

Tunnel Surveying and Alignment Control Techniques

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Abstract

Tunnel surveying is the process of establishing and maintaining the designed position, direction, and level of a tunnel during construction. Because satellite positioning is normally unavailable below the ground surface, surveyors transfer surface control into the tunnel and extend it using traverses, total stations, gyroscopic orientation, and precise levelling. This paper reviews the main techniques used for tunnel surveying and alignment control, including global navigation satellite systems (GNSS), total stations, gyro-theodolites, laser guidance, and three-dimensional laser scanning. It explains how these methods are combined to guide tunnel boring machines (TBMs), control excavation direction, verify the completed structure, and monitor deformation. The study concludes that an integrated survey approach, supported by regular checks and modern automation, is essential for achieving safe and accurate tunnel construction.

Keywords— tunnel surveying, alignment control, total station, gyro-theodolite, TBM guidance, laser scanning, GNSS, deformation monitoring.

I. INTRODUCTION

Tunnels are important components of modern infrastructure because they carry roads, railways, water supply lines, and utilities through mountains, beneath cities, and under rivers. Unlike open-cut construction, tunnelling provides limited space for observation and little or no access to satellite signals. Therefore, surveyors must establish a reliable reference system before excavation begins and maintain it continuously as the tunnel advances.

Tunnel alignment control means keeping the excavated tunnel on its planned horizontal and vertical alignment. Even a small directional error can become serious over a long tunnel because it may reduce clearance, affect drainage, interfere with railway geometry, or require costly corrective construction. Accurate surveying

therefore protects safety, quality, construction time, and project cost.

This paper discusses the objectives of tunnel surveying, surface and underground control, alignment-transfer methods, tunnel boring machine guidance, modern monitoring technologies, sources of error, and quality-control practices.

II. OBJECTIVES OF TUNNEL SURVEYING

To establish accurate horizontal and vertical control at tunnel portals, shafts, and adits.

To transfer surface coordinates and levels safely into underground workings.

To guide excavation along the designed centre line, gradient, and curve.

To provide real-time positional information to tunnel boring machines and other excavation equipment.

To check the position and shape of the completed tunnel lining.

To monitor settlement, convergence, and deformation during and after construction.

To prepare accurate as-built drawings for maintenance and future extension.

III. SURFACE CONTROL SURVEY

Before underground work starts, a surface control network is established around tunnel portals, shafts, and adits. Horizontal control is commonly developed using GNSS observations together with traversing, triangulation, or trilateration, while vertical control is established by precise levelling. Control points should be stable, intervisible where possible, and located away from construction activity and vibration.

GNSS is highly useful on the surface because it provides coordinates over long distances without requiring direct line of sight between all stations. However, it cannot be used directly inside most tunnels. Its main role is therefore to fix the surface network from which underground control is transferred.

IV. TRANSFER OF ALIGNMENT UNDERGROUND

The transfer of line and level from the surface to underground is one of the most critical operations in tunnel surveying. Through a vertical shaft, coordinates may be transferred using two plumb wires, optical plummets, or laser plummets. Levels are transferred using calibrated steel tapes, precise levelling, or specialized vertical-distance measurement methods.

After the underground base station is established, the direction of the tunnel axis must be determined. A gyro-theodolite is particularly valuable because it can determine true north independently of external reference lines. This makes it suitable for long tunnels where a conventional traverse may accumulate angular error.

V. UNDERGROUND CONTROL AND TRAVERSING

Underground control is usually extended by a traverse of survey stations fixed to the tunnel walls or roof using forced-centring brackets. A

total station measures horizontal angles, vertical angles, and slope distances between stations. The observations are then adjusted to compute reliable coordinates for each station.

In a narrow tunnel, traverse lines are short and the geometry is weak, so lateral errors can accumulate quickly. For this reason, gyro-theodolite azimuth checks are performed at regular intervals, and the traverse is closed or connected to another shaft whenever possible.

VI. TOTAL STATIONS AND TBM GUIDANCE

A total station combines an electronic theodolite with electronic distance measurement. It can determine the three-dimensional position of prisms or reflectorless points with high accuracy. In mechanized tunnelling, robotic total stations automatically track prisms mounted on the rear of a tunnel boring machine.

The guidance system compares the measured TBM position and orientation with the designed tunnel axis. It displays the machine's horizontal offset, vertical offset, roll, pitch, and yaw to the operator. The operator can then adjust thrust cylinders and steering to correct the machine path in real time.

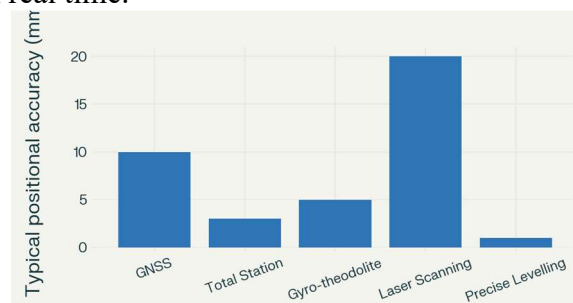


Fig. 1 Indicative accuracy of common tunnel survey methods.

VII. GYRO-THEODOLITE ORIENTATION

A gyro-theodolite uses a sensitive gyroscope to determine the direction of true north. In tunnelling, it is used to orient underground baselines and to check the azimuth of long traverses. This reduces the effect of refraction and angular error that may develop in confined underground conditions.

Gyro observations should be taken away from vibration, strong air currents, and electromagnetic

interference. Repeated observations and proper instrument calibration improve the reliability of the derived azimuth.

VIII. LASER SCANNING AND AS-BUILT SURVEYS

Terrestrial and mobile laser scanning capture millions of surface points and produce a detailed three-dimensional model of the excavated tunnel. Scanning is useful for checking lining geometry, over-break, clearance, deformation, and as-built condition. It is faster than measuring many individual points with a total station, although it requires careful registration to the tunnel control network.

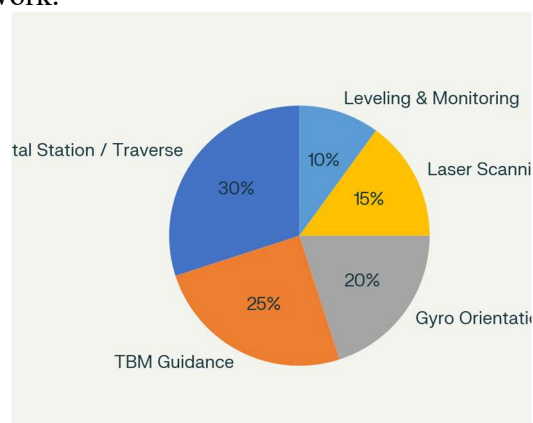


Fig.2 Indicative distribution of survey effort among common tunnelling activities.

IX. DEFORMATION AND SETTLEMENT MONITORING

Tunnel excavation changes the stress condition of the surrounding ground. Therefore, surveyors monitor surface settlement, building movement, tunnel convergence, and ground displacement. Common instruments include precise levels, total stations, inclinometers, convergence gauges, and settlement markers.

Monitoring data help engineers identify unusual movement early. If excessive settlement or convergence is observed, excavation sequence, support pressure, or ground-improvement measures may be adjusted.

X. SOURCES OF ERROR AND QUALITY CONTROL

Instrument errors, including collimation, index, and scale errors.

Centring and target errors at survey stations.

Atmospheric refraction, temperature variation, and humidity.

Vibration from machinery, blasting, and traffic.

Unstable survey monuments due to ground movement.

Human errors in observation, booking, and calculation.

Weak traverse geometry in narrow tunnels.

Quality control requires calibrated instruments, forced centring, repeated observations, independent checks, least-squares adjustment, and regular comparison with gyro or surface control. Survey records should be reviewed before excavation proceeds beyond a defined tolerance.

XI. RESULTS AND DISCUSSION

The reviewed techniques are complementary rather than competitive. GNSS provides strong surface control, total stations extend the network underground, gyro-theodolites control direction, and laser scanning verifies the completed geometry. For TBM-driven tunnels, automated guidance systems combine these measurements to provide continuous positional feedback.

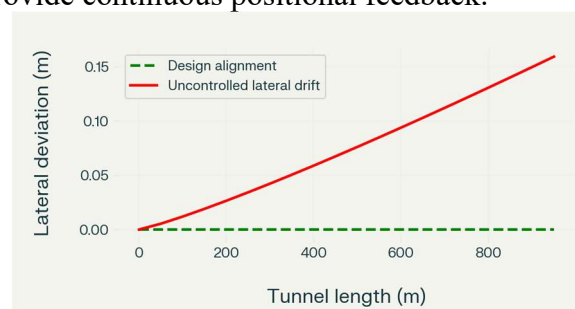


Fig. 3 Effect of alignment control on lateral drift over tunnel length.

The main conclusion is that accuracy depends not only on expensive instruments but also on planning, station stability, observation procedure, and timely error checking. A well-designed survey scheme reduces rework and supports safe tunnelling.

XII. CONCLUSION

Tunnel surveying and alignment control are essential for constructing tunnels safely and accurately. Surface control is established using GNSS and precise levelling, transferred underground through shafts, and extended using

total-station traverses. Gyro-theodolites provide independent directional control, while laser guidance supports real-time TBM steering. Modern laser scanning and deformation monitoring further improve quality control and as-built documentation. An integrated approach using suitable instruments, sound geometry, and regular verification is the most effective way to maintain tunnel alignment.

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