Geotechnical Aspects of Underground Construction in Soft Ground – Ng, Huang & Liu (eds)

Performance review of a pipe jacking project in Hong Kong

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ABSTRACT: The pipe jacking method is commonly used in Hong Kong for construction of underground cable duct crossings and stormwater drains. The method minimizes the disturbance to or interference with the activities and facilities on the ground surface. In this paper, details of a pipe jacking project completed recently in Hong Kong, involving use of a pressurized slurry tunnel boring machine to form a 222 m long, 1.95 m diameter cable tunnel, are described. Results of the performance review carried out on completion of the project are also presented.

1 INTRODUCTION

A cable duct crossing was constructed in an urban area at Kowloon West of Hong Kong. The cable duct crossing had to traverse a highway and some railway tracks. Conventional open cut excavation method was not used because of the disturbance that could be caused to the facilities on the ground surface. Pipe jacking method was used instead. The cable duct crossing was constructed in fill comprising loose to medium dense, silty coarse sand, and a pressurized slurry tunnel boring machine (TBM) was selected for the project.

In this paper, details of the project are described. A performance review was carried out on completion of the project. The key construction aspects, monitoring data obtained at the site during construction, impact on sensitive features in and surrounding the site and a summary of the observations and decisions made during construction are presented. The information given in this paper is obtained during auditing of the project by the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) of the Government of the Hong Kong Special Administrative Region. The auditing was carried out to exercise geotechnical control in the interest of public safety.

2 PROJECT DESCRIPTION

2.1 *Details*

The site is located near West Kowloon Highway at Kowloon West (see Figure 1), Kowloon.

The project involves construction of a 222 m long 1.95 m diameter tunnel to serve as cable duct crossing across a highway, the MTR Tung Chung line, the Airport Express Line and a public park. Pipe jacking method was used to form the 2 m diameter pipe opening at 8 to 9 m depth in fill, the properties of which are shown in Figure 8. The groundwater level was measured at about 2.0 m below ground. Two working pits of 14 m long × 4 m wide × 10 m deep were constructed at both ends of the cable duct crossing for the tunneling operation.

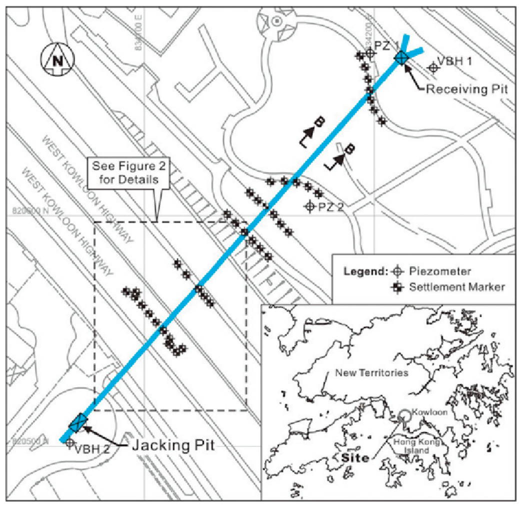


Figure 1. Location plan.

2.2 *Geotechnical aspects of the tunnel works*

At the design stage, plans and supporting documentation of the geotechnical design of the pipe jacking

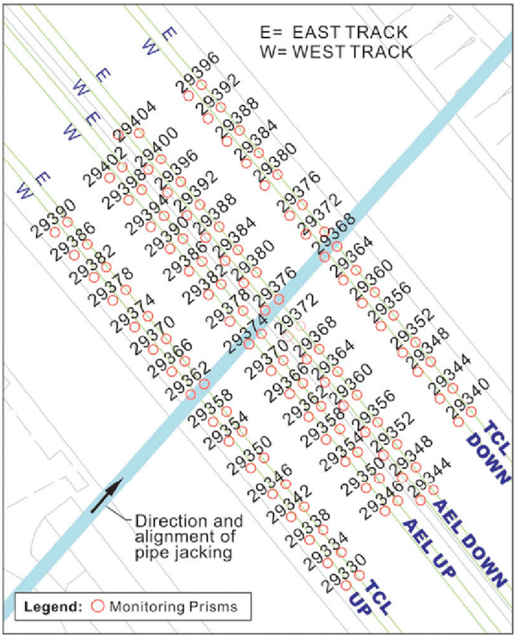


Figure 2. Locations of monitoring prisms on the railway tracks.

Figure 3. Close-up view of settlement monitoring prism.

works, a geotechnical risk assessment and a risk mitigation plan were prepared by the designer.

The most sensitive features affected by the works were the railway tracks and the underground utilities, including drainage pipes and sewers, close to the alignment of the pipe jacking.

Prior to the commencement of works, a condition survey of the existing road and the structures within 25 m of the alignment of the pipe jacking and a CCTV survey of the existing drainage pipes and sewers within 20 m of the works were carried out. Another CCTV survey was also carried out on completion of the works.

An instrumentation scheme consisting of 168 settlement markers for the road surface, 123 settlement monitoring prisms for the railway tracks and four piezometers for groundwater level was adopted. Locations of the settlement markers, settlement monitoring prisms and piezometers are shown in Figures 1 and 2.

The settlement markers were installed adjacent to the jacking pit and receiving pit and on the road surface along the alignment of the pipe jacking. Out of the 123 settlement monitoring prisms installed, 32 were installed on the Tung Chung Line (up) (TCL up) (on both rails), 30 on the Airport Express Line (up) (AEL up), 31 on the Tung Chung Line (down) (TCL down) and 30 on the Airport Express Line (down) (AEL down) (see Figure 2).

One piezometer each was installed close to the jacking pit (VBH1) and receiving pit (VBH2) and two piezometers were installed along the alignment of the pipe jacking (PZ1 and PZ2) (see Figure 1).

A monitoring plan including monitoring of settlement, groundwater level and vibration, and a site supervision plan for the works were prepared. The method statement for the works and details of the pressurized slurry machine selected were also submitted to the relevant departments including the GEO for review.

The stakeholders affected by the project were also notified and consulted by the designer. For the railway tracks, trigger levels of “alert”, “action” and “alarm” (or AAA) of 12 mm, 16 mm and 20 mm respectively for settlement and 1 in 1500, 1 in 1250 and 1 in 1000 respectively for angular distortion were set and agreed by the MTR Corporation Limited. At alert level, readings would be reviewed and plans for remedial measures and contingency actions would be prepared. At action level, the planned remedial measures would be implemented and the works could only continue if the remedial measures taken were effective. The alert and action levels would also be revised if necessary. At alarm level, all works would be stopped or contingency actions taken and the design, construction method and the planned remedial measures would be reviewed. A maximum tolerable track settlement of 25 mm was allowed.

An Automatic Deformation Monitoring System was used to take readings for monitoring the railway track settlement. Three CYCLOPS theodolites were positioned on opposite sides along the tracks, and the track settlement was monitored on a daily basis in real time. The data taken were transferred to a computer in the site office which were then processed and posted onto the internet for real time monitoring by relevant parties (Figures 3 to 5).

2.3 *Construction*

A RASA DHL1650 pressurized slurry TBM was used (Figure 6). The diameter of the shield body

Figure 4. Positions of settlement monitoring prisms on the track.

Figure 5. A CYCLOPS theodolite.

and the equipment tube of this TBM is 2,000 mm and 1,990 mm respectively. The excavated diameter is 2,040 mm. The pipe installed has an outside diameter of 1,950 mm and an internal diameter of 1,650 mm (Figure 7).

The construction method involved use of a pressurized slurry system. The slurry support pressure at the excavation face was set to balance the ground and groundwater pressure as indicated in the control panel of the TBM. The TBM operator checked the pressure gauge to control the pressure at the excavation face and the slurry-discharge pressure gauge to control the circulation pressure. The typical groundwater pressure at the excavation face was 50 to 70 kPa with an average value of 60 kPa at the tunnel axis level. To balance the ground and groundwater pressure, a slurry pressure of 10 to 20 kPa above the water pressure, which is 60 to 90 kPa, was applied at the excavation face for the operation (Figure 8). The slurry pressure applied to the

Figure 6. Pressurized slurry TBM.

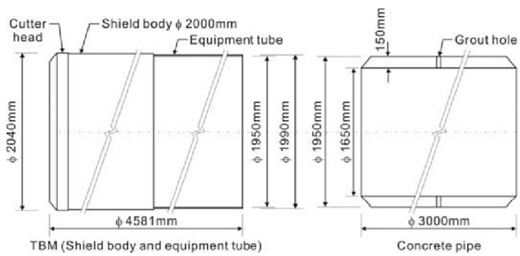


Figure 7. Dimensions of TBM and concrete pipe.

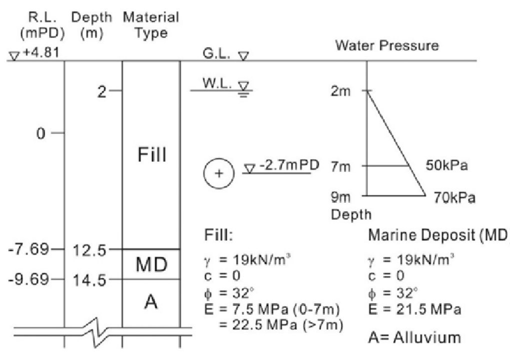


Figure 8. Typical groundwater pressure.

excavation face was controlled by the pressure control valve of a by-pass unit placed in the jacking pit.

During operation, a lubricant consisting of water, bentonite and mineral oil was injected into the annulus around the pipes to fill the voids around the pipes to reduce soil movement. On completion of the pipe jacking, the cavities around the pipes were grouted. A cement grout with a minimum compressive strength of 20 MPa was used.

3 PERFORMANCE REVIEW

3.1 *Control of amount of materials excavated*

In a pressurized slurry system, the ground was mechanically excavated while the excavated face was stabilized and supported by slurry. The excavated materials were removed by slurry transport. To check if voids had been formed in the soil above the tunnel during excavation, the amount of materials excavated was monitored during the tunneling operation. A desander was used to separate the solids from the slurry. The solids were mainly fine sand which was later used for backfilling the pits. The weight of the soil excavated from the jacking pit, receiving pit and the tunnel was worked out to be 2,262 tonnes before the works commenced. During the works, 593 tonnes of sand and 1,461 tonnes of finer soil were disposed of. The total amount of soil disposed was therefore 2,054 tonnes which was less than the calculated value. Although limited by the accuracy of measurement, this provided a rough indication that no significant voids had been formed in the ground above the tunnel. No boulders were encountered and no cutter had to be replaced for this project.

3.2 *Settlement of railway tracks*

In this project, the most sensitive features are the railway tracks.

The excavation sequence of the pipe jacking works in terms of the distance from the railway tracks is shown in Figure 9. Pipe jacking commenced on 29 March 2007. Fourteen days after commencement of the pipe jacking (12 April 2007), the TBM reached the TCL Up track and 5 more days later (17 April 2007), it went past through all the tracks. Included in the figure is also the track settlement in response to the pipe jacking.

The tracks settled as soon as the pipe was jacked past and away from the section. At the TCL Up track, the track settled by 12 mm when the pipe was installed at a distance of 23.5 m away from the section. Similar rate of settlement was noted at tracks AEL Up, AEL Down and TCL Down except in those cases, the track settlement was less. On completion of the pipe jacking, maximum settlement of tracks TCL Up, AEL Up, AEL Down and AEL Down were 22 mm, 15 mm, 10 mm and 3 mm respectively which are less than the maximum tolerable track settlement of 25 mm.

In pipe jacking, the whole length of the pipe is jacked and moved forward, resulting in disturbance to the soil around the whole length of the pipe. With the cutter head about 90 mm larger than the pipe to be jacked (see Figure 7), it is possible that voids would form around the pipe which would result in ground movement, and hence settlement along the length of the pipe even after excavation

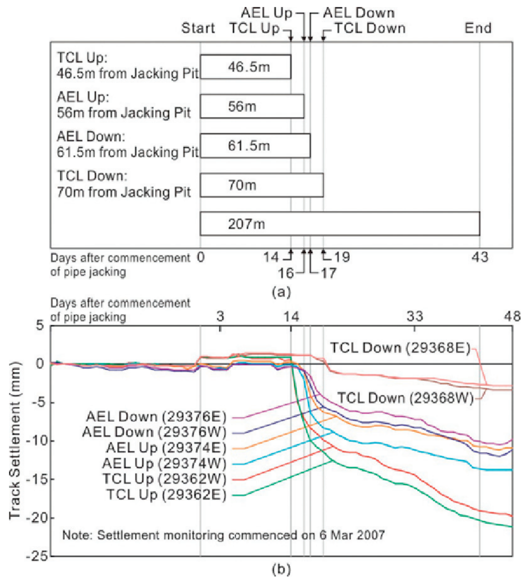


Figure 9. Excavation sequence of pipe jacking (a) and settlement profiles at tracks TCL Up, AEL Up, AEL Down and TCL Down (b).

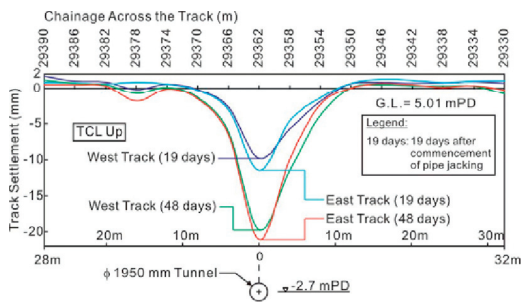


Figure 10. Settlement trough at track TCL Up.

has been carried out to some distance away from the tracks.

The settlement troughs at tracks TCL Up, AEL Up, AEL Down and TCL Down are shown in Figures 10 to 13 respectively. The settlement troughs are almost symmetrical in these cases.

The maximum settlement on the pavement was 15 mm which was recorded by settlement point SC19 adjacent to TCL Up track (Chainage 29362).

Given the ground conditions and the method of construction as described above, a maximum volume loss of 3.6% was calculated (see Figure 14).

The maximum groundwater drawdown recorded by the piezometers at the jacking pit and receiving pit (VBH2 and VBH1) was 1.1 m, which was only slightly above the permissible value of 1 m. At PZ1 location,

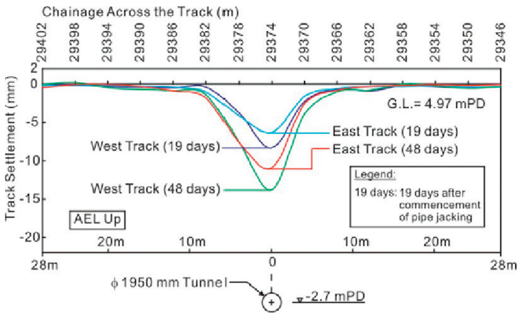


Figure 11. Settlement trough at track AEL Up.

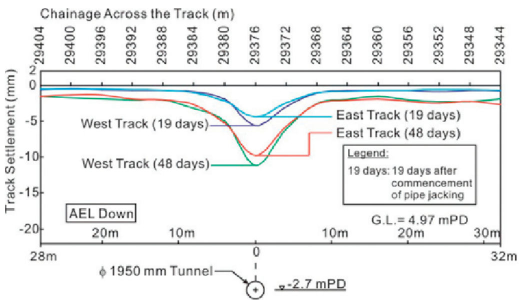


Figure 12. Settlement trough at track AEL Down.

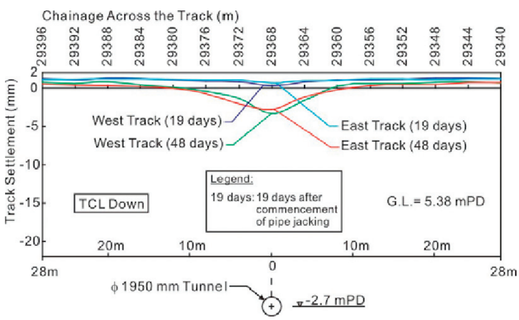


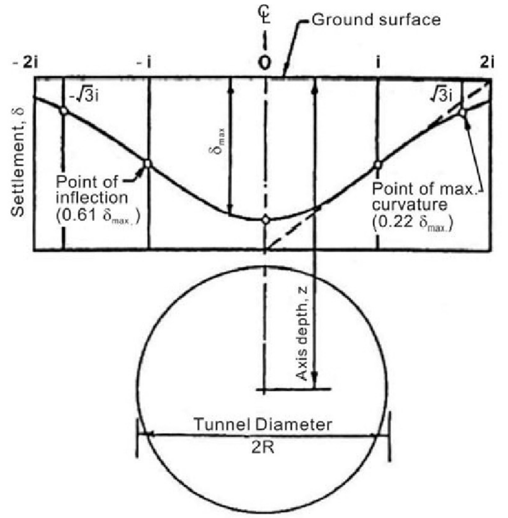
Figure 13. Settlement trough at track TCL Down.

the maximum drawdown recorded was 0.7 m, and at PZ2 location, no significant amount of groundwater movement was observed.

No undue settlement was recorded at the drainage pipes, sewers and the structures nearby.

3.3 *Actions taken at action level during construction*

Twelve one days after commencement of the pipe jacking (19 April 2007), a settlement of 15 mm was recorded at the TCL Up track which was close to the action level. An urgent meeting was held among the client, designer and contractor on that night. After



Ratio $\frac{i}{R}$ is a function of $\frac{z}{2R}$ and the soil conditions

Volume of trough ≃ 2.5 i $\delta_{max.}$ per metre run

$$\text{Volume loss } (\%) = \frac{250\, i\, \delta_{max}}{A}$$

where A = cross-sectional area of tunnel (m^2)

i = distance to the point of inflection (m)

δ_{max} = assessed immediate settlement over the centreline of the tunnel (m)

Figure 14. Properties of error function to represent the settlement trough above a tunnel (after Peck, 1969).

the meeting, it was decided that for the remaining works, an alternative type of lubricant, in lieu of a mixture of water, bentonite and mineral oil, was used to fill the gap between the pipe and the TBM over-break. This lubricant formed a solid substance once injected into the gap and it helped to reduce settlement of the overburden fill caused by closure of the overbreak voids around the pipe. The density of the bentonite slurry was also increased. The advance speed of the TBM was reduced from 9 m per night shift to about 6 m per night shift. With the actions taken, the rate of increase of track settlement was reduced and the final settlement was contained to within the permissible value.

4 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be made from the project:

1. The use of pipe jacking method was effective in forming a 222 m long, 1.95 m diameter cable tunnel

at 8 to 9 m depth. The pressurized slurry TBM used is appropriate for the type of ground conditions encountered.

2. It is necessary to apply appropriate geotechnical control measures to this type of project affecting sensitive features in the interest of public safety. With the geotechnical control measures applied, the geotechnical risk is assessed and the potential hazards are identified early. Any undue settlement or irregularities observed during construction can be detected promptly and appropriate remedial measures, such as use of a different annulus filler to suit the actual ground conditions encountered, change of the advance speed of TBM, etc. can be taken to prevent catastrophic failure from happening.
3. It is important to control the amount of materials excavated from the tunnel opening to prevent significant ground loss. This could be achieved by comparing the excavated volume with the theoretical excavation volume to check if significant voids have been formed in the soil above the tunnel and checking the amount of filler/grout used to fill the voids around the pipes. In this project, only the total amount of materials excavated from the tunnel opening is obtained. A better method should be devised for future similar operation measuring the amount of materials excavated for each section of the tunnel excavation and checking the amount of filler/grout used to fill the voids around the pipes.

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