Case Study of sewerage pipe installation using Pipe Jacking and Micro-tunnelling Boring Machine (MTBM) in Ipoh

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Abstract. This paper provides a review of the sewerage pipe installations near Jalan Pengkalan Perindustrian, Ipoh Perak using pipe jacking and micro-tunneling methods. The alignment of the pipe installation involving tunneling and jacking beneath the KTMB (Kereta Api Tanah Melayu Berhad) railway track with 191 m distance from jacking to receiving pit. The average jacking force of the micro-tunneling boring machine varies over distance and the highest recorded was 310 tons at 190 m distance from jacking pit meanwhile 50 tons was the lowest jacking force within 10 m distance from the jacking pit. The trend of the advance rate, mm/m shows the similarity with the average jacking force. The higher average of jacking force leads to a higher value of advance rate with the highest and lowest value was 270 mm/m and 5 mm/m respectively. The excessive deviation for both line and level affect the magnitude of the ground surface settlement where 100 mm and 130 mm for both line and level produce 30 mm of ground surface settlement at 40 m distance from the jacking pit. As the machine advances further and has better control in deviation, the settlement decrease where the value for both line and level below 30 mm, the settlement decrease to 10 mm at 80 m distance from the jacking pit and the trend continues to decrease for both deviation and settlement. The maximum settlement for the railway track was 2 mm after the MTBM passing through and still within the allowable limit set by KTMB (10 mm over 10 m chords for intervention).

1. Introduction
The installation of sewerage pipe within Bandaraya Ipoh was a good effort by the government in order to make the improvement of the sewerage system and better environmental quality of water effluent for the Kinta river located at Bandaraya Ipoh and its surrounding area. The reinforced jacking concrete pipe (RJCP) size 1300mm in diameter was installed in Jalan Pengkalan Perindustrian using pipe jacking and micro-tunneling method.

Pipe jacking is a technique to install an underground utility pipe by means of the micro-tunnelling boring machine (MTBM) located in front of the pipe string combine with hydraulic jacking from jacking to receiving pit. The hydraulic jacks located at the jacking pit push the pipe forward meanwhile the MTBM excavates the soil. Then the pipe is added to one another to form a string and the process repeated until the MTBM reaches the receiving pit. The excavated material then transported to the ground surface through slurry discharging pipe for slurry shield MTBM, screw conveyor to the jacking shaft by a trolley system for earth pressure balance (EPB)[1].

Micro-tunnelling is remotely controlled excavation from the ground surface suitable for installing underground utility pipelines where a maze of underground utility lines already existed. [2].

The performance of the (MTBM) can be indicated by the advance rate (mm/m) and the capacity to control the line and level during pipe jacking progress [3]. The performances of MTBM can be influenced by several factors. It can be categorizing into four categories which are underground...
conditions, operator’s experience, mechanics of the system and others. The soil with accurate parameters and descriptions based on the soil investigation report are the most important factors followed by the operator’s experience by contributing to solving the arising problem consequently. The mechanics of the systems represented by jacking force and cutter head torque. Meanwhile, the other factor’s impact is less than the first three groups [4]. The tunnel construction affecting the natural stress and hydro-geological condition of the soils that contributing to rapid inward displacement of the face and convergence of the tunnel walls [5].

The ground surface settlements due to the pipe jacking construction can be predicted using the Gaussian Function of normal distribution [6]. The use of this empirical method was widely accepted nowadays to be used in practice for the evaluation of ground surface settlement even though it has no theoretical justification [7].

2. Background of the study area

2.1. Project description

For phase 1 of the project, the scope of work for pipe jacking alignment involving crossing under the KTMB railway track located near the Jalan Perindustrian Pengkalan, Ipoh, Perak as shown in Figure 1. The pipe size is 1300 mm in diameter and 3000 mm in length. Meanwhile the distance of pipe alignment from jacking to receiving pit is 191.508 m with 19.700 m invert level and approximately 10 m depth for both jacking and receiving pit since the pump will be used in this piping network as shown in Figure 2.

![Figure 1](alignment_of_pipe_jacking_crossing_under_ktmb_railway_track_at_jalan_pengkalan_perindustrian_ipoh_perak.png)

**Figure 1.** Alignment of Pipe Jacking crossing under KTMB railway track at Jalan Pengkalan Perindustrian, Ipoh, Perak.
2.2. Ground condition
The soil investigation was carried out at the selected location as shown in Figure 3. There are eight (8) numbers of the borehole along the pipe jacking alignment starting from jacking pit to the receiving pit. Generally, the soil condition along the alignment consists of a soft soil layer where the sand silt and clay were present.

The geology condition below the railway track was determined by the Geophysical Tomography Method using three nos. of boreholes (named as BH TOMO 1,2 and 3). The results show there is no rock layer across all the boreholes where the velocities of the travels ranging from the 1.35 km/s to 1.85 km/s.

3. Field Instrumentation
The whole research was conducted in Jalan Perindustrian Pengkalan, Ipoh Perak. The method to obtain and gathered all data needed was by data collection from MTBM operation room to gain the machine parameters such as jacking force (Ton), the deviation on line and level (mm), and advance rate (mm/m). The ground settlement was observed daily by monitoring the vertical movement of installed Optical Prism and Ground Settlement Marker (GSM). Meanwhile, to gain the subsurface geological condition, a site investigation profile was conducted.

3.1. Data collection from MTBM control room
The information regarding the machine parameters such as jacking force, toque, and gradient in alignment, slurry pressure and speed of cutter head can be obtained from the control room.

3.2. Ground settlement marker
The PVC pipe attached with nails by means of concrete represented the ground settlement marker. The monitoring of ground movement by using total station with the aid of measuring staff place on top of the attached nails. There are eight numbers of arrays with a 10 m interval between each other and similar to an optical prism, in each array consist of five number of ground settlement marker as shown in Figure 3.
3.3. **Optical prism**

The optical prism is the similar prism used by the surveyor to obtain the coordinate of the proposed area. In this research in order to obtain possible accurate data for the ground movement, the optical prism attached to the steel bar and buried 300 mm from the ground surface to ensure there is no movement caused by human error while collecting the reading using the total station. There are four numbers of an array and five numbers of optical prism in each array installed transversely with 1 m interval to pipe jacking alignment as shown in Figures 4a and 4b.

3.4. **KTMB railway track monitoring**

The monitoring was conducted by taking the level of railway track before, during and after the pipe jacking process. The allowable settlement in a static condition caused by the construction works was 10 mm over 10 m chord(railroad) length (KTMB permanent way manual, 2005). The railway tracks marked with the blue color maker as a point for monitoring purposes. There are fifty-nine (59) number of points with interval 1 m to each other as shown in Figure 5 (a) and (b).
4. Performance review

The performance review for pipe jacking works using MTBM involving the jacking force (Ton), advance rate (mm/m), capacity to control line and level (mm) related to ground settlement (mm) and railway track settlement.

4.1. MTBM performance

The advance rate (mm/m) of MTBM reflects the performance during the excavation in specific shift time or day. The advance rate varies over distance. The highest advance rate was 270 mm/m recorded within 20 m distance from the jacking pit with 50 tons average jacking force and suddenly drop to 5 mm/m also within the 20 m distance from the jacking pit which is the lowest advance rate recorded along the pipe jacking total distance with 200 tons of average jacking force. However, the advance rate trend line starts to increase as the distance increase even though there is a slight decrease was observed within 100 m and 150 m distance as shown in Figure 6.

![Figure 6. Average advance rate and Average Jacking Force over the distance.](image)

4.2. Jacking Force

Generally, the jacking force increase with distance. However, there is a fluctuation in the trendline as shown in Figure 7. The highest jacking force was 350 tons measured within 180 m to 190 m distance from jacking pit where the MTBM almost reach the receiving pit and completed the pipe jacking
works. Meanwhile, the lowest jacking force recorded at the starting point with an average value of 50 tons within 10 m distance from the jacking pit.

![Jacking Force over the distance.](image)

**Figure 7.** Jacking Force over the distance.

4.3. Capacity in controlling line and level
The capacity of the MTBM machine to control the line and level indicated by the deviation during the pipe jacking progress and it can be related to the ground surface settlement. The deviation of line and level (horizontal and vertical alignment) within the 80 m distance from the jacking pit ranging from 5 mm to 100 mm for horizontal ( (+) sign to the right, (-) sign to the left) and 2 mm to 130 mm for vertical ( (+) sign upwards, (_) sign downwards). As the MTBM advance forward toward the railway track the deviation for both horizontal and vertical decreases to a value ranging from 2 mm to 15 mm for both line and level starting from 85 m to 138 m distance from the jacking pit. The predicted ground settlement calculated was 4.23 mm with volume loss of 4% as propose proposed by New and O'Reilly 1991 [6]. It can be seen that the large deviation in line and level contribute to the excessive settlement exceeding the predicted value within 85 m distance from the jacking pit where settlement ranging from 10 mm to 30 mm and when the deviation becomes smaller starting from 85 m onwards the settlement recorded was smaller than the predicted value with range of 1 mm to 2mm as shown in Figure 8.
4.4. KTMB railway track settlement

Generally, there is inconsistency in railway track settlement and heaving along the monitoring chainage as shown in figure 9. From the settlement profile plotted along the chainage, it shows that before the MTBM reaches below the railway track there is a slight heave occurred which is 1 mm at point 29 on 11/10/2018 and during the tunneling on 12/10/2018 there is 1 mm settlement was observed. After the MTBM passing through the railway crossing 2 mm settlement was observed on the following days 13/10/2018. The largest settlement observed was 6 mm, but it is located 25m away from point 29. All the settlements observed are within the allowable vertical range set by KTMB which is 10 mm over 10 m cord length. Hence, there is no effect on the safety of the railway track during the excavation works.

Figure 8. Longitudinal settlement and deviation of line and level.

Figure 9. Railway track settlement.
5. Conclusions
The performances of the micro tunneling boring machine (MTBM) govern by the mechanic’s system such as the jacking force and the type of the subsurface encountered. The soil investigation profile along the alignment was very important to identify what is the type and strength of the soil encountered during the pipe jacking process. The correlation between machine performances and soil properties might be studied for a better understanding. The ground surface settlement was very important to ensure the safety of the surrounding structure not affected by the pipe jacking works. Evaluating and observed the ground surface settlements give an early warning to the contractors to take the precaution before any unwanted thing happens. For this project, the sewer pipe installs by pipe jacking and micro-tunneling method was successful without any delay or dangerous effects to the KTMB railway track.

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