Journal of Geomatics Vol 11 No. 2 October 2017

Tunnel engineering survey at Delhi metro phase-III CC04 project

G. Jagadeswara Rao
CEC-CICI Jv, Delhi Metro Phase-III CC04 Project
Email: surveyor.jagdish@gmail.com

(Received: May 17, 2017; in final form: Sep 22, 2017)

Abstract: Tunnel Boring Machines (TBMs) are used to excavate tunnels in virtually all types of grounds and under widely different physical conditions. The history of TBMs started with soft ground shields of the type developed in England. These shields progressed by breaking the excavation in to small compartments excavated by hand. The science of mechanical underground tunnel excavation has developed continual step by step. TBMs, also known as Moles, are the recent development in the tunnel driven techniques. High precision survey is very essential for a TBM to ensure the excavation and build the tunnel, within the construction limits and tolerances, according to the Designed Tunnel Axis (DTA). TBM guidance system provides all the very important information, which is absolutely necessary to drive the TBM along DTA by continuous tracking the position during mining/excavation and display both numerical and graphical display the position of the TBM in the pilot cabin to control / steer the machine. In the paper, surveying technology adopted in the Delhi metro phase III (CC-04) project in the Metro City Delhi in the year 2013-2017 is described.

Keywords: EPBM, Guidance system, Double zigzag traverse

1. Introduction

The contract CC04 is part of the new 58 km long PINK LINE (Line 7) of the Delhi metro phase III project, which runs from Mukundpur in the North of Delhi in circle up to Shiv Vihar in the North East (Figure 1). In this project, the first 2 Earth Pressure Balance Machine (EPBM) launched at Azadpur station south

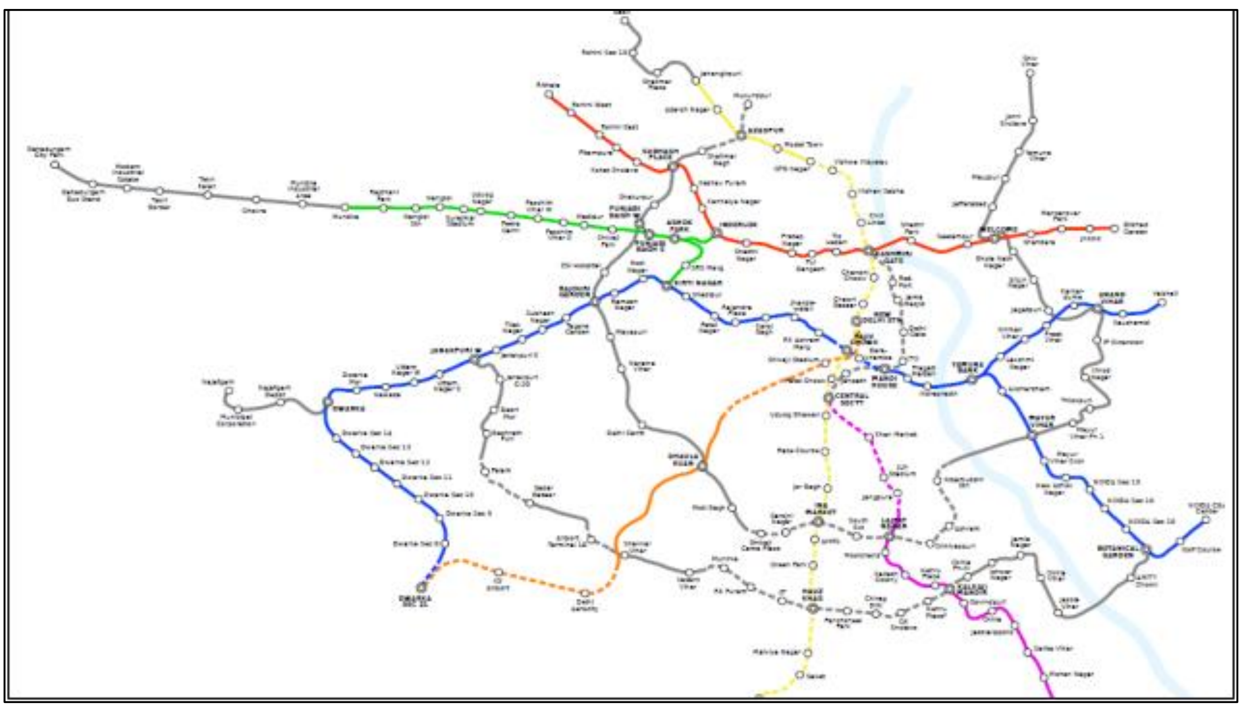

Figure 1: Delhi metro network

Shaft were moved towards Shalimarbagh station. After the breakthrough at Shalimarbagh station North end, both the machines were dismantled and shifted to North end of Azadpur station and relaunched for Tunnel from Azadpur to Mukudpur, due to unforeseen ground condition, both the machines got stuck at midway of the alignment. So 2 additional EPBMs were launched at Mukundpur Ramp to complete the tunnelling between Azadpur to Mukundpur (Figure 2).

2. Scope of work

The scope of the work consists of:
Tunnel: 5.2 km bored tunnels with ID 5.80 meters (using 4 TBM EPB Mode)
Cross passage: 1 Nos
Emergency exits: 2 Nos
Underground stations: 1 No (252m length)
Cut & cover tunnel: 1 No (96m), Ramp: 1 No (192m)

Figure 2: Work area

3. Tunnel Boring Machine (TBM)

The history of tunnel boring machine (TBM) started with soft ground shields of the type developed by Marc I. Brunel and J.H. Greathead in England. These shields progressed by breaking the excavation in to small compartments excavated by hand. A TBM, also known as a "mole", is a machine used to excavate tunnels with a circular cross section through a variety of soil and rock strata. They can bore through hard rock, sand, and almost anything in between. Tunnel diameters can range from a meter (done with micro-TBMs) to almost 16 meters. Tunnels of less than a metre or so in diameter are typically done using trenchless construction methods or horizontal directional drilling rather than TBMs.

TBM are used as an alternative to drilling and blasting (D&B) methods in rock and conventional 'hand mining' in soil. TBMs have the advantages of limiting the disturbance to the surrounding ground and producing a smooth tunnel wall. This significantly reduces the cost of lining the tunnel, and makes them suitable to use in heavily urbanized areas. The major disadvantage is the upfront cost. TBMs are expensive to construct, and can be difficult to transport. However, as modern tunnels become longer, the cost of tunnel boring machines versus drill and blast is actually less—this is because tunnelling with TBMs is much more efficient and results in a shorter project duration.

TBM can be classified by the methods for excavation (full face or partial face), the types of cutter head (rotation or non-rotation), and by the methods of securing reaction force (from gripper or segment). Several types of tunnel excavation machines are available. EPBM is a kind of TBM (Figure 3).

3.1 EPBM main components

1. Cutter Head
2. Drive Unit
3. Push Cylinder
4. Air Lock/Man Lock
5. Screw Conveyor
6. Erector
7. Screw Conveyor Gate
8. Segment Feeder
9. Segment Hoist Crane
10. Conveyor
11. Back-up Gantries

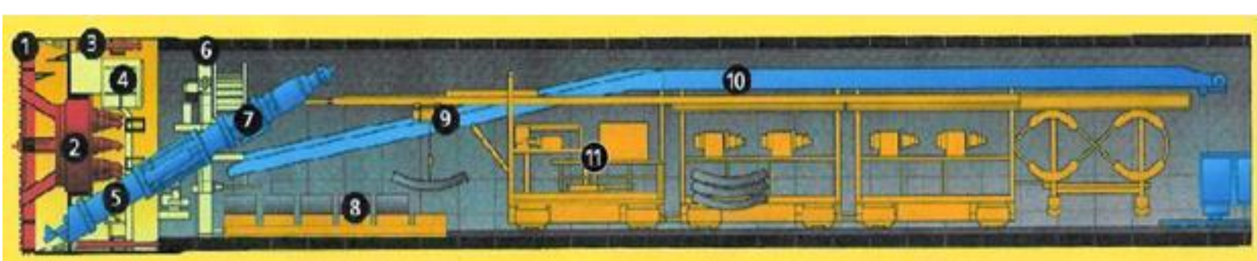

Figure 3: Tunnel Boring Machine (TBM)

3.2 EPBM operation and construction procedure

This method provides continues support to the tunnel face by balancing earth pressure by the machine trust. As the cutting wheel rotates and shield advances the excavated earth mixed foam in the cutting wheel chamber to control the viscosity. The pressure is then adjusted by means of the rate of its extraction (by screw conveyor) to balance the pressure by the ground at the tunnel face. The screw conveyor transfers the extracted material to the first conveyor belt of the conveyor belt cascade.

The extracted material reaches the so-called reversing belt via these belts. The transport cars for the extracted material in the backup system in the reversing operation are loaded via this belt. This enables near surface tunnelling in bad ground condition with minimal surface settlement.

The EPBM moved /advanced forward as its excavated the tunnel by pushing push rams/cylinders at the back to existing ring, when machine reaches desired one ring length, the advance of excavation stopped and with the ring measurement program, the best ring will be chosen and the jacks were retrieved, build the ring and according the lead, tail skin clearances, DTA, articulation cylinder,

Tendencies of the machine prediction can be done for future rings. After completion of the ring build all push rams extended for the next advance/mining (Figure 4)

4. Survey methodology

In this project, survey methodology can be divided in to three stages 1. Preconstruction stage; 2. Construction stage; and 3. Post construction stage.

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Figure 4: TBM at launching shaft

4.1 Preconstruction stage

Tunnel survey is based on above ground survey that connects points representing each portal of a Tunnel. A reconnaissance survey was carried out throughout the corridor in the metro city Delhi to establish the Master Polygon Points (MPP), far around 200m distance from the alignment of the corridor and established Construction Pillar (CP) near to the station box (Figure 5).

MPP of dimension 1m X 1m X 1.5m reinforced concrete block were made with centre stainless steel square plate with round headed bench mark point over the plate for vertical control. CP with concrete block with ϕ200mm pipe filled with concrete, circular plate over pillar and providing level bolt at bottom aside of the pillar (Figures 6 & 7).

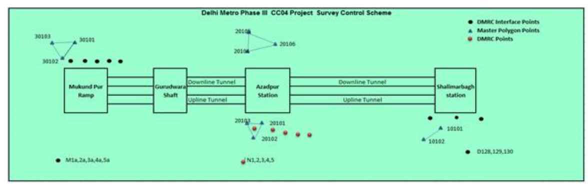

Figure 5: Survey control scheme

Figure 6: Master polygon point

Figure 7: Construction pillar

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A survey network was established between the control points with the newly established control points (MPP & CP), rigidly tied with the new known stations. All the horizontal, vertical angles, slope distances were observed with the precise surveying instruments and the observations were carried out followed by global coordinates computation with the least square technique with the help of Starnet software. The datum points (bench marks) were also established for control of vertical.

4.1.1 Instruments used: For all terrestrial measurements on surface and in tunnel the following instruments were used:

Total station LEICA TS15A (Tunnel network, Surface monitoring and setting out)

Accuracy:	σHz	≤ ± 0.3 mgon
	σV	≤ ± 0.3 mgon
	σs	≤ ± 1 mm + 2 ppm

Total station LEICA TCA1800 (Tunnel Monitoring)

Accuracy:	σHz	≤ ± 0.3 mgon
	σV	≤ ± 0.3 mgon
	σs	≤ ± 1 mm + 2 ppm

Total station SOKKIA SET1050 (station Survey)

Accuracy:	σHz	≤ ± 0.5 mgon
	σV	≤ ± 0.5 mgon
	σs	≤ ± 2 mm + 2 ppm

Total station LEICA TC15G (Guidance System)

Accuracy:	σHz	≤ ± 0.5 mgon
	σV	≤ ± 0.5 mgon
	σs	≤ ± 2 mm + 2 ppm

Digital Level LEICA DNA 03 (Tunnel Network, Surface Monitoring)
Accuracy: σdh(1km) ≤ ± 0.3 mm

4.1.2 Software:

Starnet :	Network adjustment
Eupalinos:	Wriggle survey
TUnIS:	TBM guidance system
TUnIS Office:	Guidance system
Iris:	Guidance system
LevelPak:	Level adjustment
Leica Geooffce:	Level adjustment
NRG	3D monitoring

4.1.3 Base network: The base network points and elevations were received from DMRC.

The CEC-CICI Jv surveying team establish new MPP and CP by traverse and benchmarks with reference to the handed over points. The whole network combined traverse readings were calculated by least square adjustment to compensate network-irregularities. The new MPPs & CPs were measured by using 1” accuracy total station and levelling was carried out with digital level.

4.1.4 Accuracy: Primary Horizontal Control: Second order class 1 - plus closing error 1:70,000
Primary Vertical Control: Second order class 1 - 0.7mm/Km.

4.2 Construction stage

Secondary Control station/points as Glass Prism targets on the Diaphragm wall of the Launching Shaft before launching the TBM and transferred the coordinates from the MPP & CP points.

4.2.1 Network transfer to underground: At the top edge of shaft or station d-wall prism targets (Figures 8 & 9) were fixed at symmetric positions protected against damage during excavation or tunnel works.

Figure 8: Targets at launching shaft

Figure 9: Glass prism target

Using the total station Leica TS15A measured all points and the levelling was carried out with digital level. Starting from the control pillars and elevation benchmarks at the surface these targets were measured in 3 sets with 2 faces each (bearing and distance readings) and their co-ordinates were calculated with Starnet software. (Figures 10 & 11).

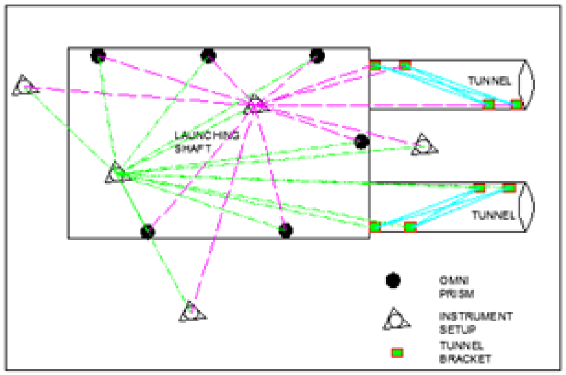

Figure 10: Launching shaft network transfer

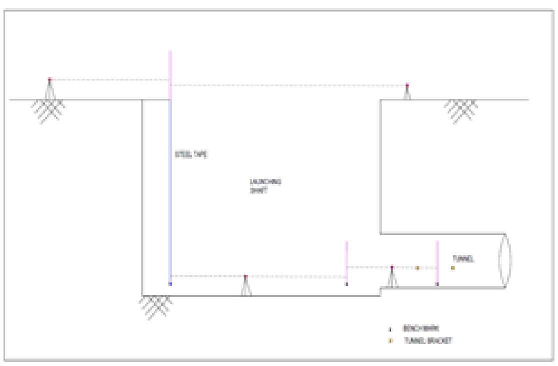

Figure 11: Vertical transfer to shaft

Six to ten targets were mounted symmetrically at the bottom of the shaft or station (walls). Then the total station was set up at the bottom. It was located approximately in the centre of the shaft or in the centre of the points fixed at the top. After setting up instrument, the readings to the fixed points at the top were taken with total station (3 sets with 2 faces each, bearing and distance). Afterwards, the new points at the bottom were measured (3 sets with 2 faces each, bearing and distance). Before taking the readings the total station was calibrated and set up very carefully to reach a maximum accuracy of the co-ordinate transfer. While carrying out these readings all work and traffic of site vehicles were stopped in an area of 20m around the total station for accurate measurements. With these readings the co-ordinates and elevations of the targets at the bottom could be calculated using least square adjustment method. The accuracy of this co-ordinate transfer were within ±0.5mm in Easting, Northing and elevation for each point related to the surface coordinates from the shaft height of 20m. This accuracy was sufficient for any kind of survey and monitoring in the adjacent bottom area of shaft or station. Due to deformation of the bottom area during tunnel excavation these observations were carried out periodically with a frequency depending on deformation and excavation progress.

4.2.2 TBM guidance system: Since the late 1970s, tunnel guidance system has been developed that make use of computers and light-sensitive target screens to automatically indicate all TBM coordinates and altitude angles. This information can be displayed digitally. The positional information is described in X and Y coordinates of the survey coordinate system (left/right and up /down in the tunnel) and the distance (Z coordinate) in the direction of the tunnel centerline. The angle measurements may be interpreted as roll (rotation about the tunnel axis), look-up or overhang (deviation from horizontal) and lead (rotation about a vertical axis) of the angle measurements; roll and look-up are obtained by the use of inclinometers, measuring an angle relative to the plumb line. The X and Y measurements at the target plane and the horizontal angle between the target and the laser beam are measured by a specially fabricated target. The target intercepts the laser beam and measures the position of the laser relative to the centre of the target. The beam strikes a screen at the front of the target, and the spot so formed is imaged on to two linear photodiode arrays. This provides the basis for the position measurement on the X and Y coordinates. The screen allows some of the laser beam to pass though unhindered to a third photodiode array, to measure angle between the target and the laser beam.

In Order to prevent undesirable movements of the TBM and sudden changes in the direction, it is important to have a permanent check on the position of the TBM with respect to Designed Tunnel Axis (DTA), especially during the Advance itself. Pilots of TBM's need continuous information about how the machine axis is positioned and oriented with respect to its DTA. At the advance rates of several centimeters per minute that are common now, the Operator must have immediate feedback about the consequences of his control actions in order to keep the machine as close as practical to the DTA. The Tunnel Navigation / Guidance System gives users continuously updated information about the spatial position and orientation of the TBM. Thus, through properly controlled steering actions, the TBM can be kept within a narrow tolerance circle around the DTA.

The main reference of the Navigation system is a visible laser beam projected from a Laser Theodolite mounted on the wall or lining of the tunnel in an area that is relatively stable. This laser beam will typically project for a distance of between 100 – 200 m depending on the power of the laser, the atmospheric conditions in the tunnel and the amount of refraction that the laser beam is subjected to. The laser beam passes through the clear space in the machine and back-up equipment (laser window) to the target mounted on the forward part of the machine. The useable laser to target distance is also dependent on the size of the laser window and the curvature of the tunnel. It is therefore necessary to periodically advance the laser to a new position. After the survey team has determined the first initial position, subsequent laser positions are determined. When the laser beam strikes the ALTU Target the precise centre of the beam relative to the centre of the target is measured. The horizontal angle at which the laser beam strikes the ALTU Target is also determined. Installed within the ALTU Target is a dual axis inclinometer transducer to monitor the pitch and roll of the ALTU Target. Attached to the front of the ALTU Target is a retro-reflective prism. The distance between the laser reference position and the ALTU Target is measured by the EDM within the theodolite. Therefore, from the knowledge of the absolute position of the laser reference, the absolute position and orientation of the ALTU Target and hence the position and orientation of the TBM can be established. This information is combined with the desired alignment of the drive to give the machine operator a simple indication of where the machine is, relative to where it should be. It presents these results to the operator in a clear, concise manner allowing him to take the necessary corrective measures. This information is then used to steer the machine as closely as practical to the desired alignment. It is, of course better for all concerned if the TBM follows exactly the desired route. However, no tunnel driving operation can keep precisely to the planned tunnel alignment. Obstructions, deformations in the TBM skin, variable densities of the surrounding rock and varying hydrological conditions etc. all affect the direction of the TBM. Steering corrections are necessary all the time, irrespective of whether the axis is straight or curved. If the shield must follow a narrow radius curve alignment, the required course corrections are more critical, and therefore more difficult, than on straight drives. A TBM with articulation jacks is more mobile and therefore can be more complicated to steer. The scope for control corrections is restricted, however, since the tunnel lining must follow the TBM advance. Corrections must be adapted to the geometry of the rings if damage to the TBM and the lining are to be avoided. When the segmental lining uses tapered rings steering is even more important. If an incorrect ring is installed, the TBM may go out of tolerance faster, and will be even more difficult to correct. The TBM must return tangentially to the DTA along a geometrically predetermined correction curve. (Figures 12 and 13)

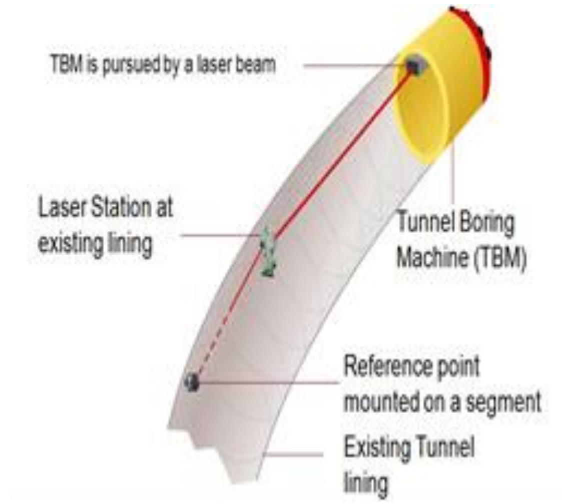

Figure 12: Guidance system

Main features of the system are:

• Computation of the TBM Position with display in graphical and numerical form
• Computation and display of the erected rings with the ring position after erection
• Computation and display of the TBM trends
• Computation and display of the ring trends
• Computation of a correction curve to return the TBM tangentially to the designed route
• Computation of the segmental rings to be installed (with respect to the correction curve)
• Full documentation of the as built tunnel drive (advance records, logbook files, etc.)
• Display of designed jack extensions to follow the computed correction curve
• Complete operation of the components from a PC
• DTA computation from standard geometric elements
• Software controlled checking of laser bearing (azimuth control)
• Automatic Position Determination of the Laser Theodolite
• Guided change of laser station during ring erection
• Display of the program screen in surface office, or anywhere else in the world (by telephone link)
• Ease of operation (Windows™ program)
• Automatic tail skin clearance measurement.

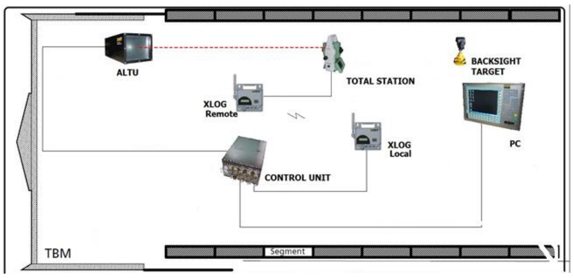

Figure 13: Guidance system schematic diagram

4.2.1.1 Main Components of guidance system

1) Tachymeter

A Tachymeter is geodetic measuring Instrument for measuring horizontal, vertical angles and distances.

2) LASER

The laser is mounted on the Tachymeter objective. The target axis and laser axis are identical. The power supply and controls are carried out externally via cable link to the laser control.

The laser is integrated in the Tachymeter. The power supply and controls are internal in the Tachymeter.

3) ALTU (Automatic Laser Target Unit)

This is an intelligent sensor; the Target receives the laser beam. It determines the point of incidence in a horizontal and vertical direction. In addition, the roll and pitch are measured by integrated inclinometers. The yaw angle is ascertained from the angle of incidence of the laser on the ALTU. The ALTU is fixed to the TBM body, its position having being determined during installation. Its installed dimensions with respect to the tunnel axis are thus known. (Figure14)

Figure 14: Automatic Laser Target Unit (ALTU)

4) Personal computer

In the Industrial PC, all the data determined are automatically combined and evaluated. The information is displayed on the monitor in numerically and graphically.

5) Modem

The modem is used for remote operation or checking of the regular telephone network. In addition, the TBM position can be displayed in the surface office.

6) XLOG (local and remote)

This is used for the power supply to the Tachymeter and lasers. Communication between PC and Tachymeter is also organized here.

7) PLC

The TBM data are imported from the TBM control computer. This control computer is called PLC (stored programmable controller). The PLC is independent. It is required and supplied by the TBM manufacturer.

4.2.2 Guidance operation

4.2.2.1 Basics: The guidance system employs three different coordinate systems

1) Global coordinate system: It is used to calculate all fixed points, set out positions, mean points etc., These include the DTA data, laser brackets etc.,

2) TBM coordinate system: Installation dimensions of the ALTU target, control points and reference points in the TBM are calculated in this system. The system relates to the axis of the TBM. It includes and documents all the points necessary for the survey. For a main control survey, the control points can be used for determining the TBM position (Figure 15)

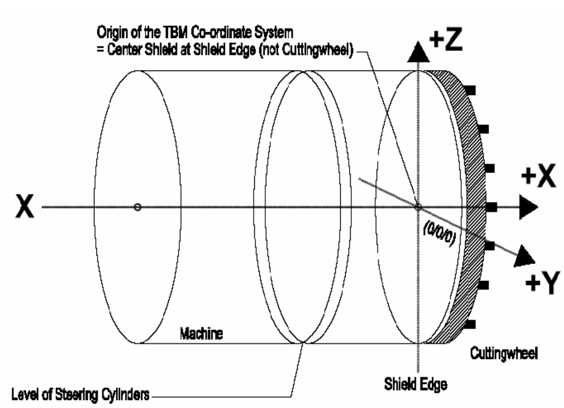

Figure 15: TBM coordinate system

3) DTA system: In the system the Chainage and offsets of the front and rear reference point of the TBM are shown. The TBM position always with respect to this system.

TBM position during advance

Basis for positioning of the TBM are two known points in the global coordinate System (Easting, Northing, Elevation). The front point is occupied by the total station with unobstructed vision to the active laser target unit. By the 2nd known point (back sight prism) the orientation is determined and so the advance direction can be defined. (Figure16&17)

The Laser Beam is directed at the ALTU. The ALTU can thus determine the Yaw angle of the laser with respect to the plane of the ALTU Axis. The roll and pitch are determined directly by means of inclinometer installed in the ALTU.All these data transmitted to PC approximately twice per second. The distance between the tachymeter and ALTU is measured directly by the tachometer.

This distance provides the Chainage of the TBM along the DTA.

Figure 16: Guidance system: TBM position

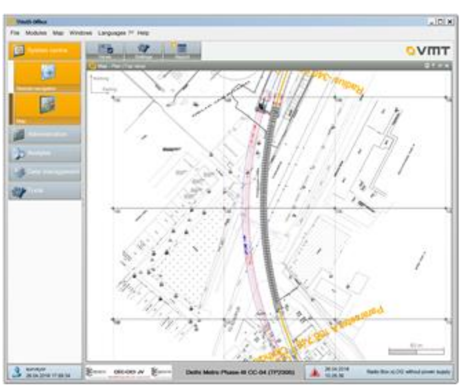

Figure 17: Guidance system: TBM position on map TUnIS navigation office

TUnIS navigation office provides the site office with real-time navigation and ring data from the EPBMs. Thus, the navigation system can be directly monitored from the site office. The TUnIS Navigation software is installed on the EPBMs to continuously indicate their current position and to monitor the ring build real time. The installed navigation software saves all data in a local database, which is continuously synchronised with the central database on the office PC. Thus, it is ensured that the site office has always the most recent data available. This is of vital importance for analysing the navigation and ring data. Communication with the TUnIS navigation systems, the site network, and with the upload to the web server is managed. Troubleshooting can be done from the office through TUnIS navigation office (Figure 18).

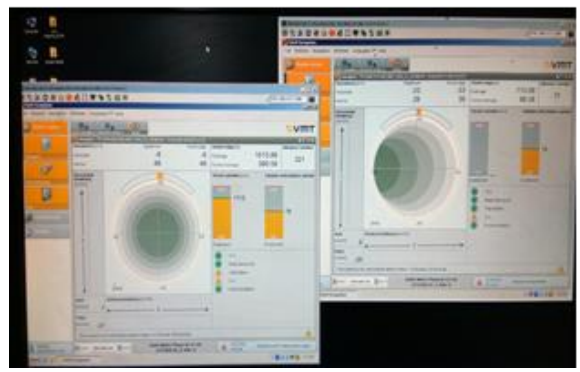

Figure 18: Guidance system: TUnIS navigation office

TUnIS ring sequencing

Here in this work, parallel, right hand tapered, left hand tapered precast rings were used. Precast concrete ring used in segments (3 rectangular, 2 Trapozoidal + 1 key segments of length of 1.2m). The most appropriate ring type must be defined as well as the expected shield drive for the advance. This is even more important using tapered rings which are most suitable for alternating curved and straight tunnel alignments.

The optimal ring positioning is a decisive part of the tunnel boring process. Depending on the selected ring rotation, the next ring will have a specific build direction which should ideally follow the shield axis to avoid damage to the outer side of the concrete segments.

Based on the ring position TUnIS Ring Sequencing provides an anticipatory calculation of ring sequencing, taking into account the actual TBM Position.

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In addition to the TBM-position the ring sequencing calculation has to consider further influencing factors such as the course actually driven by the TBM, main shove ram extensions and tail skin clearance values.(Figure:19)

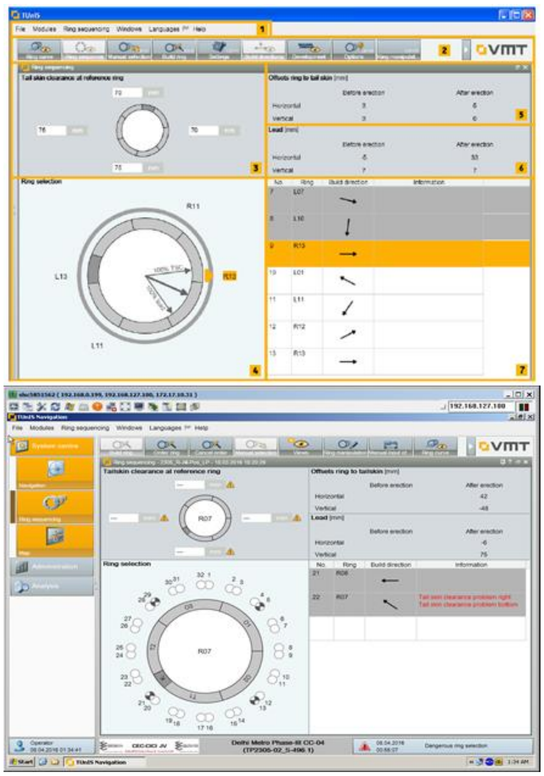

Figure 19: Guidance system: TUnIS ring sequencing

IRIS - Integrated Risk and Information System
This is a single software solution for integrated data management of infrastructure projects. Tunnel construction using TBMs represents highly complex process chain. Such process generates large amount of data which can be used for monitoring, reporting and analysis. IRIS Tunnel is a process data management system specifically developed for the data control and analysis of data generated by TBM tunnelling. Our all four TBMs connected with IRIS and all the data of four TBMs can be viewed, and position of TBMs and their locations can be view on the map (Figure 20).

4.2.3 Double zig-zag traverse: Control points were established in the tunnel by double zig-zag traverse. The control brackets were fixed in the tunnel at spring level up to last backup gantry of the TBM. The double zig-zag traverse connected up to last visible laser station, back prism of the tunnel guidance system. All the bench marks were established in the tunnel with Hilti nail on the bolt pocket of ring above the track level, between two control bracket on opposite sides. The double zig-zag traverse could detect the gross error. The setup allows each control station to be fixed by four control stations. The number of backsights of the stations increased to four, deferring more chance of getting an unobstructed line of sight from one station to the other. Also the number of known stations available on the site (Figure 21).

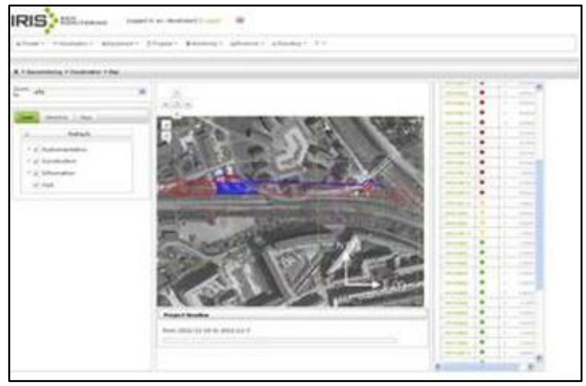

Figure 20: Integrated Risk and Information System (IRIS) guidance system

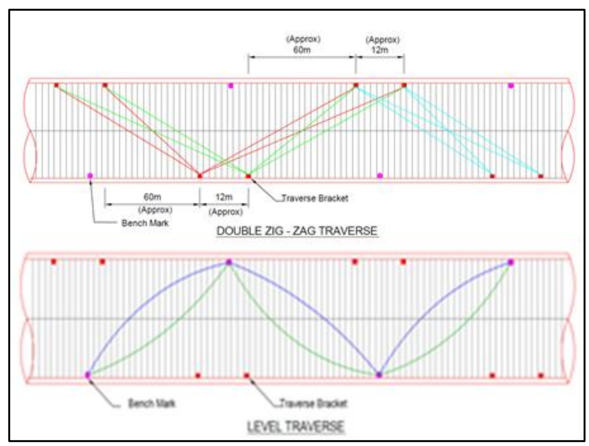

Figure 21: Double zig-zag traverse and level traverse

4.2.4 Survey control: A double zig-zag traverse was employed to advance the survey control survey station located up to last backup of the TBM. A pair of control brackets fixed at one side with space of 12m (10 rings) approximately, second pair of control brackets fixed at opposite side after 60 rings. Angles observed 2 back sight stations, 2 foresight station on the opposite of every station, distance measurements also taken as same as angels, the first two consecutive pair of station formed a slim quadrilateral, the geometry of the control stations was a chain of rigid quadrilateral stitched together.

4.2.5 Control survey of TBM: For control measurements, reference points (M8 nuts) are welded in the shield. A special adaptor bolt is screwed in to the nut thread and prism mounted. The reference points can now be measured to an accuracy of millimetres. The coordinates known and those measured can, by the three-dimensional transformation, be used to measure all parameters (deviation of front and back body, pitch roll, etc.) of TBM (Figure 22).

Figure 22: TBM manual survey points

4.2.6 Deformation monitoring: Monitoring of ground deformations in tunnelling is a principal means for selecting the appropriate excavation and support methods among those foreseen in the design, for ensuring safety during tunnel construction (including personnel safety inside the tunnel and safety of structures located at ground surface) and, finally, for ensuring construction quality management.

In urban tunnels, the main objective is limiting ground deformations around the tunnel and thus causing the minimum possible movement and disturbance at ground surface and the structures founded there. Due to the small ground deformations induced by tunnelling (usually less than 10mm at ground surface and occasionally less than 5mm), measurement precision and the early installation of the measuring devices is of utmost. Followed the Project Monitoring Scheme during tunnaling, in addition to that, excavating a deep shaft to retrieve the four TBMs from the intermediate shaft called Gurudwara shaft located highly dense buildings at Rameshwarnagar area of Model Town needs a careful and precise monitoring. Digital level and total station deployed to do surface settlement monitoring and 3D monitoring respectively.

NRGs deformation monitoring module for 3D monitoring, the Software has the option to set movement tolerance, can produce graphs warnings, according to colour code system. Individual Target movement reports can also produce from this module and prediction of alarming levels also possible in this NRGs 3D monitoring module (Figures 23 & 24).

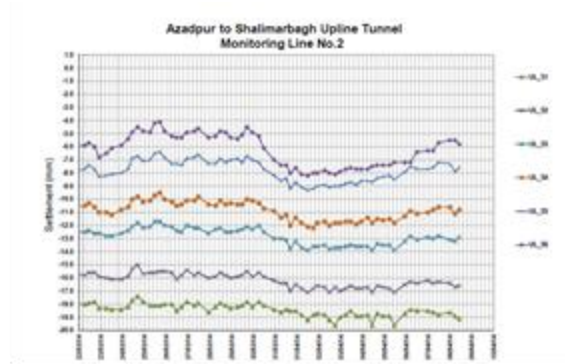

Figure 23: Surface settlement monitoring graph

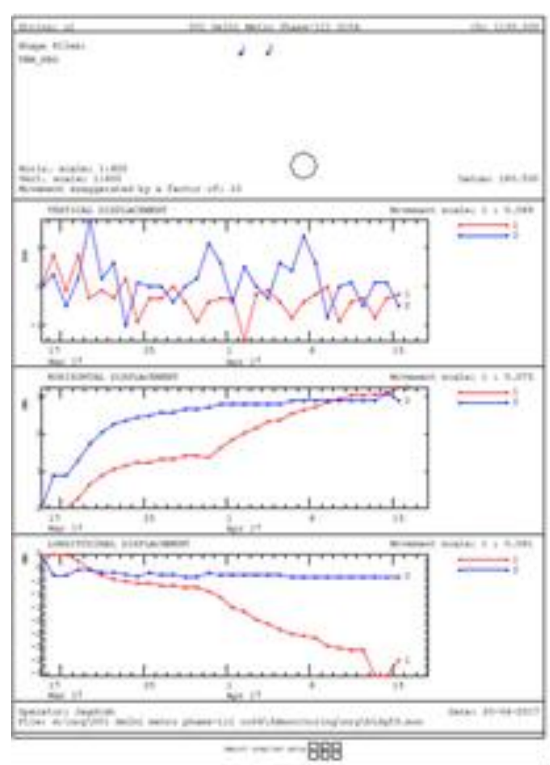

Figure 24: NRG 3D monitoring results

4.2.7 Preliminary wriggle: In order to check the construction Tolerances of the Tunnel, the Wriggle survey carried out, 8points measured to find the Horizontal deviation, vertical deviation, radius of the ring with the reference to the tunnel axis (Figure 25).

Figure 25: Preliminary wriggle survey

4.3 Post construction stage

After successful completion of the Tunnelling Operations, the Survey carried out for final submissions as the as built after the adjusting all kind of survey errors.

4.3.1 Tunnel breakthrough errors: After the breakthrough the last 2 control points tied to the other end to find the breakthrough error and closure also. The entire control network computed by least square.
All bench marks established in the tunnel with 60m approximately.

The last B.M. tied at the other end to close, the adjustment was equal weight method.
After the breakthrough, closed control points and benchmarks used for final wriggle survey, alignment and final setting out work like track centre, spring line, walkway marking etc. (Figure 26).

Figure 26: Tunnel breakthrough

4.3.2 Final wriggle

Final construction Tolerances of the Tunnel carried by measuring the profile of the Circular Tunnel with minimum of 8 Points over the Circumference, calculated by best fit circle method to find the Horizontal deviation, vertical deviation, radius of the ring with the reference to the tunnel axis. If the Deviations cross the Tolerance limits, the Tunnel has to be realigned according to the as built results (Figure 27).

Figure 27: Final wriggle survey

4.3.3 Construction tolerances: Tolerance depends upon the internal diameter of the tunnel; the minimum tunnel diameter (in the case of DMRC, it is 5600mm). But the tunnel internal diameter was fixed of 5800mm, so as to achieve +/-100mm tolerance.

4.3.4 Final realignments: In this Project the Tunnels Vertical Alignment has realigned due to unavoidable Circumstances, like Unfavourable geological conditions. The Project has a fantastic skilled Tunnel team with great experiences, but unexpected geological conditions forced us to realign the Tunnel after completing the challenges.

Azadpur to Shalimarbagh Down line Tunnel realigned from ring no.1 to 90 due to during the Initial drive of the machine (learn phase of the EBPM) vertically crossed the Limit, so it was realigned.

Azadpur to Shalimarbagh Up line, the machine went through the unexpected geological condition, machine got sunk1200mm below the designed tunnel axis, after successful completion of the challenge, and the Tunnel was realigned precisely.
Azadpur to Mukundpur drive TBMs encountered the Rock, both the Tunnels realigned. There is no Horizontal realignment was in this project, because the entire drive of horizontal alignment was perfect.

4.3.5 Schedule of Dimensions (SOD)

After completion of Track laying in the Tunnel, Structural Gauge runs in the Tunnel to find the spaces according to the Schedule of Dimensions (SOD) and safe operation of the train (Figure 28).

Figure 28: Schedule of Dimensions (SOD) checking in tunnel

5. Conclusion

Surveying is integral part of construction and high precision surveying plays a vital role especially in the underground work. TBM guidance system provides all the very important information, which is absolutely necessary to drive the TBM along DTA by continuous tracking the position during mining/excavation and display both numerical and graphical display the position of the TBM in the pilot cabin to control / steer the machine.

Acknowledgement

The author is thankful to Mr. Jaspreet Singh Kocher, Project Leader, CEC-CICI and Mr. Nigel Green, M.Inst.C.E.S, NRG Surveys Ltd, United Kingdom for encouragement. Thanks are also due to Mr. Peter Bläsi, Project Engineer, VMT-GmbH, Bruchsal, Germany for great Support for the Guidance System Installation & Support during the troubleshooting. Author will never forget the support for perfect field work from Survey Team - Mr. Fazalluddin Ansari, Mr. Chandramohan, Mr. Sachchidananda, Mr. Suresh Yadav, Mr. Ranjit Sharma, Mr. Shahid Hussein, Mr. Abdul Rahman, Mr. Anil Sharma, Mr. Wasim Rao, Mr. Manoj umar, Mr. Ram Pravesh Yadav & Mrs. Annu Manish for excellent CAD drawing work.