Extended Abstract DOI: https://doi.org/10.64862/ajeg.2025.2sp.49.164 Open Access

Resilient Tunnelling in the Himalayas and Beyond: Lessons from Recent Projects

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Received: October 1, 2025, Accepted: October 27, 2025

Abstract: The recent tunnel collapses at Silkyara (Uttarakhand, 2023) and SLBC Tunnel 1 (Telangana, 2025) have reshaped the way underground infrastructure projects are perceived and executed in India. While both incidents were tragic in scale and impact, they have provided critical insights into the gaps that exist in current tunnelling practices particularly in geological investigations, risk anticipation, contract frameworks, and crisis response mechanisms.

This extended abstract analyses these two case studies not only from a technical standpoint, but also from the broader lens of resilient engineering. At Silkyara, the collapse during re-profiling exposed the underestimated complexity of a shear-dominated zone and led to a dramatic 17-day rescue mission. At SLBC, a sudden inflow of water and debris caused the submergence of a TBM, bringing to light the risks of advancing through shear zones with limited predictive confidence.

In both cases, the aftermath triggered a re-evaluation of excavation methods, safety protocols, and planning culture. The move from TBM to Drill and Blast (D and B) at SLBC, the application of real-time monitoring and GBRs at Silkyara, and the eventual incorporation of Aerial Electromagnetic (AEM) surveys reflect a transition toward adaptive, site-specific resilience in tunnel engineering.

The paper concludes by synthesising the lessons learnt into actionable engineering strategies and policy recommendations for future projects in the Himalayas and beyond. It proposes that true resilience lies not just in reacting to failure but in anticipating it and designing systems robust enough to prevent it or recover from it swiftly.

Keywords: ***Himalayan tunnelling, Tunnel collapse, Silkyara, SLBC, Shear zones, Geotechnical baseline report (GBR), Tunnel Boring Machine (TBM), Drill and Blast, Resilient tunnelling, Emergency rescue.***

Introduction

Tunnelling in mountainous terrains, especially in the Himalayas and other geologically sensitive regions, presents a unique interplay of engineering ambition and geological uncertainty. Recent years have witnessed a surge in underground infrastructure projects across India, many of them located in complex terrains with variable rock mass conditions, active tectonics, high overburden pressures, and unpredictable water ingress. While these projects aim to boost connectivity, irrigation, and energy capacity, their execution has repeatedly exposed the limitations of current geotechnical practices, contract structures, and monitoring strategies.

This paper examines two critical tunnel incidents from India-the Silkyara tunnel collapse in Uttarakhand (2023) and the SLBC Tunnel 1 collapse in Telangana (2025) to explore the concept of resilience in tunnelling. These are not merely stories of structural failure; they serve as important reminders of what it means to build safely, recover quickly, and adapt wisely.

The Silkyara tunnel incident: rescue, rehabilitation, and reform

On 12th November 2023, a collapse inside the under-construction Silkyara tunnel in Uttarakhand trapped 41 workers behind a massive mound of debris. The incident, which occurred during re-profiling activities to correct deflected tunnel supports, exposed the risks of working in inadequately stabilized zones within a shear-dominated geology. Investigations revealed shortcomings in geological characterization, absence of real-time monitoring, and a lack of alignment between design assumptions and actual ground conditions.

What followed was a 17-day-long rescue operation, among the most complex in India's tunnelling history. It involved multi-agency coordination, advanced probing and pre-support techniques, drift-wise excavation, and round-the-clock engineering improvisation. The successful rescue showcased India's growing capabilities in emergency tunnelling response and triggered an important shift toward hazard-specific designs, adaptive excavation techniques, and the use of Geotechnical Baseline Reports (GBRs) in contract documentation.

The SLBC tunnel collapse: a tragedy and a turning point

The collapse of Tunnel 1 in the Srisailam Left Bank Canal (SLBC) project on 22nd February 2025 resulted in the submergence of a 130-metre-long Tunnel Boring Machine (TBM) and the tragic entrapment of eight workers. The TBM crew encountered violent water and silt ingress from a previously identified shear zone despite prior pre-treatment with grouting and drainage measures. Post-collapse, the tunnel was choked with slush and debris for over 2.5 km, and rescue efforts were hampered by limited access, unstable ground, and ethical dilemmas regarding safety versus retrieval.

The multi-phase search operation comprising dewatering, TBM dismantling, manual excavation, and geophysical scanning, which also underlined the engineering and moral complexity of deep tunnel disasters. Technically, the incident exposed the risks of progressing TBM drives through inadequately characterized shear zones, the insufficiency of indirect monitoring methods (e.g., cutterhead mucking), and the lack of redundancy in access strategies.

In the aftermath, the decision to abandon the TBM and switch to a Drill and Blast (D and B) method despite environmental challenges signaled a return to more flexible, context-sensitive excavation strategies. The government also planned Aerial Electromagnetic (AEM) surveys to gather macro-level geological information along the alignment, indicating a growing recognition of the role of geophysics in inaccessible or protected zones.

Key lessons and the road ahead

Both incidents Silkyara and SLBC provide a rich set of lessons that transcend the specifics of location and project type. These lessons are relevant for tunnel engineers, project managers, policy makers, and contractors alike.

- **Comprehensive Site Investigations**
  A tunnel's success hinges on what lies ahead, literally. Robust geotechnical characterisation must go beyond boreholes and walkover surveys, especially in difficult geology, by integrating geophysics, deep drilling, and continuous face mapping.
- **Use of Hybrid Geophysical Tools in Sensitive Zones**
  In areas where conventional drilling is restricted due to environmental or forest regulations, non-intrusive tools such as Aerial Electromagnetic (AEM) surveys, Tunnel Seismic Prediction (TSP), and other geophysical techniques must be mainstreamed into investigation practices.
- **Incorporation of Geotechnical Baseline Reports (GBRs)**
  Both collapses highlighted a gap between design assumptions and actual ground conditions. Incorporating GBRs in contracts can provide a common baseline for risk allocation, reducing disputes and delays.
- **Shift Toward Risk-Sharing Contracts**
  Fixed-price models often disincentivise geological transparency. Moving towards equitable, risk-sharing contractual frameworks fosters collaboration, encourages early warnings, and aligns incentives between client, contractor, and designer.
- **Real-Time Monitoring and Early Warning Systems**
  Tunnel construction in challenging ground must be accompanied by robust instrumentation systems optical targets, extensometers, piezometers, and convergence sensors feeding live data to trigger timely interventions.
- **Flexible Construction Methodologies**
  Excavation strategies must adapt to geological surprises. At SLBC, the switch from TBM to Drill and Blast (D and B) after the collapse, despite longer timelines, exemplifies how flexibility can be the safer long-term option.
- **Training, Safety, and Communication Protocols**
  Worker safety cannot be an afterthought. Regular training, wireless in-tunnel communication, mock drills, and well-rehearsed emergency protocols must be integral to every tunnelling project.
- **Emergency Preparedness as a Design Element**
  The Silkyara rescue showed the value of having pre-identified emergency access points, backup power, and alternative ventilation systems. Emergency planning should be embedded from DPR stage, not improvised post-failure.
- **Resilience as a Design Philosophy**
  True resilience lies not just in reacting to disasters, but in foreseeing them. This involves cultivating a mindset of continuous risk assessment, cross-disciplinary consultation, and readiness to revise plans mid-execution.
- **Global Best Practices and Local Integration**
  Standards such as the FIDIC Emerald Book, Austrian Tunnelling Guidelines, and ITA COSUF frameworks offer robust guidance for contracts, safety, and operational control. Local adaptations must draw from these global resources while respecting on-ground realities.

Perhaps the most powerful message from both Silkyara and SLBC is that resilience in tunnelling is not defined solely by post-collapse response, but by pre-collapse foresight. Resilient tunnels are not just designed better they are imagined, planned, monitored, and executed better.