RETHINKING THE MODERN TUNNEL

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Historically, tunnels were carved beneath the surface as pathways to transport water, to find precious metals, or as safe havens for hiding. But today, tunnels have evolved from these functions into elements of ingenuity with a new purpose. They are no longer those dingy, scary passages but vibrant architectural marvels engineered to enable connectivity, linking people, neighbourhoods, business districts, and more. Today, with cities struggling to meet their growing mobility demands, modern tunnelling is quietly reshaping urban connectivity from below. But, while tunnelling has grown smarter and more precise, can technology truly overcome persistent challenges of breakdowns, geological uncertainties, and escalating costs?

For decades, cities have grown outward, stretching and creating new roads and railway lines to serve their growing populations. As urban landscapes became increasingly congested, the underground evolved into a mobility corridor, making tunnelling an engineering necessity.

Why go smart?

Underground construction can become increasingly complex, with hidden challenges that are more difficult to spot than obvious ones. Tunnel disasters over the years have highlighted the need for safer, healthier construction strategies. Smart tunnelling enables safety through real-time monitoring and predictive maintenance, not just during construction but also during operations. "Real-time monitoring can be very helpful, especially when working in places with a high density of heritage and residential structures, for example, high-density, legacy cities like Mumbai or Chennai. From vibration to load monitoring to understanding water tables to underground pipelines and cables, technology monitors almost everything," says Ashutosh Mishra, DGM, L&T.

In parallel, Dr Rajat Gangrade, Technical Advisor – Geotechnical and Tunnelling, HNTB Corp., USA, explains how advanced techniques help project owners and stakeholders make data-driven decisions and adopt risk mitigation strategies. "Today, BIM has matured beyond simple 3D visualisation to become a comprehensive project delivery methodology requiring integrated data management throughout the asset life cycle," opines Dr Rajat.

Data availability is key

Data collection and monitoring are key to deploying smart solutions. While technology enables the collection of a wide variety of data from structural to environmental to construction progress, the success of projects lies in how these data are interpreted and made available. Emphasising the need for historical data, Dr Angus Maxwell, Founder & CEO, Maxwell GeoSystems, explains, "Not all data may get included; technology providers may include only what has been asked for. What is important is that data be collected in a standardised way, recorded, and fully transferred to project owners. Organisations undertaking tunnelling in comparable conditions can greatly benefit from previous project data, gaining valuable insights into ground behaviour and associated risks."

Adding in parallel, Ashutosh highlights the importance of interoperability. "We see a lot of data being collected. But, collecting them in silos does not

serve the purpose. Smart solutions can be effective only when interoperability is possible," asserts Ashutosh.

Dr P. C. Nawani, Former Director, National Institute of Rock Mechanics & GSI, argues for the need to chart a "Common Digitalisation System" that can serve as a standardised framework for contractors undertaking tunnelling projects.

Geological investigation still has its role to play.

Despite technological advancements, tunnels are at high risk of collapse if factors such as faults, fractured rock zones, groundwater inflows, and weak strata are not properly assessed. Dr Nawani underscores why groundwork should include accurate geological studies. "A lot of infrastructure already exists above ground. You never know what geological complexities are underground. Groundwater level and water ingress are two important factors. Then comes the rock type," asserts Dr Nawani.

He emphasises that geophysical studies are important, especially given that tunnels run several kilometres. "Geophysical surveys cannot be bypassed. They are essential for accurately mapping subsurface conditions, including soil cover, weathered zones, competent rock, and bedrock levels. They also help identify existing utilities and groundwater conditions, while borehole investigations validate the findings, ensuring informed design decisions and reducing uncertainties during tunnel construction. These are critical pieces of information which technology may not be able to offer," opines Dr Nawani.

Design principles and engineering aspects: The indispensables

Extending the narrative, Sanjoy Sanyal, Founder & MD, Bouw Consultants, explains why design principles and engineering aspects should never be compromised. "The first principle is prioritising safety – safety of workers, passengers, and adjacent structures. AI prediction may not be 100% foolproof. A design should meet all legal as well as technical requirements," explains Sanjoy.

A contractor's dilemma

As digital technologies reshape underground construction, the shift presents critical challenges in cost, acceptance, procurement, and the skills gap. "Many tunnelling projects are awarded primarily based on the lowest bid (L1), making cost competitiveness a key determinant in contractor selection. So, contractors often operate within tight financial constraints, leaving limited scope for additional investments in advanced technologies or digital solutions. Since such expenditures are rarely factored into bids at the tendering stage, contractors may be reluctant to adopt smart tunnelling systems later, despite their long-term benefits, due to concerns over cost recovery and project profitability," elucidates Ashutosh.

Challenges

Ashutosh also highlights serious challenges that stand in the way of the full-scale adoption of smart technologies for tunnelling. Quoting skill gap as a major deterrent next to cost, he highlights, "In India, only very few companies are equipped with the skill base. Skill upgrade also requires investment, which again boils down to cost."

SANJOY SANYAL
Founder & MD
Bouw Consultants

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Experts also opine that the tunnelling ecosystem comprises multiple TBM manufacturers, monitoring solution providers, and software platforms, each operating with proprietary systems and data formats. The fragmentation creates significant challenges in integrating information into a unified, project-wide digital ecosystem, making data sharing, interoperability, and standardised decision-making both complex and difficult to achieve.

How far are we from being self-reliant?

As India accelerates the expansion of its metro footprint,

tunnelling has also grown proportionately. But, with a significant portion of machinery, smart technologies, and critical hardware being imported from abroad, the question remains, "Is it because we are new to smart tunnelling as such? Or, is the reliance because of capability gaps?"

Ashutosh highlights, "TBMs are largely imported due to the substantial capital investment required to establish domestic production capabilities. For private companies, such investments can be difficult to justify without assured market demand and long-term viability. Industry stakeholders note that fostering a domestic TBM manufacturing ecosystem will require stronger policy support, incentives, and strategic encouragement from the government to mitigate risks and create a conducive environment for investment."

Dr Nawani adds that while cost is a flip side, government initiatives such as "Atma Nirbhar Bharat" have accelerated indigenous production. "TBMs have demonstrated considerable success in urban metro projects, where geological conditions are relatively predictable and well understood. However, tunnelling in the Himalayan region presents far greater challenges, particularly for railway projects, due to complex geology, unstable rock formations, fault zones and unpredictable ground behaviour.", comments Dr Nawani.

Dr Rajat opines that the Indian tunnelling sector could benefit from developing cohesive knowledge systems to connect data sources, formats, and storage locations, which could pave the way for robust technical solutions.

Are the codes good enough?

While India has made significant advances in expanding its metro rail network, it has also expanded its tunnel network. "While efforts have been made to develop tunnelling-related standards through institutions such as the Bureau of Indian Standards, progress in establishing comprehensive codes remains limited. A key challenge is that these codes are largely advisory rather than mandatory, leaving project stakeholders room to deviate from recommended practices. Although non-compliance may invite technical audits or scrutiny, enforcement remains weak. For instance, prescribing mandatory geological investigations, such as drilling at fixed intervals along a tunnel alignment to generate reliable subsurface data, would require stronger regulatory backing and industry-wide adherence to ensure consistent implementation," opines Dr Nawani.

Dr Angus shares his views on what is happening at the global front. "One of the most significant industry guidance documents to emerge over the past two decades is the Code of Practice for Risk Management of Tunnel Works, developed by the International Tunnelling and Underground Space Association (ITA) in collaboration with both insurers and the tunnelling community. Recent editions have placed greater emphasis on smart tunnelling practices, particularly the use of data-driven approaches and the need to quantify uncertainty in tunnel construction projects systematically."

Today, tunnelling has evolved into a critical enabler of connectivity, underpinning the growth of modern transportation networks. With stronger regulatory frameworks, greater policy support, and the development of indigenous technologies and equipment, the industry can accelerate the adoption of advanced digital solutions.