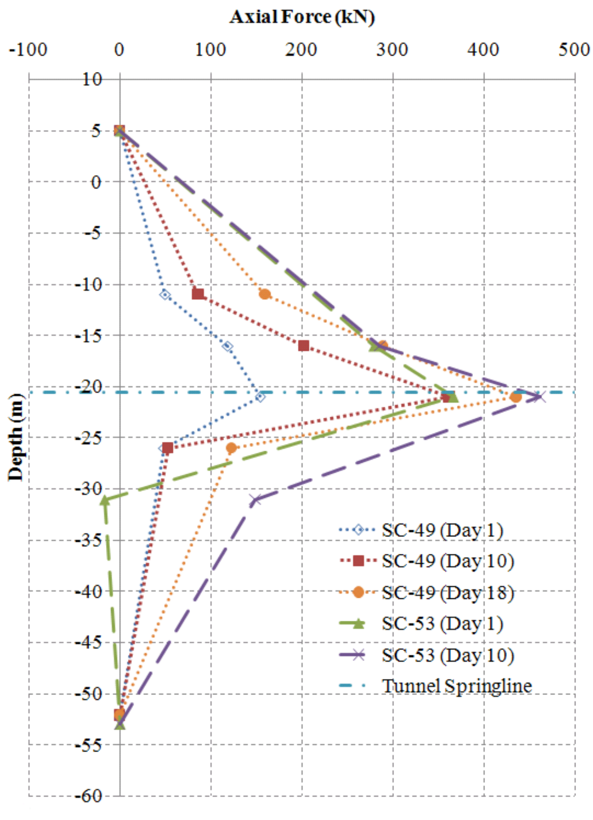


Figure 3: Arrangement of Strain Gauges on Pre-bored H-pile

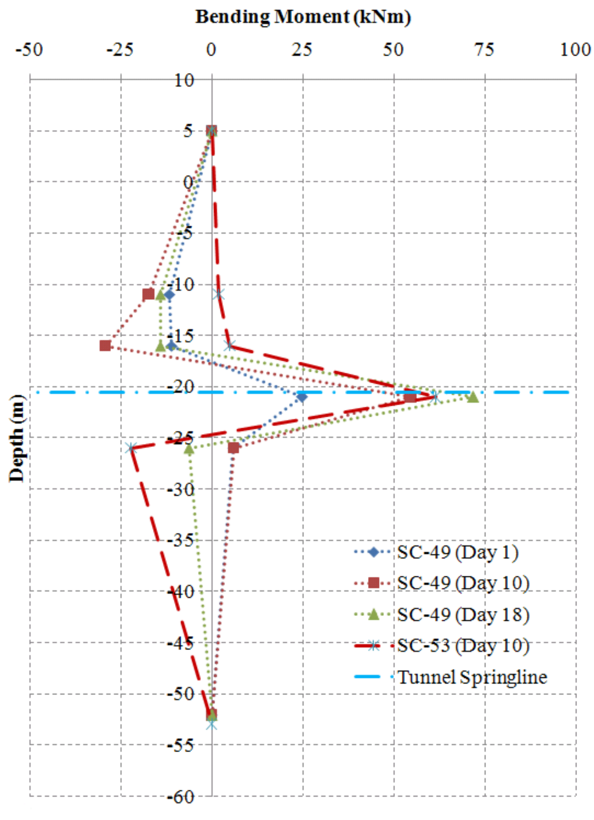
By the time of preparing this Paper, the TBM had passed through three of instrumented piles. Figure 4 shows typical profiles of the induced axial force and bending moment due to the period of adjacent tunnelling passed by at the 1st day, 10th day and 18th day. Herewith 1st day is defined as the first day TBM passed by the instrumented pile at the closest 3m distance. The interpreted profiles have the following features:-

- From the Figure 4A, it is observed that the induced pile axial force increases downward and reaches a maximum value at the level of tunnel springline.
- The reading in Figure 4A reveals that there is a significant increase in maximum axial force, 435kN at 18th day for SC-49 and 461kN at 10th day for SC-53 which is equivalent to a maximum of 8.4% of the axial working load capacity (5,500kN) within 3m from pile edge to tunnel edge.
- Figure 4B indicates that the interpreted bending moment profile has a double curvature, with the maximum value occurring at the level of the tunnel springline and the trend matches with the result derived from simplified boundary element analysis by Loganathan & Poulos (1999).
- In Figure 4B, the induced bending moment increases to 72kNm (18th day) for SC-49 and to 62kNm (10th day) for SC-53 within 3m from pile edge to tunnel edge.
- The majority of axial load and bending moment has been developed at the first 10 days after the TBM passing by the instrumented pile while there is small portion of increment occurred between 10 and 18 days, as shown in Figure 4.

In deriving the pre-bored H-pile design, 600kN axial compressive load and 100kNm bending moment have allowed to cater for the effects of tunnelling in the vicinity. From the instrumentation results, it can be seen that these values are considered adequate.



A: Induced Pile Axial Load



B: Induced Pile Bending Moment

Figure 4: Induced Pile Responses

4 MONITORING OF SOIL MOVEMENT

A comparison of surface settlement troughs obtained using various methods such as Mair (1993) and Loganathan & Poulos (1999) and measured data is shown in Figure 5.

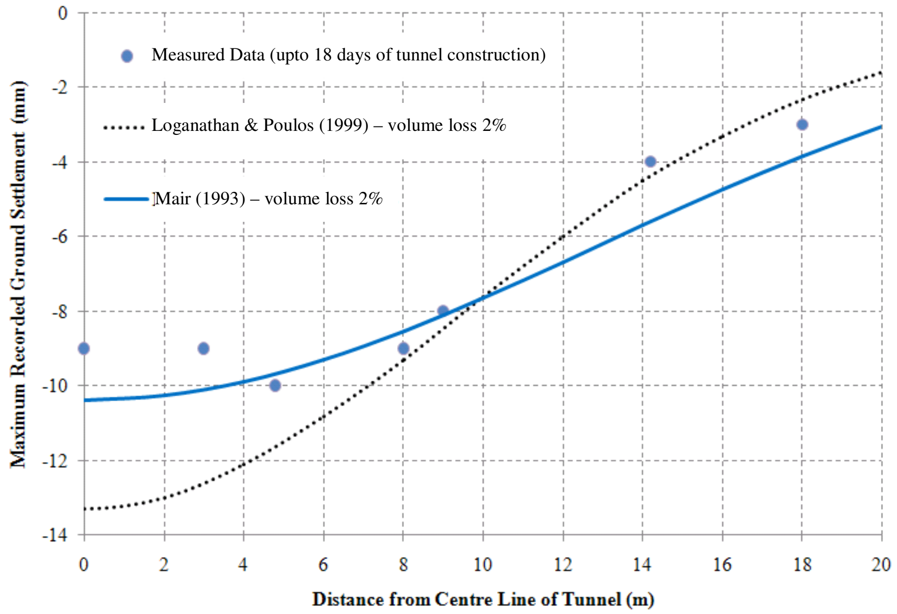


Figure 5: Comparison of Surface Settlement Predicted and Observed Values

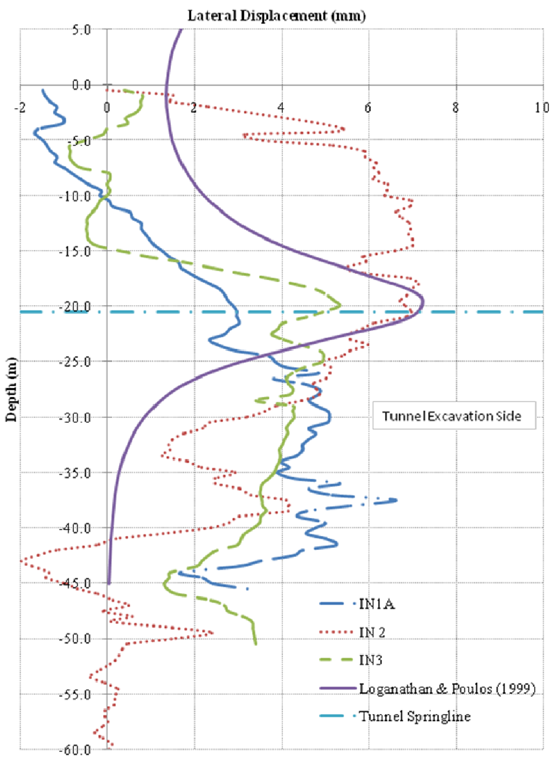


Figure 6: Induced Lateral Displacement at the 3m from Tunnel

The maximum surface settlement occurred above the centre of the tunnel was measured to be 9mm and becomes less gradually as the distance from the tunnel increases. Using a volume loss of 2%, Gaussian distribution function and i=0.5z suggested surface settlements derived by Mair (1993) and analytical method by Loganathan & Poulos (1999) are introduced for comparison with the measured data. As shown in Figure 5, it is noted that the measured immediate surface settlement trough at 18^{th} Days after excavation more or less follows the well-established Gaussian distribution. Although the analytical method by Loganathan & Poulos (1999) is more commonly adopted for tunnel designs in Hong Kong, it is observed that the empirical method by Mair (1993) has a better fit for the tunnelling induced settlements in reclaimed land under the conditions of this project.

Ten inclinometers were installed adjacent to the interconnection tunnel and the TBM had passed through six of them. Figure 6 shows the typical lateral displacement profiles for several inclinometers. The maximum lateral soil displacement occurs at the tunnel springline with a maximum value of 7 mm. The observed data comparing with the analytical prediction by Loganathan & Poulos (1999) with a volume loss of 2% and distance of 3m from the tunnel edge is shown in Figure 6. The maximum predicted displacement value is in good agreement with maximum measured displacement. It is also noted that the lateral soil movement has similar trend as the analytical predictions as illustrated in Figure 6.

Therefore from this result, it is observed that the assumption of 2% volume loss is reasonably adequate for estimating the lateral soil displacement.

5 CONCLUSION

Although according to Ran (2004) and Pang et al. (2005), the long term effect of the tunnelling may be notable, it is considered not quite applicable to this project since there are several occasions in the past showing the surface settlement occurred almost immediately within 2-3days after the construction activities. The paper presents the results covering the period of 3-4 days before and as long as 18 days after the TBM passed by the instrument. As such this period is considered to be sufficient to include the immediate effect and even the delay response of the ground.

This Paper presents the typical rock socketted pre-bored steel H-pile responses within a distance of 3m from the tunnel edge in reclamation area. The monitoring data reveals that the induced maximum pile axial force and bending moment due to the tunnel construction are 461kN and 72kNm respectively. Both the maximum axial force and bending moment are located at a level close to the tunnel springline. Adequate allowance of additional axial force and bending moment was provided in the original pile design.

In this Paper, the available field data for estimating the tunnelling-induced ground movement for the HATS2A project are assessed and reviewed. The surface settlement is described with reasonable accuracy by Gaussian distribution proposed by Mair (1993) for tunnel in reclamation area with 2% volume loss.

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