TBM (TUNNEL BORING MACHINE) GUIDANCE SYSTEMS FOR TUNNEL CONSTRUCTION

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Abstract: This paper presents a summary of the means for directing the process of tunnel boring machine using geodetic techniques and procedures, noting the essential aspects in order to meet the accuracy requirements for this kind of breakthrough in special underground construction.

It is concluded that a good configuration of the underground geodetic network and its periodic review can provide accurate control of the work of achieving tunnels reducing downtime of the TBM.

Keywords: TBM, Control Stations, Laser Station, Video Target, Zigzag Traverse.

1. Introduction

Tunnel construction using the TBM (Tunnel Boring Machine) has become a preferred method of construction nowadays. In addition, this is well accepted by the environmentalist and the green groups. This state-of-art technology limits all works in underground for building the tunnel to keep the disturbance to land, wildlife and mankind activities at ground level to a minimum throughout the period of construction.

Tunnel construction by TBM is quite different from the traditional Drill and Blast Method.

The tunnel is excavated using a machine instead of blasting with explosive. The tunnel lining is put in place at the back of the machine immediately following a ring length advancement of TBM. A well thought engineering survey scheme is devised to integrate with the operating system and working sequence of the TBM.

A tunnel guidance system is tailored made for the TBM to continuously track the position and direction of the machine in course of excavating. The geo-spatial data of the machine is instantaneously displayed on the screen at the TBM control cabin. The pilot would make use of the information to steer the machine to match the design alignment.

2. Major components of TBM

Component Function [3, 4]:

1) Cutter Disc - To excavate rock or soft ground by the rotation of an assembly of teeth or cutting wheels under pressure against rock face.

2) Shield Skin - To keep the soil from getting into the machine and to provide a safe space for the workers.

3) Pushing Jack - To be in full contact with the erected segment and extend by hydraulic as the cutter disc turns and thrusts forward.

4) Main Drive - To provide a force in rotating the cutter disc and is powered by electricity.

5) Screw Conveyor - To move the spoil at the cutter disc and feed onto a conveyor system.

6) Erector - To erect the segments to form a complete ring after showing at the tail of the TBM.

7) Back Up Facilities - To travel with the TBM and to service the operation of annular grouting, welding, extension of ventilation, power and track etc.



The TBM moved forward as it excavated the tunnel by extending the pushing jacks at the back. When the advancement of the machine reached distance of the length of a ring, the excavation stopped and the pushing jacks were retrieved, a concert circular ring in form of a numbers of segments were then put together at the tail of the shield. The pushing arms were once again extended in full contact with the concert ring just erected and excavation resumed. The cycle of excavation and ring erection repeated as the TBM advanced to form the lining of the tunnel (Figure 2).

3. Survey methodology

3.1. Pre-construction Stage

- Identifying the geographic coverage of the construction works and designing a geodetic network control scheme on the surface to cover the area
- Performing a reconnaissance survey on site to identify the known control stations nearby and established the new survey stations
- Set up a survey control network, the new stations were rigidly tied to the known stations
- Performing field measurements of angle and distance among the stations followed by computation of global coordinates of control stations.

3.2. Construction Stage

- Prior to the initial drive of TBM, secondary control station was established at the TBM Launching Shaft at surface by transferring co-ordinates from the primary control stations
- Transferred the secondary control station from surface at the TBM Launching Shaft to the tunnel control station at underground level
- Moved up the tunnel control station by Double Zigzag Traverse behind the TBM as the machine travelled ahead, and transferred a temporary station to the shoulder position of the erected ring at the back-up gantry of the TBM



- Traversed the temporary control stations at the erected rings above the TBM back up gantry to reach the Laser Station located about 30-50 m behind the TBM.



Fig. 5. Transfer of control station at the TBM back up gantry

- The Laser Station carried the coordinates from the control station shot the prism target affixed to the bulkhead of TBM to determine the absolute spatial coordinates (x, y, z) of the TBM at that point. The tunnel guidance system and the dual axial inclinometers simultaneously measured the amount of rotation along the three perpendicular axes of the TBM to determine the orientation of the heading of the machine [1, 2].
 - 3.3. Working Principle of the TBM Guidance System

In the XY Plane: The Laser Station shined onto the Video Target. By analyzing the laser image, the Video Target was able to measure the angle of incidence of the ray with the

plane of the Video Target to determine the twist of the TBM. By adding the twist to the true bearing carried forward from the Laser Station, the true bearing of the heading of the TBM was determined. A built in inclinometer (no. 1) was placed in alignment with X-axis. The inclinometer measured electronically the roll of the TBM with respect to the plumb line.



Fig. 6. TBM Guidance System

In the YZ Plane: Another built in inclinometer (no. 2) was placed in alignment with Yaxis. The inclinometer measured electronically the tilt of the TBM with respect to the level line. The Laser Station determined the 3D position of the TBM, the Video Target determined the twist in XY plane, the Inclinometer 1 determined the roll in XZ plane and the Inclinometer 2 determined the tilt in YZ plane.

This management process of TBM can be automated when using electronic tilt sensors on two directions, motorized high precision geodetic instruments, wireless connection between them and the appropriate software to correlate all the data, to process quickly and compare the parameters of designed TBM movement and based on previously acquired data can make projections of 3D trajectory of the TBM [2].

If the guidance system gives immediate feedback the advance speed can be maximized and is determined by the capabilities of the TBM. TBM steering must be done smoothly so that rings can be built without distortion.

If deviation of the TBM position exceeds a certain limit the guidance system must calculate a correction curve which returns the TBM smoothly back to the DTA (Designed Tunnel Alignment). This allows the operator to steer the TBM in a way so that the TBM capabilities and ring geometry are taken in consideration. Waiting time for delivery of the next ring is minimized if the guidance system pre-calculates the sequence of rings to be delivered to the TBM.

The main reference point is defined by a laser station mounted on the wall of the tunnel and emitting a visible laser beam. The laser station will be relocated periodically to a new mounting point, re-determining the new position of the laser station [8].

The actual TBM position and its horizontal and vertical deviation relative to the DTA are determined. If the deviation of TBM position or direction relative to the DTA exceeds a given amount, is determined a correction curve, which takes into account for these restrictions as well as for a given ring sequence and will lead the TBM back to the DTA.

In these conditions, the laser station with the built in robotic mechanism tracked the prism continuously as the TBM advanced, being able to update the spatial position and the orientation of the TBM at every 10 seconds.



The system linked to the TBM control cabin (Figure 8), where on the screen the positional deviation of the TBM with the Design Tunnel Axis was displayed (Figure 9) instantaneously in graphical and numerical formats at all times is aiding the pilot to steer the machine.



Fig. 8. TBM control cabin

Fig. 9. Tunnel axis positional deviation

The extension of the Articulation Jacks allowed the TBM to turn flexibly and advance forward in the direction of the design tunnel axis.



3.4. Post-construction Stage

If they are fastened eight points in the tunnel lining profile will be checked:

1) construction tolerance

2) dimension tolerance of the diameter



Fig. 11. Points on the tunnel lining in profile

Surveyor verified the wriggle survey data before it was passed to the Railway System Group for further assessment. Should the tunnel infringe the structure gauge occur, either the tunnel builder would propose a method for rectification or the tunnel builder would seek relaxation from the Railway System Group [5, 6, 10].

A "Double Zigzag Traverse" method was employed to advance the survey control station at the back of TBM to keep pace with the machine in moving forward.



Fig. 12. Points on the tunnel lining in profile

Prior to the breakthrough, computation of the stations coordinates was performed by Traverse Method on site and verified by Variation of Coordinate Method at the office for the detection of gross error. The surveyor at the TBM tunnel was capable to provide accurate survey information with confidence to keep the TBM operation uninterrupted at all times. After the tunnel breakthrough, the last TBM control station was tied to the known station at the other end for closure check. The coordinates of all control stations were recomputed with the Method of Least Square of Adjustment [7].

The set of control stations and benchmarks come up after the tunnel breakthrough were deemed to be final and would be used for wriggle survey, track work, and electrical and mechanical service layout.

4. Conclusions

Increasing demands for better underground infrastructure have spurred tunnel construction all over the world, within which the TBM tunneling method is the most commonly applied. The lack of effective TBM guidance solutions, however, potentially contributes to increased risks and uncertainties in tunnel construction.

Despite the tunnel guidance system is claimed to be a total solution to provide positional information of the TBM, a responsible surveyor cannot just accept the result output by the system without making any sound judgment at all. Manual checking of the position of the TBM is mandatory. The result of manual checking should be in agreement with that of the automatic system.

The Double Zigzag Traverse method could detect the survey gross error, the setup allows each control station to be fixed by four control stations. The merit of the method is that number of the backsight of a station has been increased to four, offering more chance of getting an unobstructed line of sight from one station to the other.

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