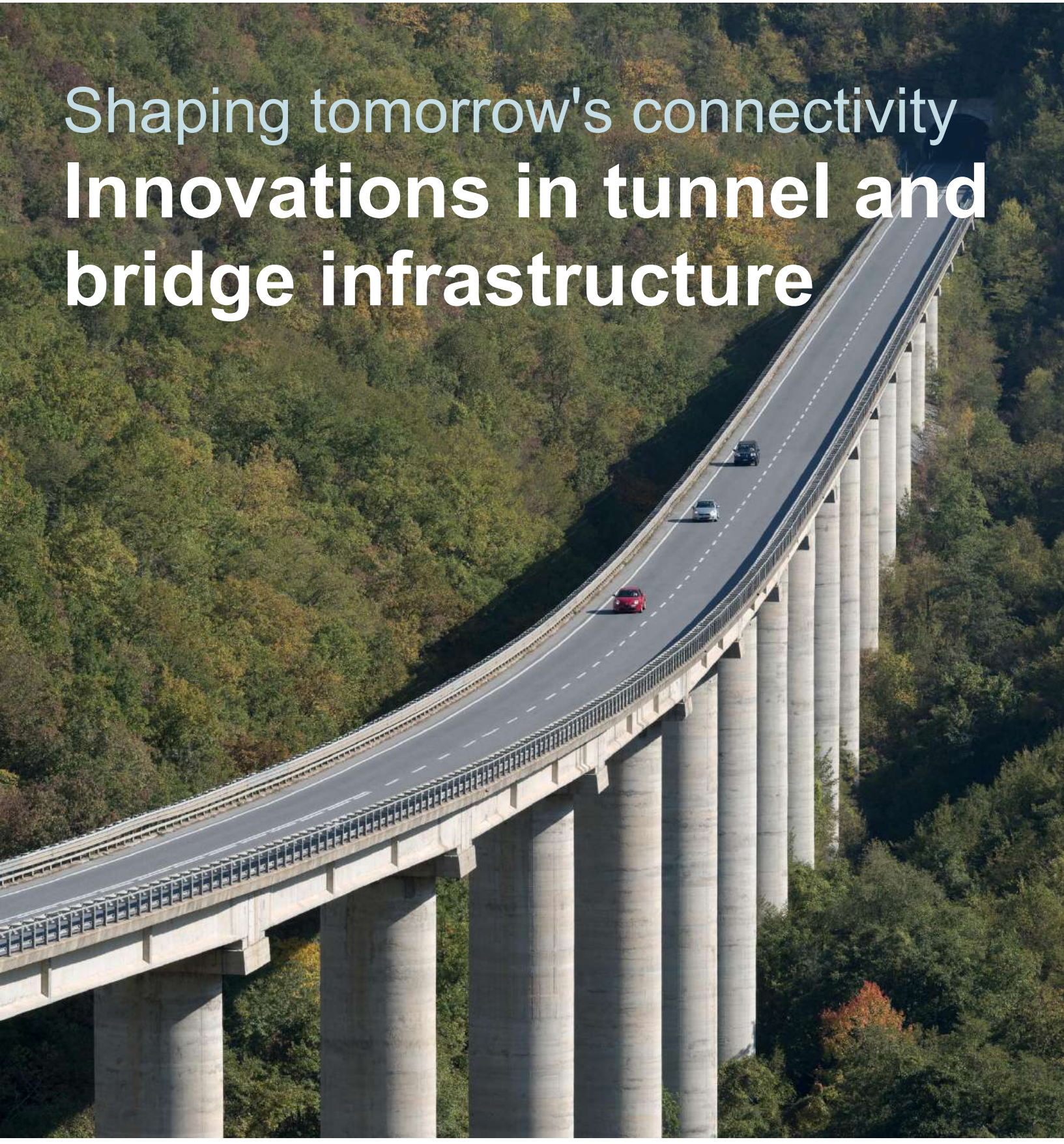
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Shaping tomorrow's connectivity

Innovations in tunnel and bridge infrastructure



by S&P Global

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Acronyms and abbreviations

AI	Artificial intelligence
AIMC	Automated and intelligent machine-aided construction
BRO	Border Roads Organisation
BIM	Building information modelling
CAGR	Compound annual growth rate
CSIA	Chhatrapati Shivaji Maharaj International Airport
DMRC	Delhi Metro Rail Corporation
DPR	Detailed project report
DTS	Digital thermal sensing
DT	Digital twins
FIDIC	Fédération Internationale des Ingénieurs-Conseils
FOB	Foot over bridge
GIS	Geographic Information Systems
GSI	Geological Survey of India
GFRP	Glass fibre reinforced polymer
GBS	Gross budgetary support
GGBS	Ground granulated blast furnace slag
HSR	High-speed rail
InvIT	Infrastructure investment trust
IDEP	Integrated digital engineering platforms
IoT	Internet of things
J&K	Jammu and Kashmir
ML	Machine learning
MoU	Memorandum of understanding
MoRTH	Ministry of Road Transport and Highways
MoSPI	Ministry of Statistics and Program Implementation
MMRDA	Mumbai Metropolitan Region Development Authority
NMIA	Navi Mumbai International Airport
NHIDCL	National Highways and Infrastructure Development Corporation Ltd
NHAI	National Highways Authority of India
NIP	National Infrastructure Pipeline
NATM	New Austrian tunnelling method
NPA	Non-performing asset
PPP	Public-private partnership
RFI	Request for information
RFP	Request for proposal
SHM	Structural health monitoring
SCMs	Supplementary cementitious materials
TBM	Tunnel boring machine
TEM	Tunnel excavation material
USBRL	Udhampur-Srinagar-Baramulla Rail Link
UHPC	Ultra-high-performance concrete

Message from FICCI



Mr S Paramasivan
Chair, FICCI Committee on Roads & Highways and
Managing Director, Afcons Infrastructure Limited

It is a privilege to share with you this FICCI-Crisil Knowledge Report, *"Shaping tomorrow's connectivity: Innovations in tunnel and bridge infrastructure,"* unveiled at the 4th Edition of the FICCI Tunnels & Bridges Conference 2026, organised by the Federation of Indian Chambers of Commerce and Industry.

As India advances towards its aspiration of becoming a developed nation by 2047, infrastructure development is taking place at an unprecedented scale. At the heart of this transformation, tunnels and bridges are emerging as critical components of the country's connectivity infrastructure, enabling seamless mobility, strengthening economic linkages, and creating new pathways for growth.

India's diverse terrain, from the Himalayas to its coastlines and densely populated urban centres, has historically posed significant challenges to physical connectivity. Today, technological advancement and innovation are enabling the sector to address these challenges in new ways. Tunnel projects are improving connectivity to remote and strategically important regions, metro and underwater tunnels are reshaping urban mobility, while advances in bridge engineering are enabling technically challenging crossings. At the same time, the sector continues to navigate complex challenges relating to geology, design, safety, project execution, and timelines, underscoring the need for sustained innovation, stronger institutional capabilities, and greater collaboration.

This report traces the evolution of tunnelling and bridge engineering in India while examining the policy and regulatory reforms shaping the sector. It brings together perspectives on project preparation and investigation, design and construction standards, contractual and payment frameworks, and their implications for quality, safety, supervision, and implementation. It also explores the growing role of digital technologies and artificial intelligence in planning, monitoring, and decision-making, alongside automated casting, precast construction, robotics, and other next-generation construction practices.

Importantly, the report recognises that the creation of infrastructure is only one part of the journey; ensuring its long-term performance, safety, and resilience is equally critical. Its focus on structural health monitoring, tunnel and bridge safety, sustainable construction, and circular economy principles reflects the sector's growing emphasis on the entire lifecycle of infrastructure assets. The global and Indian case studies provide valuable, practice-oriented insights for planners, engineers, policymakers, and industry stakeholders.

I hope this report serves as a valuable reference and catalyst for dialogue between government and industry as India works towards shaping the next generation of connectivity infrastructure -technologically advanced, sustainable, and resilient.

We welcome your feedback and suggestions.

Message from Crisil



Mr Jagannarayan Padmanabhan
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India's infrastructure buildout is entering a new phase, one driven not only by scale, but also by sustainability and innovation. For the country to realise its vision of Viksit Bharat by 2047, the increased pace of construction of tunnels and bridges is a critical infrastructure ask, as it will further connectivity, economic growth, regional integration and national competitiveness.

On the eve of FICCI's **4th Edition** of the **Tunnels & Bridges Conference 2026**, we are pleased to present our knowledge report, **Shaping tomorrow's connectivity: Innovations in tunnel and bridge infrastructure.**

The report provides an in-depth perspective on the technologies, systems and processes that are transforming the planning, construction, operation and maintenance of tunnels and bridges in India. It also provides an overview of the marquee tunnel and bridge projects built in India since 2014 and highlights the growing role of artificial intelligence (AI), advancements in material sciences for sustainable construction, and digital solutions such as digital twins (DTs) and building information modelling (BIM), structural health monitoring (SHM) and predictive maintenance systems.

The report also examines key policy and regulatory developments aimed at improving the planning, execution and lifecycle management of tunnel projects. These include the **recent standardised tunnel alignment framework** incorporating worker-safety considerations, reforms in the **awarding mechanism for detailed project report (DPR) consultancy services**, and **stringent contractor selection criteria under the new request for prequalification (RFP) framework for specialised hybrid annuity model and engineering, procurement and construction projects**, among others.

Collectively, these measures have drawn lessons from challenges encountered during the past decade, and seek to strengthen risk management, enhance project governance, and improve cost, schedule and quality outcomes of projects undertaken by government authorities.

Preface

Tunnels and Bridges: From Infrastructure Expansion to Infrastructure Excellence

India's infrastructure development has entered a new phase, marked not only by the scale of investment but also by a growing emphasis on resilience, safety, technology and long-term asset performance. Over the past decade, sustained public investment and stronger execution capabilities have enabled the delivery of increasingly complex projects across challenging geographies and urban environments. Landmark achievements in recent years such as the Chenab Rail Bridge, Aunta Simariya Road Bridge and the Mumbai-Pune Expressway Missing Link reflect the sector's growing engineering capability and ambition.

As the sector matures, success will increasingly be defined not only by what is built, but by how projects are planned, procured and delivered. Tunnels and bridges are inherently complex assets, carrying significant geotechnical, engineering and operational risks. Recent project experience has reinforced the importance of stronger project preparation, improved risk identification and greater technical oversight. Fickle geology being faced when working in the Himalayas and subsequent damages in tunnel portals and rock slopes due to landslides are often encountered. Consequently, cost and schedule overruns continue to remain a challenge across several projects, highlighting the need to address risks much earlier in the project lifecycle.

The 2026 edition of the FICCI Tunnels & Bridges Report captures an important shift underway across the sector. Recent initiatives by the Ministry of Road Transport and Highways (MoRTH) and the National Highways Authority of India (NHAI) signal a stronger focus on project preparation, technical due diligence and accountability. Enhanced requirements for tunnel alignment studies, geotechnical investigations, diligence in DPR preparation and tunnel safety recognise that project outcomes are often determined long before construction begins.

Safety has emerged as an equally important priority. Recent tunnel incidents have reinforced the need for robust investigations, appropriate construction methodologies, continuous monitoring, emergency preparedness and effective risk management. At the same time, increasing adoption of technologies such as BIM, digital engineering, drones, sensors, structural health monitoring and AI-enabled analytics is enhancing design coordination, construction monitoring and lifecycle asset management.

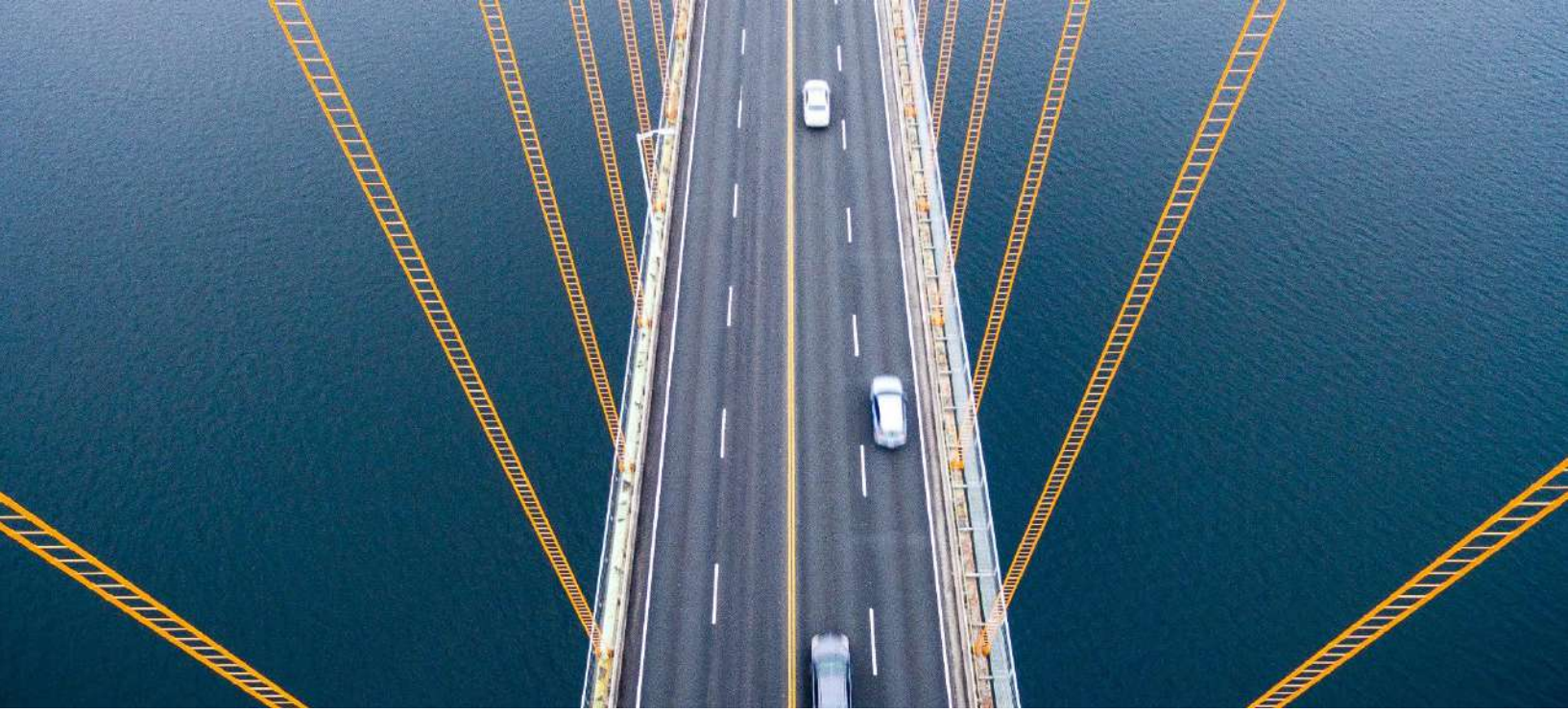
India's growing tunnelling and bridge construction programme also highlights the importance of strengthening domestic capabilities in specialised construction equipment and technology. Towards this goal, the Government of India announced the Scheme for Enhancement of Construction and Infrastructure Equipment (CIE) in the Union Budget FY 2026-27 to promote indigenous manufacturing of key and sensitive tunnelling and construction equipment. With an outlay of ₹200 crore, the scheme aims to reduce import dependence, strengthen domestic capabilities, and support India's growing infrastructure development agenda. Building a resilient ecosystem for manufacturing, innovation, and localisation will be essential to improving supply chain reliability, enhancing project certainty, and strengthening long-term competitiveness.

As the sector enters its next phase of growth, a coordinated focus will be required on a few critical priorities:

	Strengthening project preparation through better investigations, design quality and technical due diligence.
	Embedding safety across the project lifecycle, from planning and procurement to construction and operations.
	Promoting capability-based procurement that rewards technical expertise, experience and risk management.
	Accelerating digital adoption through integrated use of BIM, digital twins, monitoring systems and data-driven decision-making.
	Developing domestic manufacturing and specialised capabilities to enhance resilience and support future infrastructure growth.

The FICCI Tunnels & Bridges Report 2026 seeks to contribute to this transformation by examining the policy, technology and industry developments shaping the sector, while highlighting the reforms and capabilities required to deliver safer, more resilient and future-ready infrastructure assets.





Infrastructure transformation

India’s economic prosperity is through tunnels and bridges

Infrastructure enables productivity gains, regional integration, logistical efficiencies and enhanced global competitiveness. Over the past decade, India has undertaken one of the world's largest infrastructure development programmes, with capital expenditure focused on multimodal connectivity and strategic asset creation.

However, the country’s next phase of infrastructure development will be measured not only by the kilometres constructed or projects commissioned, but by the resilience, adaptability and long-term performance of the assets. Recent monsoon-induced disruptions and infrastructure failures in several regions have highlighted the growing need for climate-responsive planning, robust engineering standards and risk-informed project delivery, particularly for complex and strategically important assets such as tunnels and bridges.

Tunnels and bridges are critical for overcoming geographical barriers, reducing travel time and enabling connectivity across challenging terrains, urban centres and strategic regions. From all-weather access in the Himalayas to underground metro systems and long-span sea crossings, these assets are reshaping mobility and driving socio-economic integration.

Landmark projects such as the Atal Tunnel, Chenab Rail Bridge, Sela Tunnel, Mumbai Trans Harbour Link and Mumbai-Pune Missing Link exemplify India's growing engineering capabilities and commitment to next-generation infrastructure.

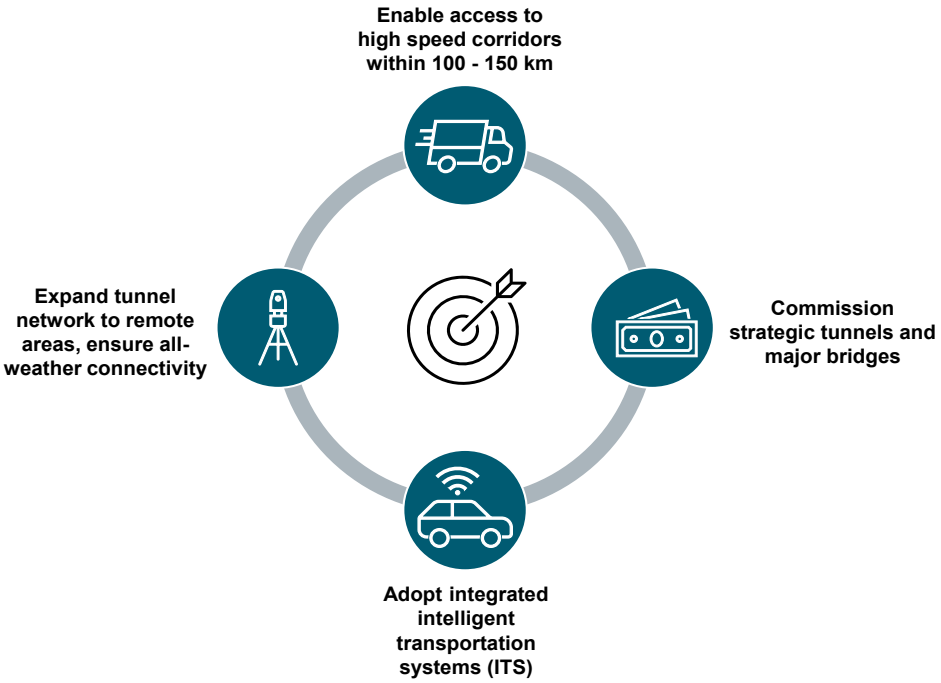
Tunnels and bridges building the foundations of Viksit Bharat

The Indian government envisages the country to become developed, globally competitive and inclusive economy by the centenary year of Independence. At the heart of this vision lies the creation of a world-class infrastructure that enhances productivity, strengthens logistical efficiency, promotes balanced regional development and improves the quality of life.

Improved road connectivity has already contributed to a decline in India's logistics cost, which has fallen to single digit of gross domestic product (GDP) from a historically 13-14% of GDP in the early-to-mid 2010s[12], owing largely because of the expansion and modernisation of national highways and expressways, alongside broader multimodal logistics reforms.

[1] *https://www.business-standard.com/markets/capital-market-news/india-s-logistics-costs-have-reduced-to-7-97-of-gdp-126011300771_1.html*

Key objectives



Landmark initiatives include

Bharatmala Pariyojana, 2015	Setu Bharatam, 2016	PM Gati Shakti, 2020	Metro Rail Policy, 2017	PM DevINE, 2022	North Eastern Railway Connectivity	National High Speed Corridor

Tunnels and bridges to be the catalysts hereon

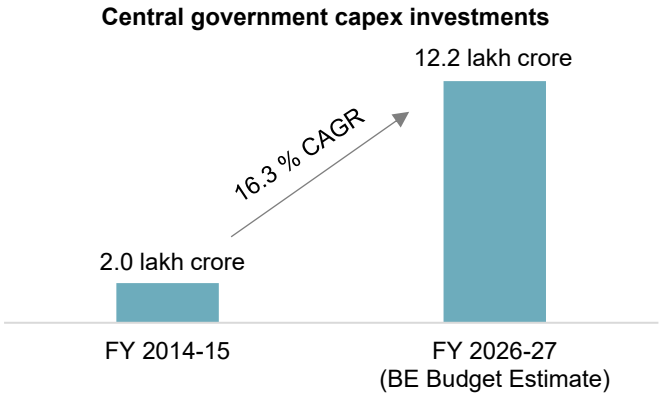
Tunnels and bridges have evolved from engineering interventions into strategic enablers of economic competitiveness, regional integration and national resilience. Sustained public capital expenditure, integrated planning under the PM Gati Shakti National Master Plan, the NIP, Bharatmala Pariyojana and the National Logistics Policy have accelerated the development of complex transport infrastructure that has improved multimodal connectivity and reduced logistics inefficiencies.

Technology is emerging as an equally significant catalyst, redefining the planning, construction and lifecycle management of tunnel and bridge infrastructure. The adoption of BIM, DTs, AI, IoT-enabled structural health monitoring, LiDAR, drone-based surveys, advanced geospatial analytics and predictive asset management are improving design accuracy, construction safety, operational reliability and long-term asset performance.

As India scales its next generation of infrastructure, future tunnel and bridge projects will increasingly be designed as intelligent, climate-resilient and digitally connected assets that minimise lifecycle costs while enhancing safety and operational efficiency.

Supported by continued policy reforms and technology adoption, these critical assets will remain central to the country's vision of building a globally competitive, multimodal and future-ready infrastructure ecosystem.

Infra investments in India



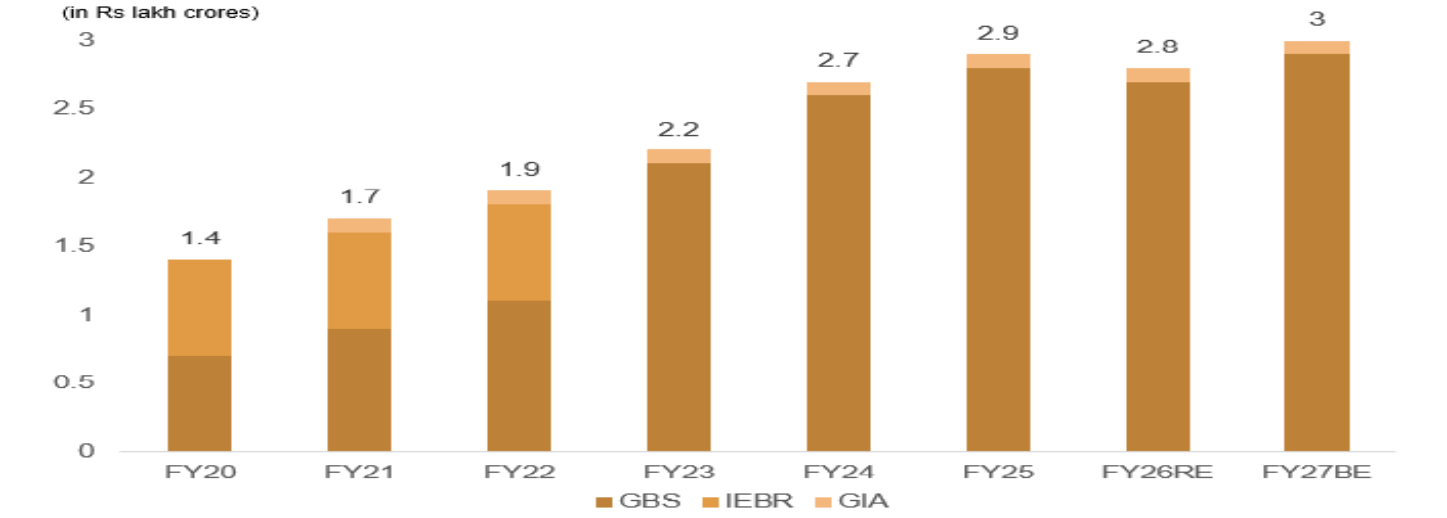
- **Public capital expenditure**

Infrastructure investments have expanded significantly in recent years, reflecting the government's continued emphasis on infrastructure-led economic growth and its Viksit Bharat vision. Public capital expenditure has increased from Rs 2.0 lakh crore in fiscal 2015 to Rs 12.20 lakh crore in Union Budget 2026-27[34], underscoring a sustained commitment to developing world-class transport, logistics and urban infrastructure.

- **MoRTH allocations over the years**

Gross budgetary support (GBS) for the Ministry of Road Transport and Highways (MoRTH) rose from Rs 0.70 lakh crore in fiscal 2020 to Rs 2.90 lakh crore in fiscal 2027—an over 4x increase—reflecting the government's commitment to developing road infrastructure, including tunnels and bridges.

However, the GBS for MoRTH stagnated to Rs 2.70-2.90 lakh crore in fiscals 2026 and 2027, which could limit the government's ability to undertake new projects and complete ongoing ones. It could also impact the government's ability to meet its ambitious targets for road development, such as the constructing new highways and the upgrading of existing ones.



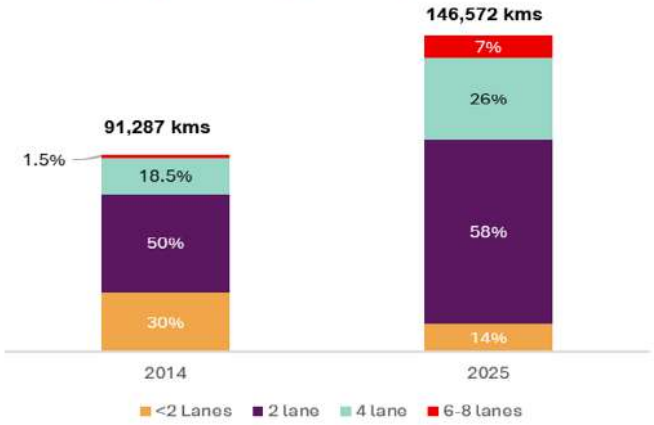
E – estimated, P – projected
Source: MoRTH, Crisil Intelligence

[3] *https://www.indiabudget.gov.in/*
[4] *https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=157846&ModuleId=3&reg=3&lang=1*

The government's fiscal constraints, competing priorities and the need to allocate resources to other critical sectors are among the key reasons for the stagnation in public funding.

Nevertheless, the continued allocation of significant funds to MoRTH is a positive sign and the sector is expected to continue to receive substantial public funding in the coming years.

National highways witness significant expansion in last decade

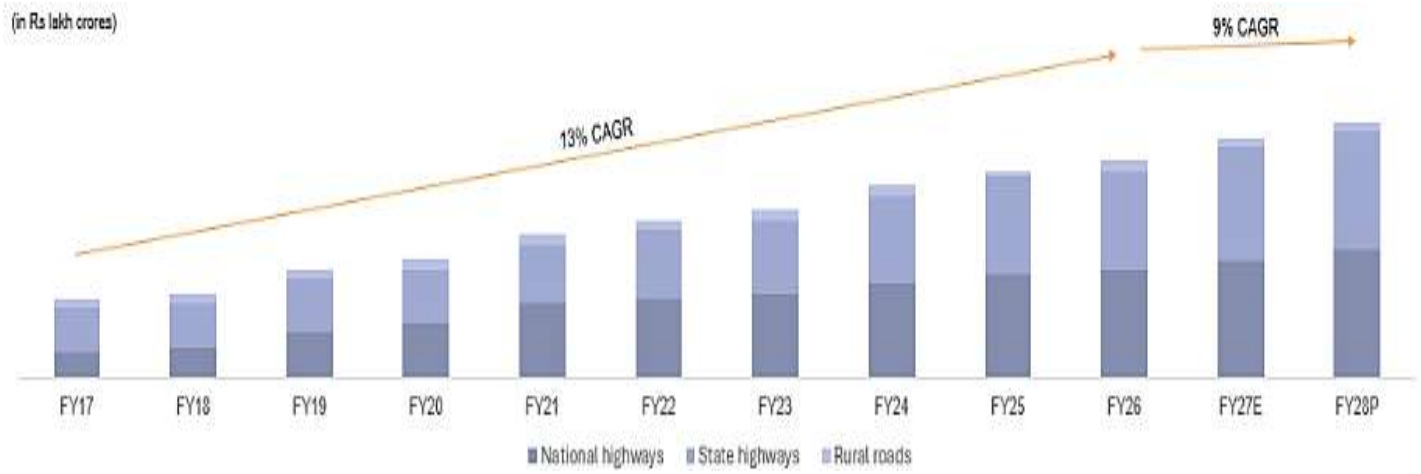


Source: MoRTH, Crisil Intelligence

- **Road network over the years**

The scale of India's infrastructure transformation is reflected in measurable outcomes. The national highway network has expanded from ~91,287 km in 2014 to over 146,572 km in 2025[5], while the length of highways with four or more lanes increased nearly threefold. Also, highway construction speeds rose from ~12 km per day in fiscal 2015 to nearly 34 km per day in fiscal 2024[6], supported by record levels of public investment.

The road sector is expected to maintain strong growth momentum, supported by a robust pipeline of HSC projects and sustained government investment in road infrastructure, with capital expenditure projected to grow at a 9% CAGR between fiscals 2026 and 2028.



E – estimated, P – projected
Source: MoRTH, Crisil Intelligence

[5] *https://morth.gov.in/backend/documents/uploaded/RTH%20Annual%20Report%20English.pdf*
[6] *https://morth.gov.in/backend/documents/uploaded/RTH%20Annual%20Report%20English.pdf*

As the sector enters this new phase of identifying and developing broader highways and expressways, the government has announced plans to develop 20,000 km of high-speed corridors (HSCs) over the next 5-6 years and aims to establish a 50,000 km-long HSC network by 2040.

This focused approach is expected to significantly enhance logistics efficiency, reducing travel time and increasing the competitiveness of Indian industries.

Milestone projects in tunnels and bridges in India

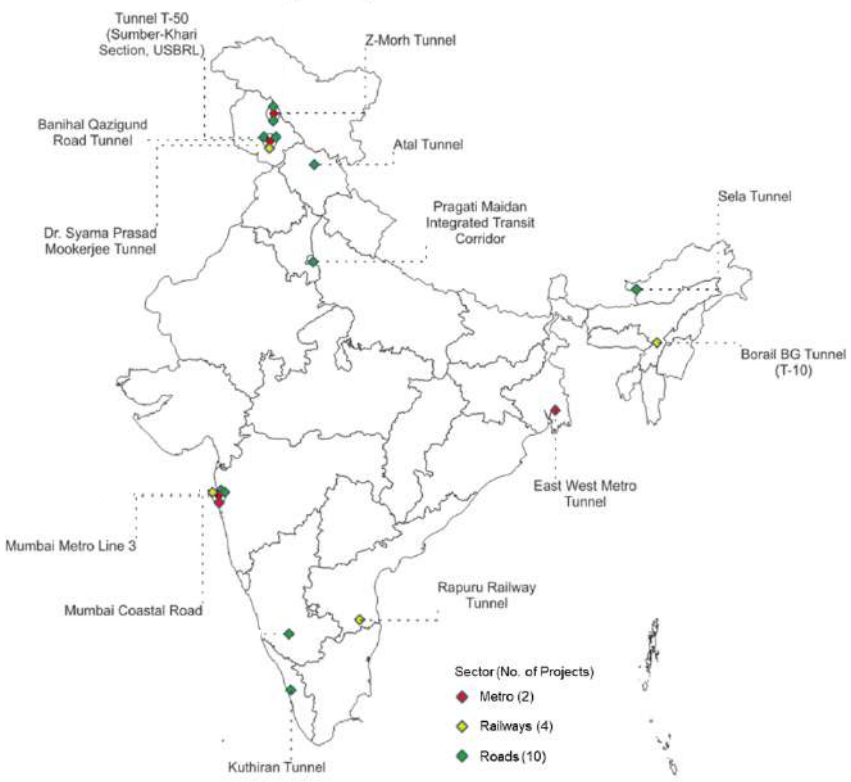
Key tunnels and bridges built over the past decade

The tunnel and bridge sectors in India have seen significant pace of execution since 2014, supported by increased infrastructure investment and policy focus. Several large-scale projects have been executed over the period, such as including the Mumbai Trans Harbour Link, alongside extensive development of modern railway and highway bridge infrastructure nationwide.

Overview of tunnels

Over the past 10 years, India has implemented several landmark tunnel projects across the road, railway and metro sectors, especially in challenging mountainous regions and dense urban areas. Key projects include strategic tunnels in the Himalayas, new railway lines and the country's first underwater metro line.

Prominent tunnel projects commissioned in India over the past decade



Note: The projects shown above and showcased below have been selected based on their unique characteristics such as geographic conditions, strategic importance, adoption of complex engineering techniques for construction, ticket size and schedule/time construction period and widespread media coverage gathered during construction and inauguration.

Prominent road tunnels built since 2010

- **Dr. Syama Prasad Mookerjee Tunnel (Chenani-Nashri, Jammu and Kashmir), 2017**: This 9.2 km tunnel on NH 44 is India's longest road tunnel, bypassing the treacherous terrain of Patni top and reducing the travel distance between Jammu and Srinagar by 31 km.



(Illustrative Picture)

- **Atal Tunnel (Rohtang Pass, Himachal Pradesh), 2020:** Constructed at an altitude of above 10,000 feet, the ~9.02 km tunnel is the world's longest highway tunnel at this elevation. It provides year-round connectivity between Manali and the Lahaul and Spiti district, which would earlier be cut off during winter due to heavy snowfall.
- **Banihal Qazigund Road Tunnel (Jammu and Kashmir), 2021**: This 8.45 km twin-tube tunnel provides an all-weather route on NH 44, reducing the road distance between Banihal and Qazigund by 16 km.
- **Kuthiran Tunnel (Kerala), 2021:** This 1.6 km tunnel, which eases traffic congestion on the Thrissur-Palakkad stretch of NH 544, is Kerala's first and south India's longest six-lane road tunnel
- **Pragati Maidan Integrated Transit Corridor (Delhi), 2022:** This project, includes a 1.3 km main tunnel beneath Pragati Maidan, which helps decongest traffic in central Delhi



(Illustrative Picture)

- **Z-Morh Tunnel (Jammu and Kashmir), 2023:** This 6.5 km road tunnel on the Srinagar-Leh highway provides all-weather connectivity to Sonamarg, which is prone toavalanches
- **Mumbai Coastal Road (Dharamveer Swarajya Rakshak Chatrapati Sambhaji Maharaj Marg, Maharashtra), 2024:** Completed sections of this project include a 2.07 km undersea twin tunnel, which provides high-speed connectivity to suburbs along the Mumbai coastline
- **Sela Tunnel (Arunachal Pradesh), 2024:** Inaugurated in March 2024, the project comprises two tunnels with a combined length of 2.59 km and over 8.6 km of approach roads, providing strategic all-weather connectivity to Tawang. By bypassing the high-altitude Sela Pass, it ensures safer, faster and uninterrupted movement throughout the year, and significantly enhances regional connectivity and logistics



(Illustrative Picture)

- **Mumbai-Pune Expressway Missing Link Twin Tunnels[7] (Maharashtra), 2026:** Completed in 2026, the tunnel package consists of twin eight-lane road tunnels measuring 8.92 km and 1.75 km in length[8]. Built through the challenging geology of the Western Ghats, the longer tunnel has an internal width of 22.33 metre—making it the world's widest underground road tunnel. By bypassing the steep and congestion-prone Khandala Ghat section, the project significantly improves safety and operational efficiency.

Prominent railway tunnels built since 2010

- **Borail BG Tunnel (T-10, Assam), 2015:** This 3.23 km tunnel is part of the gauge conversion project in north-east India
- **Rapuru Railway Tunnel (Andhra Pradesh), 2019:** This 6.64-km tunnel is on the Obulavaripalli–Krishnapatnam railway line
- **Udhampur-Srinagar-Baramulla Rail Link (USBRL, Jammu and Kashmir), 2025:** Numerous tunnels on the USBRL have been completed or are nearing completion, including:
  - Pir Panjal Railway Tunnel (T-80): At 11.2 km, this was India's longest railway tunnel when it opened in 2013
  - Tunnel 50 (T-50): This 12.7 km tunnel between Sumber and Khari was competed in 2024
  - Tunnel 49 (T-49): Completed in 2024, this 10.17-km tunnel is located between Sangaldan and Sumber
  - Tunnel 44 (T-44): The trial run for this 11.13-km tunnel between Katra and Banihal was conducted in 2024

Prominent metro rail tunnels built since 2010

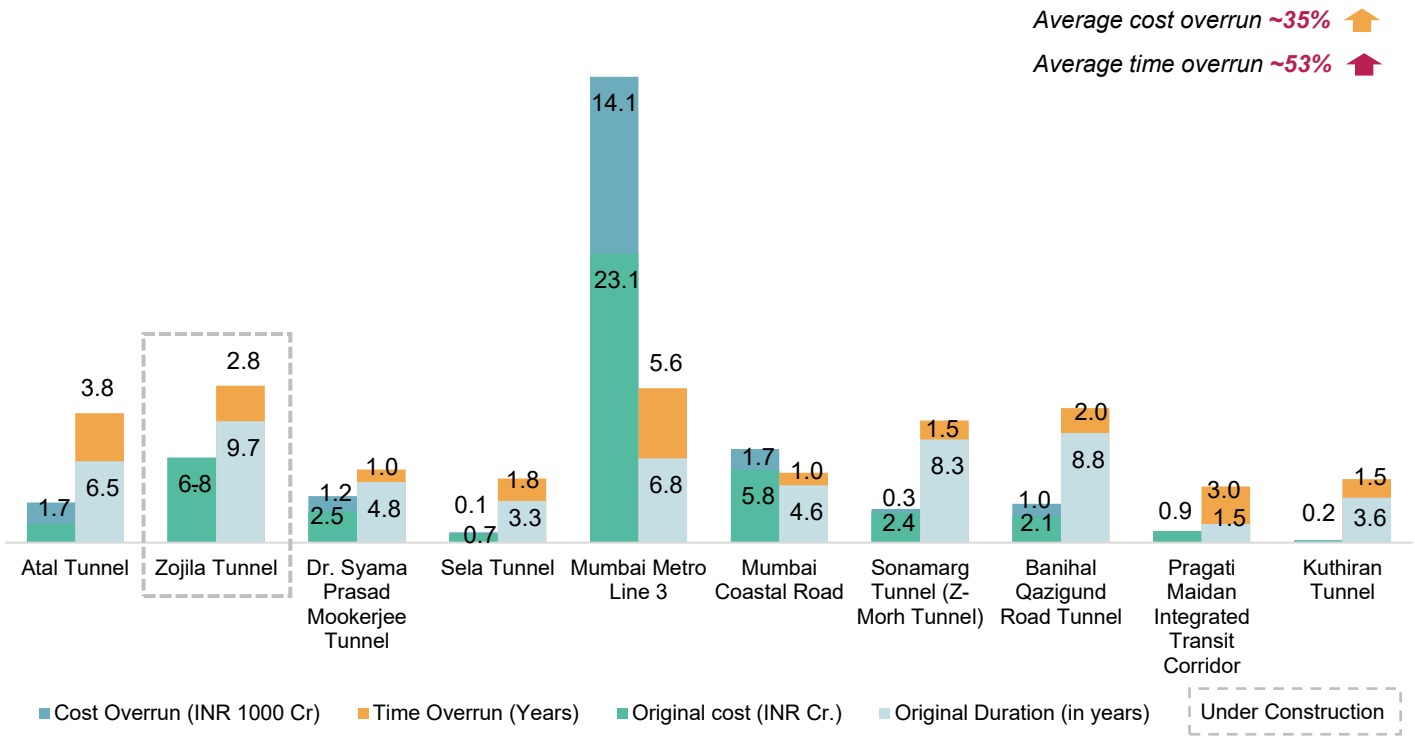
- **East-West Metro Corridor (Kolkata, West Bengal), 2024:** The East-West Metro corridor launched India's first underwater metro line, with tunnels running beneath the Hooghly River
- **Aqua Line (Mumbai Metro line 3, Maharashtra), 2025:** Inaugurated in Oct 2025, Mumbai Metro line 3 spans 33.5 km, connecting Colaba, Bandra and SEEPZ through a fully underground corridor, except for one at-grade station

Cost and time overrun comparison for prominent tunnels over the last decade

Tunnel projects have consistently faced challenges. An analysis of the selected key tunnel projects shows cost and time overruns of ~35% and ~53% on average, respectively.

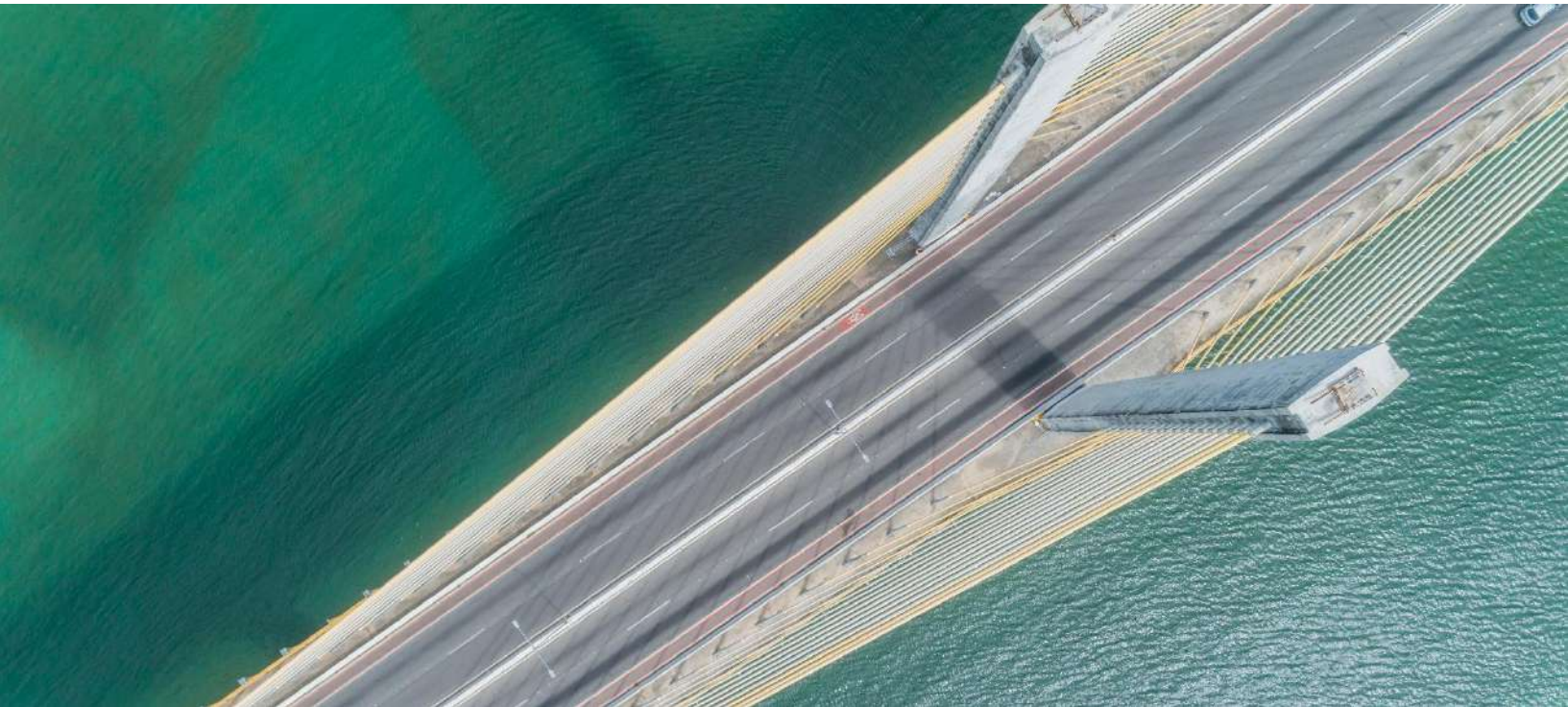
[7] *Press-Release-01.05.2026-Afcons-delivers-Indias-tallest-road-cable-stayed-bridge-on-Mumbai–Pune-Expressway-Missing-Link-Project.pdf*
[8] *https://theprint.in/india/governance/worlds-widest-underground-tunnel-mumbai-pune-missing-link-opens-with-a-guinness-world-record/2919689/*

Time and cost overruns in tunnel projects



Source: Annexure 1 (refer page 54)

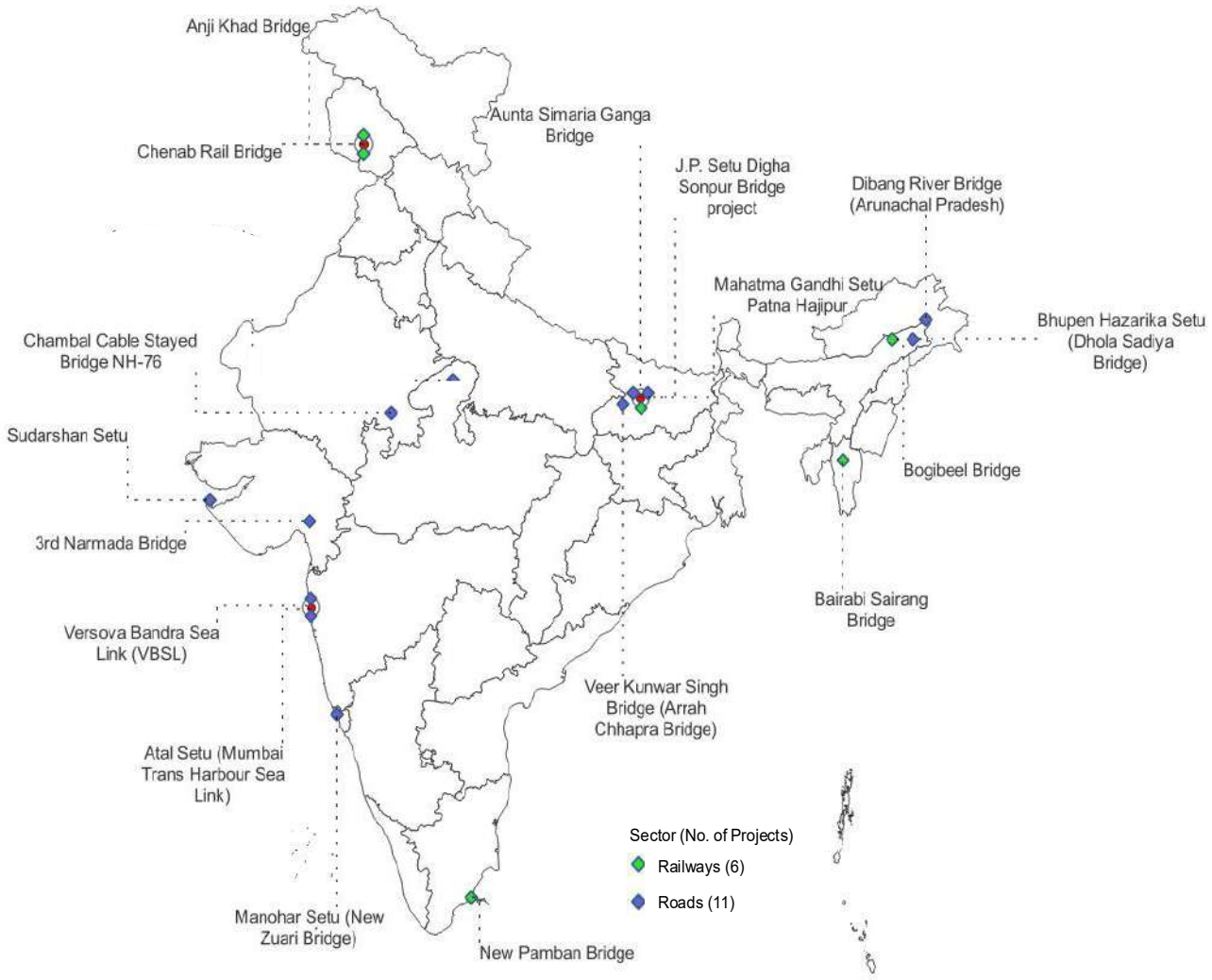
Disclaimer: The information presented has been compiled from publicly available sources, news articles and other referenced materials, as detailed in the annex. Crisil has not independently verified the accuracy or completeness of this information. The purpose is to provide general perspective on the nature of delays and cost overruns typically observed in complex infrastructure projects. The examples cited represent a selective sample from the past decade.



Overview of bridges

Over the past decade, India has completed several major bridge projects, ranging from the challenging terrain of the Himalayas to broad rivers and coastal regions. These projects include record-breaking railway and sea bridges, as well as crucial links that improve connectivity and strengthen defence logistics.

Prominent bridge projects commissioned over the past decade



These projects were selected based on their unique characteristics such as geographic conditions, strategic importance, adoption of complex engineering techniques for construction, large ticket size in terms of cost and schedule/ duration of construction, and widespread media coverage gathered during construction and inauguration.

- **Bhupen Hazarika Setu (Dhola Sadiya Bridge, Assam), 2017:** This 9.15 km bridge spanning the Lohit River, is India's longest over-water bridge. It provides connectivity between Assam and Arunachal Pradesh, benefitting civilian and defence logistics

- **Arrah-Chhapra Bridge (Veer Kunwar Singh Bridge, Bihar), 2017:** This 4.35 km road bridge across the Ganga significantly reduced the travel distance between Arrah and Chhapra
- **Third Narmada Bridge (New Narmada Bridge, Gujarat), 2017:** This cable-stayed bridge near Bharuch was built to relieve traffic congestion on the Ahmedabad-Mumbai NH 8
- **Dibang River Bridge (Arunachal Pradesh), 2018:** This 6.2-kilometer bridge improved road connectivity in remote regions of Arunachal Pradesh and is also strategically important for national security
- **Manohar Setu (New Zuari Bridge, Goa), 2022:** This is India's second-longest cable-stayed bridge, which improved connectivity on the Mumbai-Goa highway
- **Mahatma Gandhi Setu (Bihar), 2022:** Completed in 2022, its rehabilitation involved dismantling the original balanced cantilever concrete bridge and replacing it with a new steel framework, making it India's first and longest steel-supported river bridge



(Illustrative Picture)

- **Mumbai Trans Harbour Sea Link (Atal Setu, Mumbai), 2024:** This 21.8 km sea bridge is India's longest, connecting Sewri in Mumbai to Nhava Sheva in Navi Mumbai, and reducing travel time to and from Mumbai
- **Sudarshan Setu (Okha-Beyt Dwarka Signature Bridge, Gujarat), 2024:** This cable-stayed bridge connects mainland Okha to Beyt Dwarka island, improving access to a major pilgrimage site
- **Aunta–Simaria Bridge (Bihar), 2025:** This six-lane, 1.86 km extradosed bridge over the Ganga in Bihar, inaugurated in August 2025, connects Patna and Begusarai



(Illustrative Picture)

- **Kumar Bhaskar Varma Setu[9] (Assam), 2026:** This 1.2 km extradosed, prestressed concrete bridge inaugurated in February 2026 is north-east India's first extradosed bridge. The six-lane structure reduces the travel time from Guwahati to North Guwahati to just seven minutes and marks a major milestone in Assam's infrastructure development
- **Mumbai-Pune Missing Link[10][11] (Maharashtra), 2026:** The project bypasses the Khandala Ghat section, significantly improving connectivity between Mumbai and Pune. The 650-metre viaduct features India's tallest road cable-stayed bridge

[9] *https://www.pmindia.gov.in/en/news_updates/pm-inaugurates-kumar-bhaskar-varma-setu-in-guwahati-assam/*
[10] *Press-Release-01.05.2026-Afcons-delivers-Indias-tallest-road-cable-stayed-bridge-on-Mumbai–Pune-Expressway-Missing-Link-Project.pdf*
[11] *https://msrdc.in/Site/Common/ProjectListDetails.aspx?ID=75&MainId=18*

Prominent rail bridges built over the past decade

- **J P Setu (Digha–Sonpur Bridge, Bihar), 2016:** This 4.55 km rail-cum-road bridge crosses the Ganga and links Digha Ghat in Patna to Pahleja Ghat in Sonpur



(Illustrative Picture)

- **Bogibeel Bridge (Assam), 2018:** The 4.94 km rail-cum-road bridge spans the Brahmaputra. It links Dibrugarh and Dhemaji, providing a crucial transport link for India's north-eastern region and significantly reducing travel time
- **Chenab Rail Bridge (Jammu and Kashmir), 2025:** Inaugurated in June 2025, this is the world's highest railway arch bridge. At 359 metre above the Chenab River, the 1,315-metre-long steel arch structure is engineered to withstand high wind and seismic conditions. It is a key part of the USBRL
- **Anji Khad Bridge (Jammu and Kashmir), 2025:** Opened in June 2025, this is India's first cable-stayed railway bridge. It provides critical rail connectivity in challenging hilly terrain



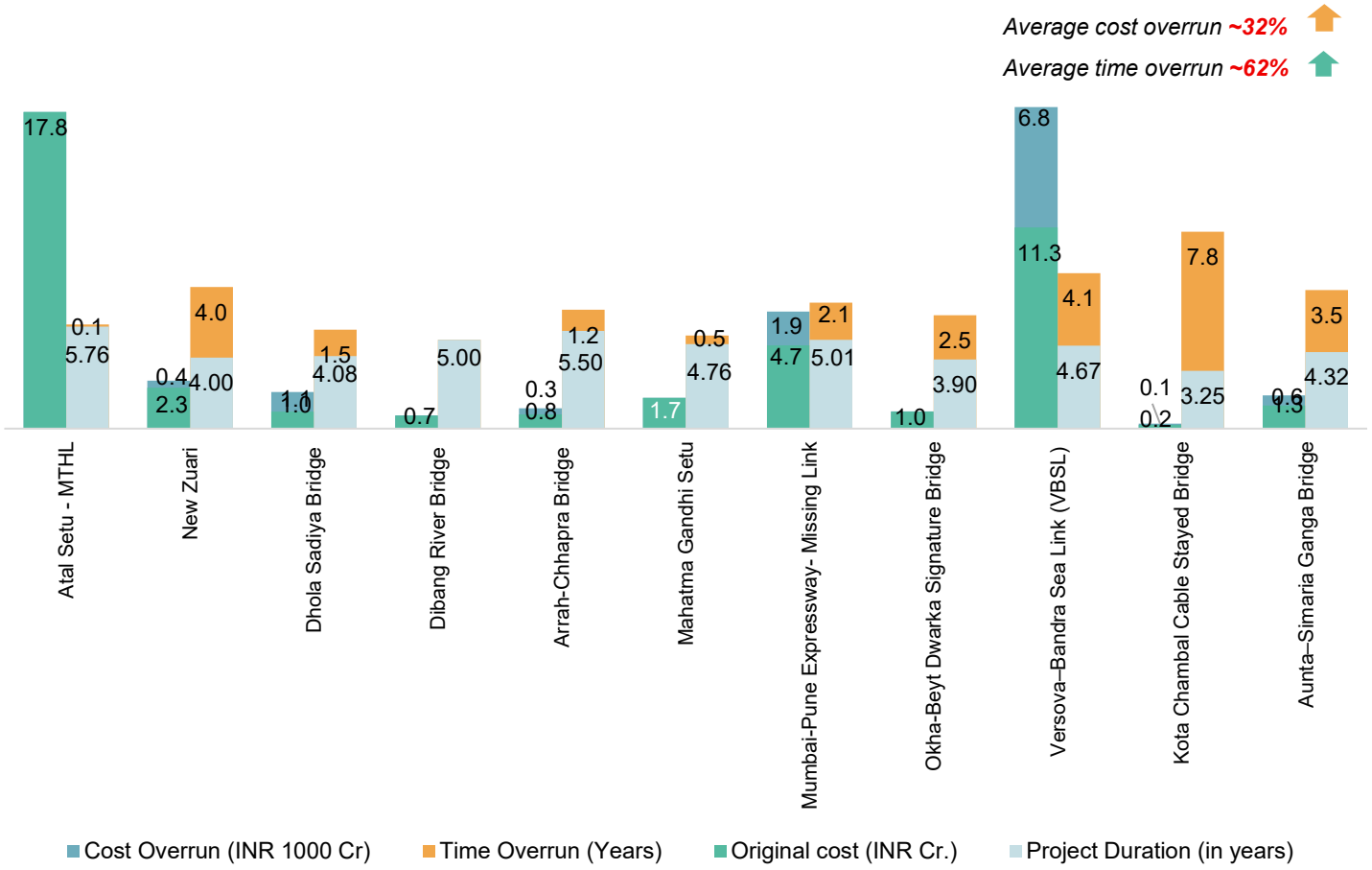
(Illustrative Picture)

- **New Pamban Bridge (Tamil Nadu), 2025:** This is India's first vertical-lift railway sea bridge, which was completed in 2024 and inaugurated in April 2025. The 2.07 km bridge connects mainland India with Rameswaram, replacing a century-old bridge to accommodate higher vehicular speeds and more traffic
- **Bairabi-Sairang Rail Line (Mizoram), 2025:** As part of a new railway line inaugurated in September 2025, a 114-metre-tall railway bridge (Bridge No 144) was built near Sairang. It is the tallest pier railway bridge in India

Cost and time overrun comparison for prominent bridge projects over the past decade

Bridge projects in India have faced considerable challenges. An analysis of the selected key bridge projects shown below reveals cost and time overruns of ~32% and ~62% on average, respectively.

Time and cost overruns for bridge projects



Source: Annexure 1 (refer page 56)

Disclaimer: The information presented has been compiled from publicly available sources, news articles, and other referenced materials, as detailed in the annex. Crisil has not independently verified the accuracy or completeness of this information. The purpose is to provide general perspective on the nature of delays and cost overruns typically observed in complex infrastructure projects. The examples cited represent a selective sample from the past decade

Next wave of tunnel and bridge projects in India

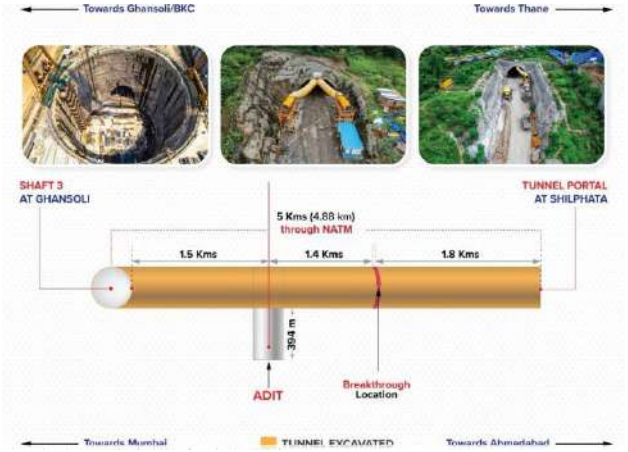
A new generation of tunnel and bridge infrastructure is set to emerge, transforming the nation's transportation landscape. These upcoming projects are poised to enhance connectivity, improve mobility, and underscore the scale of progress in infrastructure across the country.

- **Zojila Tunnel[12][13] (J&K)**: A transformative infrastructure project that will provide all-weather connectivity between Ladakh and the rest of India. Built using the New Austrian Tunnelling Method (NATM) and equipped with advanced smart tunnel systems, the project has already completed nearly 12 km of tunnelling and generated savings of over Rs 5,000 crore. Scheduled for completion in 2028, it will become India's longest road tunnel and Asia's longest bi-directional tunnel, significantly enhancing regional and strategic connectivity[14]



Zojila Road Tunnel Project, Jammu & Kashmir

- **Mumbai-Ahmedabad High-Speed Rail Tunnel[15] (Maharashtra):** Currently under construction, this is a key component of India's first bullet train corridor. Featuring a 4.8 km undersea section, the tunnel is being built using the New Austrian Tunnelling Method (NATM and advanced safety systems. Excavation from both the Ghansoli and Shilphata ends has successfully navigated complex underwater conditions, marking a significant engineering milestone[16][17]. Designed as a single-tube tunnel accommodating two high-speed rail tracks, the project reflects India's growing expertise in next-generation transportation infrastructure and high-speed rail development



- **Shiradi Ghat Tunnel (Karnataka):** The Shiradi Ghat is a mountain pass in Karnataka's Western Ghats on the NH-75 (formerly NH-48), connecting the coastal city of Mangaluru with Bengaluru via Hassan and Sakleshpur. While the Shiradi Ghat currently does not have a tunnel, a long-planned tunnel project has been proposed to bypass the difficult terrain and reduce travel time on this route through the forests of the Western Ghats, a UNESCO World Heritage Site. The proposed tunnel, along with the realignment, is expected to be completed within five years[18]
- **Rishikesh-Karnaprayag Rail Line Tunnels[19] (Uttarakhand):** This is one of India's most ambitious railway tunnelling initiatives—traversing the challenging Himalayan terrain of Uttarakhand. Spread

[12] *https://www.pib.gov.in/PressReleasePage.aspx?PRID=2214471&reg=3&lang=1*
[13] *https://meil.in/zojila-tunnel-construction-meil*
[14] *https://www.pib.gov.in/PressReleasePage.aspx?PRID=2214471&reg=3&lang=1*
[15] *https://www.nhsrcl.in/en/media/press-release/media-brief-5-km-tunnel-completed-between-ghansoli-and-shilphata-mumbai*
[16] *https://www.nhsrcl.in/en/media/press-release/media-brief-5-km-tunnel-completed-between-ghansoli-and-shilphata-mumbai*
[17] *https://www.pib.gov.in/PressReleasePage.aspx?PRID=2168979*
[18] *https://www.thehindu.com/news/cities/Mangalore/realigned-highway-to-bengaluru-via-shiradi-ghat-will-be-ready-in-five-years-says-nhai-official/article69851377.ece*
[19] *https://rvnl.org/project-details/539/New%20Line*

across a 125 km alignment, the project comprises 16 main tunnels (105 km) and 12 escape tunnels (98 km), with 199 km of tunnelling completed out of a total scope of 213 km. A key milestone has been the first-ever deployment of a tunnel boring machine (TBM) in Himalayan geology by Indian Railways, achieving a breakthrough in the 14.8 km-long Tunnel T-8. Leveraging advanced tunnelling technologies and rigorous monitoring systems, the project is setting new benchmarks in safe, sustainable and high-altitude railway infrastructure development in India



- **Thane and Borivali[20] (Maharashtra):** The 11.84 km Thane-Borivali Twin Tube Road Tunnel is a flagship MMRDA project that will provide direct connectivity between Thane and Borivali through Sanjay Gandhi National Park. Featuring 10.25 km of tunnelling, the project is expected to reduce travel distance by 12 km and save up to one hour of travel time, significantly easing congestion and improving cross-city connectivity. With an investment of Rs 16,600 crore, construction commenced in 2023 and the project has been accorded strategic importance by the Government of Maharashtra



- **Bengaluru North–South Tunnel Road[21] (Hebbal–Central Silk Board):** The Bengaluru North–South Tunnel Road is a 16.75 km twin-tube underground corridor connecting Hebbal's Esteem Mall Junction to Central Silk Board Junction, being developed by the Karnataka government through Bengaluru Smart Infrastructure Limited (B-SMILE) on a Build-Operate-Transfer basis, with Adani Enterprises being the lowest bidder for the project. The corridor is expected to reduce the Hebbal–Silk Board commute from about 90 minutes to roughly 35 minutes
- **Dwarka Expressway–Vasant Kunj Tunnel and Elevated Road[22] (NH-148AE):** The Dwarka Expressway–Vasant Kunj corridor is an 8.1 km, six-lane project approved by the Cabinet Committee on Economic Affairs in July 2026 at a capital cost of Rs 6,969.67 crore, connecting the Dwarka Expressway (NH-248BB)/UER-II at Shiv Murti Interchange to Nelson Mandela Marg in Vasant Kunj, South Delhi. The alignment comprises a 3.14 km underground twin-tube tunnel built using Tunnel Boring MachineTBM technology, along with approach ramps, about 2.5 km of elevated road, at-grade stretches, and a flyover with an elevated U-turn near the Mahipalpur–Chhatarpur Road junction. NHAI is executing the project under the Hybrid Annuity Mode

[20] *https://mmrda.maharashtra.gov.in/en/TBTthane#gsc.tab=0*
[21] *https://www.thehindu.com/news/national/karnataka/tenders-invited-for-167-km-twin-tunnel-project-linking-hebbal-and-silk-board/article69815904.ece*
[22] *https://newsonair.gov.in/govt-approves-construction-of-six-lane-dwarka-tunnel-in-delhi/*

- **Golden Line Metro[23][24] (MML 8):** Mumbai Metro Line 8, Connecting CSMIA Terminal 2 to Navi Mumbai International Airport, remains at a nascent stage despite formal government clearance. The Maharashtra Cabinet approved the roughly 35 km, Rs 22,862-crore corridor in January 2026 for execution by CIDCO under a public-private partnership on a design-build-finance-operate-transfer (DBFOT) basis, with the Centre and State each committing 20% viability gap funding. However, the project has yet to move past preparatory groundwork: land acquisition of about 30.7 hectares and statutory clearances are still being processed; CIDCO has only recently invited consultancy bids to secure Coastal Regulation Zone, forest, and other clearances
- **Chambal River Bridge (Madhya Pradesh):** This 1.2-km cable stayed structure being built on the Agra-Gwalior National High-Speed Corridor, a greenfield expressway section, will be one of the longest in the country upon completion, which is scheduled for 2028
- **Swatantrya Veer Savarkar Sea Link (Versova–Bandra Sea Link[25], Mumbai):** Construction of the **9.89-km** bridge in Mumbai, connecting the Bandra-Worli Sea Link to Versova, is expected to alleviate traffic congestion. The project, which is scheduled to be completed in 2028, involves cable-stayed bridge technology



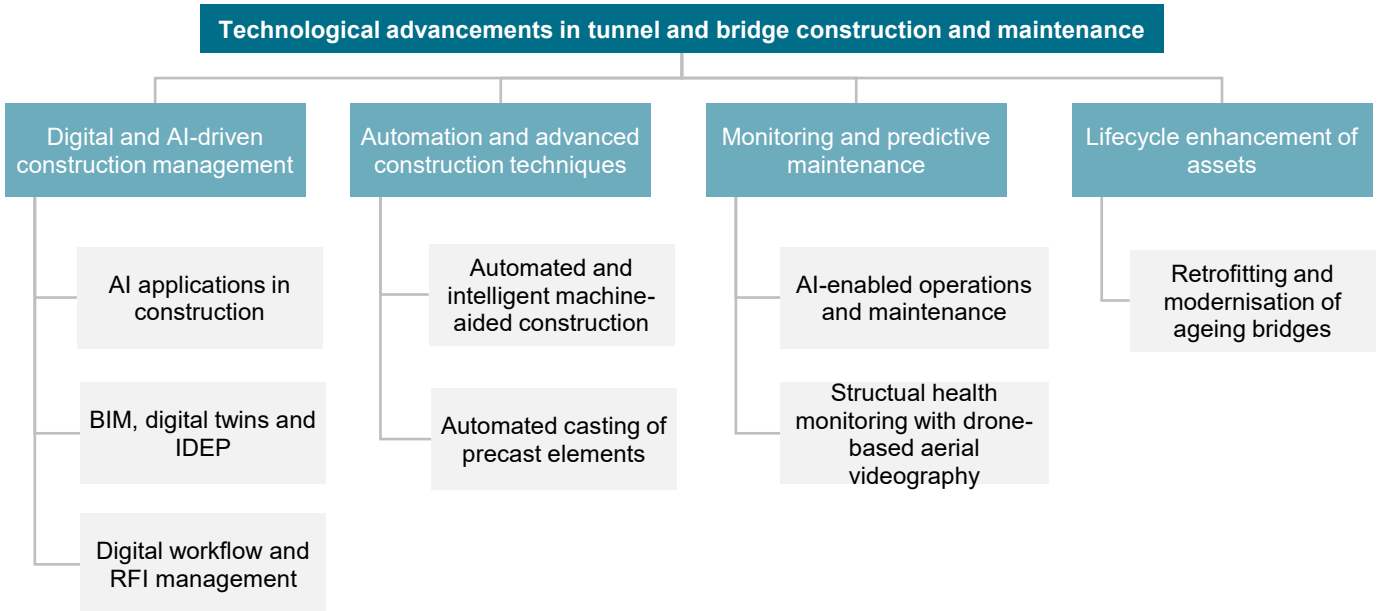
[23] *Mumbai Metro: Status Update, Route Map, Fares & Tenders [2026]*
[24] *Explained: How Metro Line 8 Will Connect Mumbai And Navi Mumbai Airports With Faster, Easier Commute*
[25] *https://www.hindustantimes.com/cities/mumbai-news/bandraversova-sea-link-redesign-gets-green-nod-cost-rises-by-60-101775503889781.html*



New-age technologies

Construction of modern bridges and tunnels is increasingly being shaped by technological innovations that enhance efficiency, precision and asset performance. From the adoption of digital platforms and AI-driven tools to automation in the construction processes, these technologies are transforming the way infrastructure is built, monitored and maintained. **Advanced sensing systems, drone-assisted inspections and predictive maintenance** enable real-time insights into structural health; while retrofitting and modernisation techniques extend the life of existing assets.

The following sections explore digital management, automation in construction, monitoring and maintenance, and lifecycle enhancement of an infrastructure project.



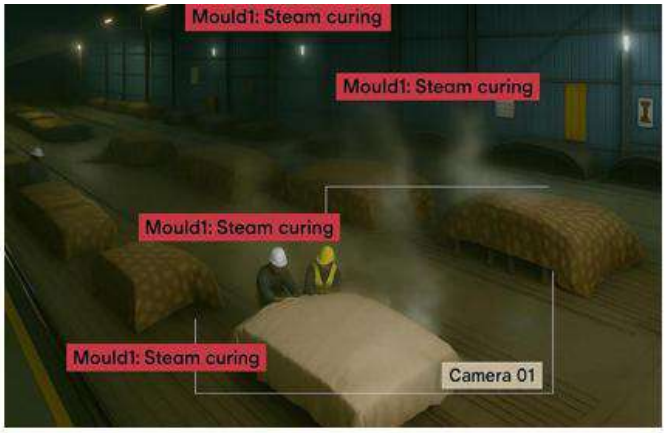
AI and ML applications in construction, operations and infrastructure safety

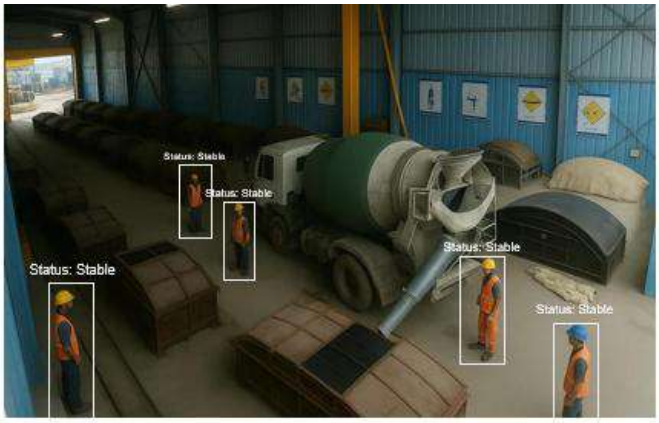
Artificial Intelligence (AI) and Machine Learning (ML) are transforming the construction and infrastructure sector by enabling data-driven decision-making, enhancing productivity, improving safety, and optimising asset performance throughout the project lifecycle. In bridge and tunnel projects, AI technology is increasingly being integrated across planning, design, construction, operations and maintenance (O&M), creating opportunities for greater efficiency, cost optimisation and risk mitigation.

The key applications include:

a) **Productivity analysis and resource optimisation:** AI-enabled computer vision systems, integrated with CCTV cameras, drones and site monitoring platforms, facilitate comprehensive productivity assessment through automated time and motion studies (TMS). These systems can track construction activities, analyse workforce movement, measure equipment utilisation, detect idle time and identify operational bottlenecks in real time. Objective productivity measurements enable project teams to optimise labour deployment, improve equipment utilisation, reduce delays and enhance overall construction efficiency.

Figure: Activity-wise time and labour movement tracking





b) **Automated safety compliance monitoring:** Safety remains a critical priority in bridge and tunnel construction, where work is often undertaken in complex and high-risk environments. AI-powered cameras, sensors and drone-based surveillance systems enable continuous monitoring of worksites and can automatically detect unsafe practices, absence of personal protective equipment (PPE), unauthorised access to restricted zones, and other hazardous conditions. Real-time alerts and automated reporting improve compliance with safety protocols while enhancing site supervision and incident prevention. Figure: AI-based safety (PPE) compliance monitoring

Figure: AI-based safety (PPE) compliance monitoring





c) **Predictive equipment maintenance and asset performance:** ML algorithms can analyse operational and sensor data generated by construction machinery to identify patterns associated with wear, degradation or potential failures. Predictive maintenance systems enable proactive intervention before breakdowns occur, reducing equipment downtime, improving asset utilisation and extending the service life of high-value equipment. Such systems contribute to smoother project execution and lower lifecycle costs

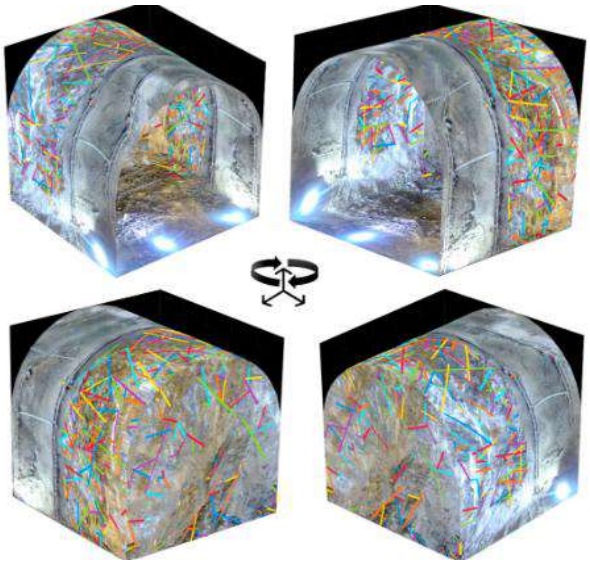
d) **Computer vision-based tunnel excavation and face mapping:** AI and computer vision technologies are increasingly being deployed in tunnel construction to support excavation monitoring and geological face mapping. By analysing images and sensor data collected during excavation, AI systems can assist in identifying geological features, assessing rock mass conditions, classifying strata and detecting anomalies that may influence excavation strategies. These capabilities improve decision-making, enhance safety and support more efficient tunnel construction operations.

e) **AI in O&M:** Beyond the construction phase, AI can significantly enhance the operation and maintenance of bridge and tunnel assets. Applications include predictive maintenance of critical systems, SHM, energy optimisation, traffic and capacity management, inventory optimisation, manpower planning and waste management. Continuous analysis of operational data allows infrastructure owners to improve asset reliability, reduce maintenance costs and enhance service levels over the asset lifecycle.

f) **Tunnel seismic prediction (TSP) for ahead-of-the-face geological forecasts:** TSP is gaining wider acceptance as an advanced geophysical technique for identifying geological conditions ahead of the tunnel face. By detecting seismic reflections associated with faults, fractured or weak rock zones and water-bearing formations, TSP can provide advance indications of potential geological anomalies before excavation reaches them. This supports more informed decisions on excavation and ground-support requirements, helping reduce construction uncertainties and improve safety and risk management, particularly in complex geological conditions. TSP is applicable to both drill-and-blast and TBM tunnelling.

BIM, digital twins and integrated digital engineering platforms

The adoption of digital technologies has transformed the planning, construction and management of complex infrastructure, such as bridges and tunnels. Among these, BIM, DT and IDEP are enabling data-driven decision-making, enhancing collaboration and improving lifecycle performance.



Building information modelling: BIM has evolved into a cornerstone of modern engineering practice. It offers a model-based, data-rich environment, where multidisciplinary inputs are integrated into a central digital framework. For bridges and tunnels, BIM supports:

- Visualisation of complex geometries and design alternatives
- Early clash/conflict detection and error reduction
- Optimised resource allocation and interdisciplinary coordination
- Improved stakeholder communication and risk management

Digital twins – the foundation of infrastructure digitalisation

- A digital twin is a synchronised virtual representation of a real-world asset that is continuously updated through the asset's life cycle.
- Unlike static BIM models, digital twins are dynamic and can integrate 3D geometry, design data, documentation, photographs, construction progress, inspection information, sensor data and operational history
- Digital twins can be used from design to construction to O&M, enabling stakeholders to access, update, visualise and respond to asset information through web, mobile and mixed-reality interfaces
- For tunnels, this is especially important as tunnelling involves multiple disciplines: geology, geotechnical engineering, structural engineering, ventilation, electrical systems, transport planning, safety systems and construction management
- An integrated digital model allows all disciplines to collaborate, detect clashes, review alternatives, visualise complex designs and identify problems before construction begins
- Examples from international rail projects and the Mumbai Coastal Road project, where BIM/digital modelling helped improve visualisation, reduce design modification time and support faster approvals
- Construction of digital twins can link BIM with scheduling to create 4D models, improve productivity, avoid rework, plan equipment movement, monitor earned value, compare actual versus planned progress and reduce cost overruns.
- During O&M, digital twins can support asset management by tagging every component, linking maintenance manuals, recording inspections and preserving the full change history of the asset

Automated casting for precast elements

Automation in precast construction has become increasingly relevant for large-scale tunnel and bridge projects, where **innumerable repetitive concrete elements** must be produced with the same standards. Automated casting systems integrate batching, concrete transport and hydraulically operated moulds to streamline this process. The main objectives are to improve consistency, reduce manual intervention and accelerate the production cycle.

Key features of automated casting for precast elements:

- **Automated batching and feeding:** Centralised batching plants, coupled with computerised dosing, ensure precise control of mix proportions
- **Concrete transport systems:** Shuttles, conveyors or bucket systems deliver concrete directly to moulds, reducing handling losses and variability

- **Hydraulic mould operations:** Hydraulics support vibration, compaction, alignment and demoulding, minimising defects and labour requirements
- **Carousel or battery mould setup:** Enable simultaneous casting of multiple elements, such as tunnel ring segments, girders, slabs and barriers
- **Curing chambers:** Controlled curing (often steam or hot air) improves strength gain and uniformity

Automated casting methods hold considerable potential for application in tunnel segments, bridge girders, noise barriers and parapets. For instance, the Mumbai-Ahmedabad High-Speed Rail (MAHSR) project has used automated casting machines for noise barrier panels, deploying shuttle-fed concrete systems and multi-segment moulds[26].

However, these systems have certain limitations. The high initial capital investment required for moulds, hydraulics and handling equipment can be substantial. In addition, automated casting systems are most efficient for repetitive, standardised elements and less adaptable to unique or complex geometries.

Despite these challenges, automated casting represents a significant step towards industrialised construction in transport infrastructure, offering improved productivity, consistent quality control and enhanced efficiency in the fabrication of tunnel and bridge components.

AI-enabled O&M and traffic management

Predictive maintenance and advanced surveillance technologies are transforming infrastructure management by leveraging AI, IoT devices, sensors, data analytics and BIM. AI-powered sensors monitor parameters to detect anomalies early, enabling timely interventions. Advanced surveillance and mapping tools, such as DT, drones and light detection and ranging (LiDAR) strengthen infrastructure monitoring.

In tunnels, they deliver high-resolution insights for rock bolt monitoring and optimisation of drilling and blasting operations. **Integrated tunnel control systems** include advanced safety features, such as fire detection and alarm systems, which are crucial for the safety and efficient operation of long tunnel, digital thermal sensing (DTS) technology, fibreoptic networks and public address/voice alarm (PA/VA) systems, which provide critical, real-time monitoring for the tunnel.

A notable example is **Boston's Big Dig:** The Central Artery/Tunnel Project, popularly known as the Big Dig, is one of the largest infrastructure undertakings in the US, involving the construction of an extensive tunnel system beneath downtown Boston. To ensure structural safety and operational efficiency, the project integrated advanced tunnel monitoring systems equipped with sensors to track critical parameters such as temperature, stress, load, pressure, pore water pressure, deformation and strain. These systems provided real-time data on potential issues such as cracks or mass displacements in the rock strata. The continuous monitoring and data-driven analysis enabled early detection of anomalies, improved decision-making and optimised tunnel safety and performance throughout the project's lifecycle[27].

A notable case was witnessed in Mumbai September 2025, when a car travelling through the Mumbai Coastal Road underground tunnel caught fire, which was sensed by **linear hear detector cables** that alerted the control room and the installed **video incident detection system** helped locate the vehicle to initiate immediate fire extinguishing action within 10 minutes. Regular traffic resumed within 30 minutes with no casualties.[28].

Safety and security

Digital twin models and drone-based LiDAR have been used for underground tunnel mapping and post-accident rescue operations. A notable example for safety and security is AI-enabled surveillance systems that enhance security through vehicle identification, licence plate recognition and facial detection. They also monitor

[26] *https://blogs.lntecc.com/mumbai-ahmedabad-high-speed-railway-corridor-mahsr-the-first-bullet-train-of-india/*
[27] *https://www.encardio.com/blog/how-smart-tunnel-monitoring-systems-are-transforming-infrastructure-management*
[28] *https://timesofindia.indiatimes.com/city/mumbai/horrific-car-blaze-traps-motorists-at-mumbai-coastal-road-tunnel-disrupts-traffic/articleshow/124106916.cms*

attendance and helmet compliance checks, ensuring a safer working environment. For instance, the J&K Police deployed an AI-based facial recognition system to bolster tunnel safety and security. This system uses high-resolution CCTV cameras along the Jammu-Srinagar national highway. By leveraging these technologies, construction and infrastructure projects can improve safety, reduce risks and enhance efficiency.

Structural Health Monitoring (SHM of tunnels and bridges

Structural failure is a real risk even when structures have recently passed inspections. Visual inspections and manual monitoring are insufficient because many early signs of failure, such as fatigue, internal movement, crack propagation, soil instability or changing structural behaviour, cannot be detected by the naked eye.

- Monitoring should move from discrete, expert-dependent inspection to continuous sensor-based monitoring using IoT, AI, ML, drones, geospatial technologies, cloud storage and advanced analytics. Modern sensors are not merely passive devices; some can process data at the edge and generate alerts almost instantly
- **In tunnels -** important parameters are vibration, displacement, tilt, acceleration, velocity, ground movement, structural strain, triaxial strain, crack growth, joint movement, leakage, liquefaction risk, slab movement and rock/soil stability
- **In bridges -** Sometimes, the sensors may show different recovery behaviour in two spans after heavy vehicle movement. One span may return to normal quickly, while another does not, indicating fatigue and reduced resilience. Such data helps engineers decide whether heavy vehicles should be restricted, whether repairs are needed, and how future designs should be modified
- According to experts, AI when combined with good engineering judgment, can help predict residual life, identify anomalies, detect fatigue, and support preventive action.

Key benefits of AI in O&M

- **Optimised inspections:** Automated and remote data collection makes inspections faster, more comprehensive and safer
- **Reduced downtime**: Predictive maintenance scheduling prevents unexpected breakdown, minimising costly interruptions
- **Extended asset life:** Early detection and correction of issues prevent minor problems from escalating, maintaining asset integrity and extending the lifespan
- **Improved cost efficiency:** Lower downtime, optimised resource allocation and reduced inventory for spare parts contribute to significant cost savings
- **Enhanced decision-making:** Data-driven insights and advanced visualisations empower stakeholders to make informed decisions about maintenance planning and resource allocation

Implementation and future direction

Successful implementation of the integrated system requires careful planning, including the selection of appropriate SHM sensors, drones with suitable payloads and AI/ML tools tailored to the specific needs of the assets being monitored. Continuous training of AI/ML models with new data is essential to improve their predictive accuracy.

As technology advances, we can expect even more sophisticated SHM systems, drones with enhanced capabilities (such as autonomous navigation and advanced sensor suites) and more powerful AI/ML algorithms capable of handling larger datasets and providing more precise predictions. The future of asset management is moving towards a fully automated, predictive and proactive model, where maintenance is optimised, downtime is minimised and asset performance is maximised, thanks to the synergy of SHM, drones and AI/ML.

A notable example in this case is the **Chenab Railway Bridge in J&K, India**, which is recognised as the world's highest railway bridge. It has been equipped with a state-of-the-art **Bridge Health Monitoring System** to ensure

structural integrity under extreme conditions. Given its location in a high seismic zone and exposure to strong winds, the monitoring framework integrates a wide range of sensors, including accelerometers, strain gauges, anemometers and displacement metres to continuously measure parameters such as wind loads, vibrations, temperature variations and material stresses. The collected data is transmitted in real time to a central monitoring system, enabling engineers to assess structural performance, detect anomalies and implement predictive maintenance strategies. By integrating these systems with digital modelling tools, the Chenab Bridge exemplifies the use of advanced digital and cyber-physical technologies in ensuring the safety, resilience and longevity of critical infrastructure assets[29]. The Chenab Bridge has become operational with a range of advanced safety features, including **120 sensors** and **150 servers**[30].

Retrofitting and modernising ageing bridges

Industry approaches involve a systematic process of structural assessment, strengthening and lifecycle extension to enhance durability and safety.

Structural assessment

- Visual and component-level inspection: Detailed visual inspections identify the existing damage and deterioration
- Advanced technologies: Non-destructive testing methods such as ground penetrating radar (GPR) detect internal defects

Strengthening and retrofitting techniques

- Column jacketing: Columns are encased in jackets to increase strength and ductility
- Adding structural elements: New walls, frames, or bracing elements improve lateral strength and stiffness

Lifecycle extension and modernisation

- Focus on sustainability: Interventions prioritise minimally invasive and sustainable approaches
- Digitalisation: Digital tools enhance reliability and accuracy in structural ratings, leading to better maintenance strategies



[29] *https://iricen.gov.in/iricen/ipwe_seminar/2017/IPWE%202018/24%20Warning%20and%20Structural%20Health%20Monitoring%20System%20for%20the%20World%20Highest%20Railway%20Bridge%20across%20the%20Chenab%20River.pdf*
[30] *https://risingkashmir.com/worlds-tallest-rail-bridge-equipped-with-120-sensors-for-safe-train-operations/*

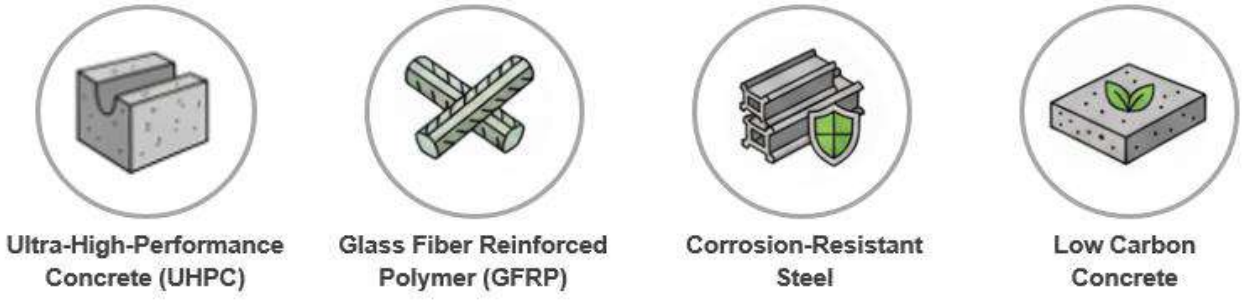


Sustainable practices and safety systems

The tunnelling industry is witnessing key developments that are setting new benchmarks in sustainability and efficiency. The use of sustainable materials and the recycling of construction waste are becoming central to reducing environmental impact. This chapter explores these developments.

New-age materials

The infrastructure sector is undergoing a transformation aided by the adoption of advanced materials that deliver unprecedented performance, sustainability and longevity. Modern bridge and tunnel construction is increasingly depending on these innovative materials to address durability, environmental impact, maintenance costs and long-term resilience.



- **Ultra-high-performance concrete**

  Ultra-high-performance concrete (UHPC) represents a breakthrough in cementitious materials, with compressive strengths exceeding 150 MPa and exceptional durability. Its dense microstructure prevents liquid ingress, while the steel fibre reinforcement provides post-crack tensile strength, reducing the need for secondary reinforcement.

  – **Khambataki Ghat Tunnel (India)**: The tunnel demonstrated the use of ultra-high-performance fibre reinforced concrete (UHPFRC) in tunnel linings through shotcreting, providing enhanced durability. [31]

[31] *https://uniqueuhpcinfra.com/uhpfrc/*

- **Langat River Bridge (Malaysia)**: The bridge achieved a world-record 105-metre precast U-girder span using UHPC, eliminating in-river piers, improving sustainability and reducing maintenance costs.[32]

- **Glass fibre reinforced polymer (GFRP)**

  GFRP rebars provide superior corrosion resistance and strength-to-weight ratios, making them ideal for harsh environments that cause a deterioration of steel reinforcement. They are 4–5 times lighter than steel, up to twice as strong in tension, non-conductive and non-magnetic. Their long lifespan reduces maintenance requirements and environmental footprint.

  - **Patna Metro rail project:** GFRP bars were used in viaducts and stations to withstand monsoon conditions.[33]
  - **Dubai Metro viaduct:** Dubai Metro leveraged GFRP's corrosion resistance in a humid, marine environment.
  - **Düsseldorf Wehrhahn line:** It employed GFRP reinforcement in underground stations to provide efficient TBM breakthroughs.

- **Corrosion-resistant steel**

  Advanced stainless-steel grades form a self-healing chromium oxide layer, extending the lifespan of bridges from 15-20 years to more than 100 years, while lowering lifecycle costs, and minimising lifecycle maintenance and environmental impact.

  - **Bhayandar Railway Station FOB, Mumbai (India):** India's first stainless-steel foot overbridge, designed for a 100+-year lifespan, used 170 MT of IRS350CR grade stainless steel.[34]

- **Low-carbon concrete**

  Green and low-carbon concretes reduce CO_2 emissions while maintaining performance. Supplementary cementitious materials, such as fly ash, ground granulated blast furnace slag (GGBS) and silica fume, can replace 40-70% of Portland cement. Geopolymer concretes take this a step further, eliminating ordinary Portland cement entirely by using aluminosilicate-rich waste materials, and offering improved resistance to heat, fire and chemical corrosion.

Limitations

Although advanced materials offer significant advantages, their widespread adoption faces practical constraints such as:

- **High initial costs:** Materials such as UHPC, GFRP and stainless steel involve higher upfront investment than conventional alternatives, which can be a barrier in cost-sensitive projects
- **Specialised knowledge and training:** Design, handling and installation often require new skills and familiarity among engineers, contractors and construction workers
- **Codes and standards:** Formal codes, specifications and design guidelines for certain advanced materials are still limited in India, leading to challenges in uniform adoption and undermining confidence in their long-term performance
- **Construction constraints:** Some materials pose specific challenges—e.g., UHPC requires precise mixing and curing processes, GFRP cannot be bent on-site like steel, and high-GGBS concretes can suffer from delayed strength gain

These constraints underline the need for cautious adoption and gradual scale-up, rather than blanket substitution of traditional materials.

[32] *https://www.pci.org/PCI/PCI/Project Resources/Project_Profile/Project_Profile_Details.aspx?ID=259730*
[33] *Glass Fiber Reinforced Polymer Rebar | GFRP Rebar*
[34] *https://wr.indianrailways.gov.in/view_detail.jsp?lang=0&id=0,4,268&dcd=6541&did=16541734620610E46D0F721224F42895378624369733A*

Recycling of tunnel excavation material (TEM)

In parallel with material innovation, sustainable infrastructure requires effective management of waste generated during construction. Tunnelling produces massive volumes of **TEM**, often referred to as muck or spoil. Traditionally disposed of in landfills, this practice creates both environmental and financial challenges.

Key applications of TEM recycling include:

- **Reuse as aggregates:** Processed TEM can replace conventional aggregates in road construction, embankments and base layers. In Croatia's **Istrian Y Motorway**, TEM was used to produce a low-carbon concrete, saving more than 200,000 ton of virgin aggregates[35]. In India, around 300,000 cubic metre of tunnel muck was used in the **Udhampur-Srinagar-Baramulla Railway Link (USBRL)** project in retaining the wall to support one of the Chenab bridge abutments[36]
- **Reuse in grouting:** Spoil can be blended with binders to form cost-effective grouting materials in shield tunnelling. The **Vienna S1 Project** successfully reused 14 million cubic metre of TEM for grouting a 19 km tunnel, reducing shrinkage issues and overall costs[37]
- **Soil conditioning:** Spoil from slurry operations can enhance soil conditioning in mechanised tunnelling. The **Yellow River Tunnel (China)** replaced lime with waste sand for slurry dewatering, achieving similar technical performance at lower cost and environmental impact
- **Refilling abandoned sites:** TEM can be used to backfill exhaust quarries, reducing land disturbance. The **Katzenberg Tunnel (Germany)** reused 2.3 million cubic metre of spoil for quarry rehabilitation, with environmental safeguards to protect groundwater

Through these applications, TEM recycling not only minimises disposal requirements, but also provides a cost-effective source of construction inputs, reduces carbon emissions and aligns with circular economy principles.

Collectively, advanced materials such as UHPC, GFRP, corrosion-resistant steel and low-carbon concrete deliver superior durability, reduced maintenance, enhanced safety and better environmental performance. Although their upfront costs are higher, lifecycle analyses consistently demonstrate significant long-term economic and sustainability benefits.

At the same time, their limitations—including higher initial costs, availability constraints and lack of standardisation—must be carefully weighed before large-scale adoption. A balanced approach that combines selective use of advanced materials with responsible recycling of tunnelling spoil should deliver the most sustainable outcomes.

By reusing excavation materials such as aggregates, grouts, soil conditioners and refilling materials, projects can reduce environmental impact, lower costs and ease the pressure on natural resources. Together, advanced materials and muck recycling represent a complementary strategy that can help build resilient, cost-efficient and environmentally responsible bridges and tunnels of the future.

Advanced environmental impact assessments

- **Geographic information system (GIS)**

  GIS-based spatial analysis is used to provide a more detailed understanding of the spatial distribution of environmental impacts, which is crucial in complex terrains and for sensitive projects

[35] *https://www.holcim.com/who-we-are/our-stories/ecopact-saves-co2-croatia-tunnel*
[36] *https://www.holcim.com/who-we-are/our-stories/ecopact-saves-co2-croatia-tunnel*
[37] *https://www.mdpi.com/2071-1050/16/12/4889*

- **Sustainable techniques**

  Adopting energy-efficient building practices and sustainable construction materials can significantly reduce the overall environmental footprint of tunnels and bridges

- **Satellite-imagery-based assessment/geospatial AI analytics**

  Managing physical risk, driven by climate change, and compliance risk, driven by regulatory shifts, leveraging advanced monitoring tools[38]

  These include:

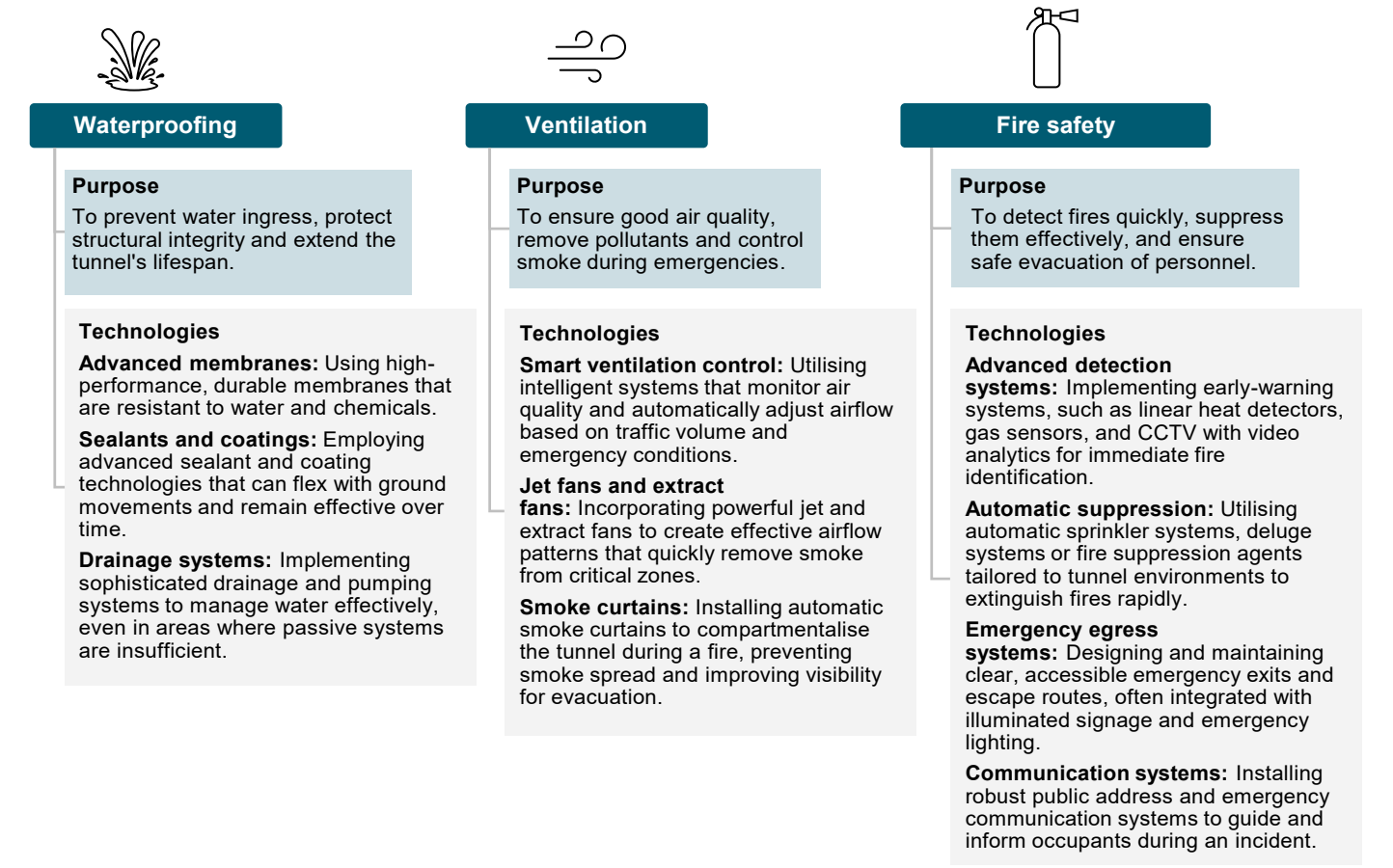
  – **Wildfire** risk monitoring and **methane** watching

  – **Deforestation** tracker and **vegetation/forest carbon** monitoring

  – **Forestry** due diligence

Tunnel safety systems

Upgrading tunnel safety systems for operational excellence involves integrating advanced waterproofing, ventilation and fire-safety technologies to enhance durability, safety and functionality. Advanced waterproofing systems prevent structural damage and ensure long-term stability. Enhanced ventilation systems provide clean air and control smoke in emergencies, while modern fire-safety systems enable early detection, automatic suppression and clear evacuation routes to protect occupants and infrastructure.



[38] *https://www.kayrros.com/products-risk-solutions/*

Disaster preparedness in tunnel and bridge construction

Integrated strategies include performing robust risk assessment, implementing mitigation measures during design and construction (e.g., earthquake-resistant structures), developing comprehensive emergency plans with clear protocols, establishing early warning systems, conducting regular training and drills, ensuring access to communication and control centres, and creating detailed recovery and business continuity plans.

Risk assessment and mitigation

- **Comprehensive risk analysis:** Conduct detailed assessments to identify potential hazards such as seismic activity, flooding, landslides and structural failures specific to the project site
- **Design for resilience:** Incorporate design features and materials that enhance resistance to anticipated hazards, such as seismic-resistant components for bridges or fire-retardant materials for tunnel linings
- **Site selection and planning:** Choose construction sites and design them to avoid high-risk areas such as floodplains or unstable geological zones

Robust safety protocols and preparedness

Emergency response plans	Develop detailed plans outlining actions for various scenarios, including evacuation procedures, rescue operations and coordination with external agencies.
Staff training and capacity building	Provide extensive training to construction personnel on safety procedures, emergency protocols and proper use of safety equipment.
Emergency control centers	Establish and equip command posts or control centres for effective communication, coordination and decision-making during emergencies.
Early warning systems	Implement systems to provide advance notice of potential threats, allowing for proactive measures and timely evacuation or safety actions.
Community engagement	Engage with the local community and emergency services to foster collaboration and integrate construction site safety into broader community emergency plans.
Emergency equipment and supplies	Stockpile essential equipment such as personal protective gear, first-aid supplies, rescue tools and temporary shelter materials.



Recent improvements in infrastructure policy

Regulatory mechanisms play a critical role in ensuring that infrastructure development is not only efficient and economically viable but also safe and resilient. The successive tunnel-collapse incidents at **Tihra (2015)[39], Silkyara[40] (2023)** and the **SLBC tunnel in Telangana (2025)[41]** fundamentally reshaped the policy discourse surrounding underground infrastructure in India. By exposing systemic weaknesses in project planning, geological investigations, risk assessment, construction oversight and emergency preparedness, these incidents accelerated the adoption of a more rigorous, risk-based regulatory framework. The reforms that followed reflect a decisive shift towards proactive safety management, standardised technical evaluation and lifecycle governance of tunnel projects.

Strengthening tunnel project planning through a standardised alignment assessment framework[42]

- The reform trajectory begins with a Ministry of Road Transport and Highways (MoRTH) circular dated October 24, 2024, which introduced a mandatory checklist governing the submission of proposals for long tunnel projects (length exceeding 1.5 km) on national highways. The circular required all executing agencies—the NHAI, State Public Works Departments, the Border Roads Organisation and NHIDCL—to furnish standardised documentation encompassing desk studies, alignment reports, geotechnical investigations, tunnel design, electrical and mechanical works, cost estimates, risk assessments, and environmental clearances, to be certified by the competent technical authority prior to ministry-level review. This circular established the first formalised, ministry-level appraisal framework for tunnel proposals
- This was followed by the Standard Operating Procedure (SOP) for Tunnel Alignment Studies and Approval, issued on September 2, 2025, which codified the methodology for tunnel route selection. The SOP mandates evaluation of a minimum of three alignment alternatives, integration with the PM Gati Shakti portal for infrastructure-conflict assessment, preparation of geotechnical baseline reports and risk registers, adherence to prescribed borehole density standards, and completion of a structured 12-step multi-criteria decision analysis prior to alignment finalisation. The SOP effectively standardised route-

[39] *https://www.ndtv.com/india-news/tunnel-collapse-himachal-pradesh-high-court-seeks-rescue-report-1219167*
[40] *https://ndrf.gov.in/en/operations/silkyara-tunnel-collapse*
[41] *https://www.hindustantimes.com/india-news/months-after-roof-collapse-telangana-tunnel-project-remains-an-uphill-task-101746472254584.html*
[42] *https://library.nhai.org/Circulars*

selection practices that had previously varied across implementing agencies

- A significant safety-related reform was introduced through the MoRTH Guidelines for Prevention and Mitigation of Road Tunnel Collapses, dated December 5, 2025, promulgated in direct response to recent tunnel collapse incidents on national highways. The guidelines address the entire project lifecycle—planning, design, tendering and execution—and introduce substantive operational requirements. These include adoption of the New Austrian Tunnelling Method (NATM) with observational monitoring, daily risk-review meetings, mandatory escape pipes in high-risk zones, strategically positioned rescue containers with specified survival capacity, weekly-updated emergency response plans, and a formal incident command structure coordinating the national and state disaster response forces, local administration, and construction agencies during rescue operations, with detailed protocols set out in a dedicated response-strategy annexure
- The NHAI subsequently gave effect to each of the above MoRTH directives through internal policy circulars:

  a. Policy No. 11.87/2026 (March 5, 2026) for the collapse-prevention guidelines

  b. Policy No. 11.88/2026 (March 7, 2026) for the alignment SOP

  c. Policy Circular No. 11.102/2026 for the 2024 checklist

  Each of these policies mandates strict compliance across NHAI headquarters, regional offices, project implementation units, construction management units and site offices.

Improvements in DPR awards with the MoRTH's new rating system

- Bridges and tunnels have historically been procured under the same Detailed Project Report (DPR) consultancy framework as general highway works, despite carrying materially higher geotechnical, hydraulic and safety risk. Through 2024-2026, the MoRTH and NHAI have progressively dismantled this one-size-fits-all approach, replacing it with dedicated procurement tracks, tighter eligibility filters and a formal consultant rating system specifically calibrated for structure-heavy projects
- Creation of dedicated 'standalone bridge' and 'standalone tunnel' procurement tracks

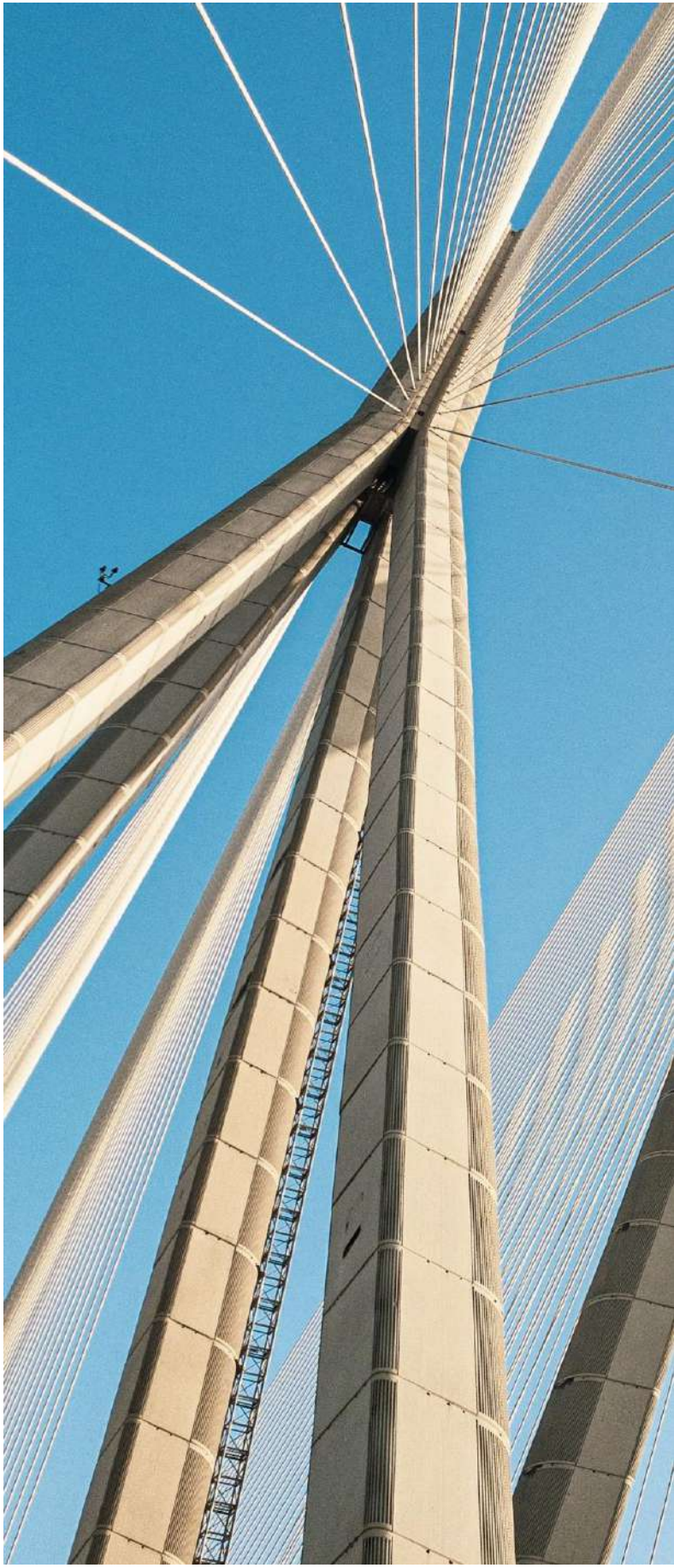
Raising technical rigour and reducing price-led underbidding

- The MoRTH initiated a comprehensive reform of the DPR consultancy procurement framework through an office memorandum dated July 7, 2025, inviting stakeholder comments on a concept note proposing amendments to the DPR consultancy RFP originally issued on February 9, 2024[43]. A key reform was the creation of separate procurement categories for standalone bridge projects and standalone tunnel projects, recognising their specialised technical requirements and distinguishing them from general highway DPR assignments
- For these standalone structure projects, the revised framework provides that the project cost shall be fixed by the procuring authority, eliminating the need for consultants to submit financial bids. Consultant selection is undertaken through a modified QCBS methodology, with 60% weightage assigned to technical evaluation, including DPR ratings, and 40% weightage to the performance bank guarantee (PBG) offered by bidders.[2] The framework also introduced stricter participation requirements for joint ventures (JVs), limiting them to a single partner structure, with the JV partner required to meet at least 50% of the prescribed eligibility criteria and the lead partner 75%

[43] *MoRTH Office Memorandum No. RW/NH-33044/29/2021-S&R(P&B), dated 07.07.2025, referencing original RFP dated 09.02.2024*

independently. Further, subcontracting is restricted to specialised survey and investigation activities, subject to prior approval and capped at 10% of the project cost[44]

- In parallel, the ministry solicited comments on a companion concept note establishing a formal DPR rating criteria system for consultancy firms, intended to objectively assess historical performance and separate high-performing and underperforming firms and supporting the application of performance-based incentives and disincentives in future procurements[45]
- Both proposals were finalised through a MoRTH circular dated September 29, 2025, which superseded the original February 2024 RFP and all interim amendments. The revised RFP took effect from November 1, 2025—the date on which the NHAI/ministry began publishing consultant ratings on its website[46]
- The NHAI subsequently consolidated the reform at its own level through Policy Circular No. 11.85, dated February 17, 2026, formally adopting the ministry's revised RFP and folding in the provisions of three intervening NHAI circulars (dated February 25, 2025, August 23, 2025, and December 12, 2025), while superseding its two earlier circulars from June and September 2024[47]



[44] *MoRTH Office Memorandum dated 07.07.2025—Concept Note on DPR Rating Criteria*
[45] *MoRTH Office Memorandum dated 07.07.2025—Concept Note on DPR Rating Criteria*
[46] *MoRTH Circular No. RW/NH-33044/29/2021-S&R(P&B), dated 29.09.2025; effective 01.11.2025*
[47] *NHAI Policy Circular No. 11.85/2026, dated 17.02.2026*

Sharper eligibility and rating thresholds for structure-heavy work

- Following the recommendations of an expert committee on long-term remedial measures for landslide-prone areas in hilly regions, the MoRTH circulated the committee's report through an office memorandum dated November 28, 2024, and mandated its adoption by DPR consultants undertaking landslide investigations and mitigation planning for hill-road and tunnel projects[48]
- The revised terms of reference (ToR) for DPR preparation in hilly terrain require consultants to prepare a comprehensive inventory of tunnels and geologically vulnerable stretches, including landslide-prone, slip-prone, rockfall-affected and avalanche-susceptible locations. The ToR also prescribes cross-section surveys at 25-metre intervals, reduced to 10 metres in areas characterised by sharp curves or rapidly varying geological and soil conditions
- For tunnel projects, geotechnical and subsurface investigations are required to be conducted in accordance with IRC: SP:91 and may only be undertaken by consultants with demonstrated experience in carrying out comparable geotechnical investigations, thereby strengthening technical due diligence requirements for underground infrastructure projects
- Collectively, these measures strengthen the technical standards governing DPR preparation for structure-intensive projects and complement the broader procurement reforms introduced by the MoRTH and NHAI. The reforms reinforce the use of specialised expertise, enhanced investigation and performance-based consultant assessment mechanisms in the development of bridges, tunnels and other geotechnically complex assets

Summary of the key changes and their implications

No.	Change	Description	Impact
1	Standalone procurement tracks for bridges and tunnels	Separate RFP category for standalone bridge and standalone tunnel projects, with fixed project cost and 60:40 (technical) modified QCBS evaluation instead of price-based bidding	Shifts competition from lowest price to highest technical merit, curbing underbidding-driven quality risk on high-risk structures
2	Category-specific eligibility and rating thresholds	Bridge/tunnel eligibility scored on aggregate DPR length of comparable structures (feasibility-study experience excluded); stricter current-rating bands for bridges (95-100 for full marks vs. 90-100 elsewhere)	Filters out consultants without direct, recent standalone bridge/tunnel delivery experience
3	Mandatory landslide/hilly-region technical protocol	Expert committee guidelines (November 2024) and IRC: SP:91 geotechnical standards embedded into binding TOR for hill-road and tunnel DPRs	Standardises tunnel alignment and hill-road safety design, reducing discretion in landslide-prone stretches

[48] *MoRTH Office Memorandum, dated 28.11.2024, circulating Report of Expert Committee on Cost-Effective Long-Term Remedial Measures for Landslide Prone Areas in Hilly Regions*



The road ahead

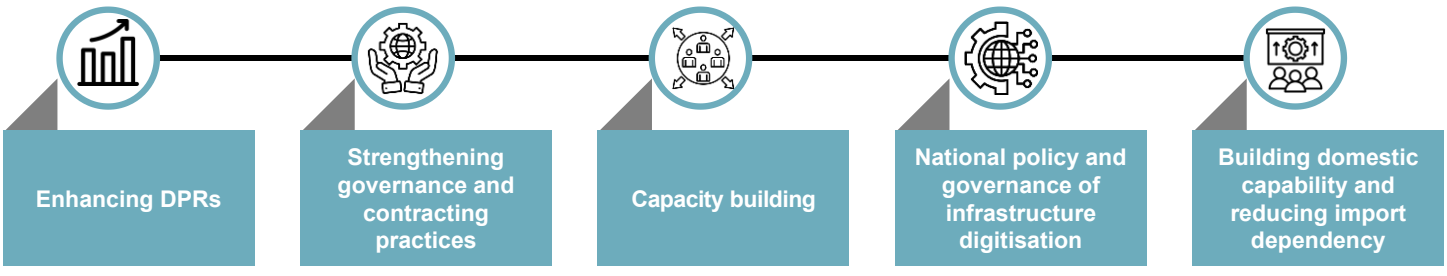
Outlook, challenges and areas for improvement

India's continued focus on infrastructure development, supported by large-scale investments in transportation and connectivity projects, presents significant opportunities for the bridge and tunnel construction sector. The expansion of highway networks, multimodal logistics corridors, high-speed rail systems and urban mobility projects is expected to drive sustained demand for advanced engineering solutions in the years ahead.

However, the sector continues to face several challenges that can impact project execution, cost efficiency and timely delivery. Land acquisition delays, funding constraints, environmental clearances, utility shifting requirements, and complex geological and geotechnical conditions remain key concerns, particularly for tunnel projects and structures located in environmentally sensitive or seismically active regions. In addition, increasing project complexity, supply-chain disruptions and the need for skilled technical resources require focused attention from all stakeholders.

Despite the use of new-age technologies and policy reforms undertaken, the sector continues to face systemic **challenges** as per feedback from stakeholders**:**

- **DPR quality and risk management:** While several policy interventions have been introduced to improve the quality and accountability of DPRs, ensuring consistent implementation and measurable improvements in project outcomes remains a key challenge. Inadequate site investigations, limited integration of geological and geotechnical data, and variations in consultant capabilities continue to result in design changes, scope revisions and unforeseen risks during construction. The effectiveness of recently introduced reforms will need to be demonstrated through improved project preparedness, reduced construction-stage surprises and better risk allocation



- **Governance and contracting practices:** Contracting frameworks for tunnels vary across central and state authorities, resulting in inconsistencies in risk allocation and dispute resolution. Additionally, bidder selection frameworks often prioritise financial capacity over technical competence and project-specific experience, affecting timely, on-budget and quality delivery
- **Skilled workforce:** The sector faces a shortage of engineers and contractors skilled in advanced construction techniques and use of digital engineering tools
- **Limited digital integration and adoption barriers:** While technologies such as DT, IoT-based predictive maintenance and AI-driven monitoring are available, their adoption remains lacklustre. Challenges include high upfront costs and limited skilled workforce for implementation
- **Equipment and resource self-reliance:** India's tunnel equipment market was valued at ~Rs 8,000 crore in fiscal 2024 and is projected to reach nearly Rs 11,000 crore by fiscal 2030. Despite this growth, the country remains heavily dependent on imported tunnelling and mechanised construction equipment[49], TBMs and high-value critical components, particularly for large-diameter and technologically complex applications.[50] This increases project costs and exposes projects to global supply-chain disruptions. In one recent case, three TBMs tunnel boring machines critical to the MAHSR project became stuck at Chinese ports for over 10 months, significantly impacting the project schedule

Addressing the above challenges requires an integrated approach that combines technology adoption, domestic capability building, governance reform and skill development. **The following measures outline a structured path forward:**

1. **Enhancing DPRs**

- The recent introduction of DPR rating frameworks, revised consultant selection criteria and strengthened project preparation guidelines is a positive step towards improving the quality and accountability of infrastructure planning. However, the effectiveness of these reforms will need to be demonstrated through improved project preparedness, reduced construction-stage surprises and better risk allocation. Continuous monitoring of their implementation, supported by the dissemination of best practices across projects, will be critical to achieving the intended outcomes
- Going forward, greater emphasis on comprehensive site investigations, advanced geotechnical assessments, digital surveying technologies and independent technical reviews can enhance the reliability of DPRs and reduce execution-related uncertainties. In addition, strengthening institutional capacity, fostering knowledge sharing from completed projects, and establishing robust accountability mechanisms will help ensure project risks are identified, assessed and managed more effectively during the planning stage, ultimately leading to improved project delivery and asset performance
- Other infrastructure sectors can also adopt similar accountability-driven systems, creating uniform practices that raise quality across the board

2. **Strengthening governance and contracting practices**

- Standardising contract frameworks across central and state agencies can improve clarity in risk allocation, dispute resolution and project governance[51]
- Embedding sustainability and safety criteria (low-carbon materials, reuse of excavation material, tunnel safety systems) as mandatory evaluation and compliance parameters in contracts

[49] *https://www.livemint.com/opinion/online-views/tbm-indigenisation-make-in-india-china-supply-chains-infrastructure-tunnel-boring-machine-urban-himalayan-geopolitics/amp-11759312943956.html*
[50] *https://www.volza.com/p/hsn-code-84303120/import/*
[51] *https://foxmandal.in/News/nhai-revises-qualification-criteria-for-epc-projects/*

- Bidder evaluation frameworks should place greater emphasis on technical capability, project-specific experience, past performance and safety credentials, alongside financial capacity, to ensure the selection of qualified contractors for complex bridge and tunnel projects
- The adoption of structured and time-bound dispute resolution mechanisms can reduce project disruptions, enhance contractual certainty and strengthen stakeholder confidence, thereby supporting more efficient infrastructure delivery[52]

3. Capacity building

- Imparting specialised training and certification programmes for engineers, consultants, contractors and site personnel in areas such as digital engineering, BIM, advanced tunnelling techniques, asset management and sustainable construction practices can help build a future-ready workforce. Recent industry initiatives and training programmes indicate a growing focus on upskilling professionals to support digital transformation in infrastructure delivery

4. National policy and governance of infrastructure digitisation

- India would benefit from a comprehensive national policy framework for infrastructure digitisation, as current initiatives remain fragmented and are often driven by individual technologies, vendors or project-specific requirements, resulting in inconsistent ownership and implementation
- The state or asset owner must take responsibility for digital data, decision protocols, interoperability and long-term monitoring
- Systems such as Supervisory Control and Data Acquisition (SCADA), BIM, DTs, structural health monitoring and asset management should not remain isolated silos; they must be interoperable
- Policy should define minimum technology requirements, data ownership, cybersecurity requirements, contractual responsibility, scalability, modularity, skill development, decision-making protocols and life-cycle costing
- Centralised data repositories are recommended so that project data, drawings, geological records, inspection histories, sensor readings and maintenance records can support future projects, research and education
- Several speakers emphasised that data is a national asset and should be available to government agencies, researchers, Indian institutes of technology, engineering institutions and future project teams
- Government representatives said India has already begun digitisation in modules, including LiDAR-based surveys, digital data books, electronic tolling, automated inspection and digital contract management. However, integration across planning, construction and operation remains a major challenge

5. Growing TBM requirements and the need for domestic manufacturing

- The increasing scale and complexity of India's tunnelling programme is driving greater adoption of mechanised tunnelling and specialised construction equipment. Tunnel construction methodology is increasingly influenced by tunnel length, geological conditions, construction constraints and project economics. Cut-and-cover remains a commonly adopted approach for shorter underground sections of less than 1 km, while drill-and-blast and NATM are generally relevant for tunnel stretches averaging ~2 km and 3 km, respectively. For longer tunnel drives of ~5 km and above, TBMs are increasingly being deployed, particularly where continuous mechanised excavation can support productivity and construction predictability. These length ranges are indicative, and the selection of the actual methodology depends on project-specific conditions.
- With the expansion of India's tunnelling pipeline, the requirement for TBMs is expected to exceed 200 units over the next two decades. Meeting this requirement will require adequate availability of

[52] *https://library.nhai.org/Circulars*

specialised equipment, supporting infrastructure and technical expertise. At present, India remains dependent on international OEMs for advanced TBM technology and equipment, with companies such as Herrenknecht, Robbins, Terratec and CRCHI forming a part of the global supplier ecosystem. Such dependence can expose projects to longer procurement lead times and supply-chain disruptions. A recent instance involved three TBMs critical to the Mumbai–Ahmedabad high-speed rail project that were reportedly held at Chinese ports for more than 10 months, affecting the project schedule[53][54]

- Therefore, the strengthening of domestic manufacturing and localisation of tunnelling equipment can therefore play an important role in supporting India's growing infrastructure requirements. Greater domestic capability can improve equipment availability, reduce exposure to international supply-chain disruptions and support the development of local expertise in manufacturing, operation and maintenance of specialised tunnelling equipment. Technology partnerships and localisation of critical components can further contribute to the development of a broader domestic tunnelling-equipment ecosystem.
- The government's scheme for enhancement of construction and infrastructure equipment (CIE) provides an important policy opportunity in this direction. With a proposed overall outlay of Rs 14,300 crore over seven years, the scheme includes tunnel-boring equipment used in metro projects and high-altitude road construction. The initiative is expected to support the development of domestic manufacturing and technology capabilities across the construction and infrastructure equipment ecosystem.[55][56]
- A combination of domestic manufacturing, technology partnerships, skilled manpower and reliable after-sales support will be important to meet the growing demand for TBMs. Building a resilient equipment ecosystem can help reduce import dependence, improve project readiness and strengthen India's capability to deliver its expanding portfolio of complex tunnelling projects.
- Promoting industry–academia collaboration to advance research on terrain-specific and cost-effective tunnelling technologies

India's vision for next-generation bridge and tunnel infrastructure requires a balanced focus on technology, localisation, governance, sustainability and skills. Strengthening domestic manufacturing capabilities, improving project planning and contracting frameworks, and developing a highly skilled workforce will be essential to delivering infrastructure that is efficient, resilient and environmentally responsible.

With these foundations in place, India will be well-positioned to meet rising infrastructure needs while reducing external dependencies and enhancing project performance. Such an approach will ensure the country's bridges and tunnels not only support economic development but also meet global benchmarks for quality, safety and sustainability.

[53] *https://www.thehindubusinessline.com/companies/tunnel-boring-machine-maker-herrenknecht-to-expand-chennai-operations-with-new-plant/article70127766.ece*
[54] *https://www.indiabudget.gov.in/doc/budget_speech.pdf*
[55] *https://www.pib.gov.in/PressReleaseDetail.aspx?PRID=2238257&reg=6&lang=1*
[56] *https://www.pib.gov.in/PressReleasePage.aspx?PRID=2281288&reg=48&lang=2*

Case studies

Modern projects (international and domestic)

Several recent infrastructure projects demonstrate how digital engineering and sustainability-linked funding frameworks can improve project viability, transparency and long-term performance.

Central Tunnel of the Central Kowloon Route, Hong Kong

The Central Tunnel of the Central Kowloon Route (Route 6) is a strategic urban road infrastructure project in Hong Kong, developed to enhance east-west connectivity across the Kowloon Peninsula and alleviate severe traffic congestion in one of the city's busiest districts. The 4.7 km route includes a 3.9 km dual three-lane underground tunnel, providing a high-capacity transport corridor that significantly improves travel efficiency while reducing surface traffic impacts.



The project was executed in a highly complex urban environment, with tunnelling works passing through seven geological fault zones and beneath existing metro lines, major roads, healthcare facilities and other sensitive infrastructure. The successful delivery of the tunnel demonstrates best practices in urban underground construction, risk management and sustainable transportation infrastructure development.

Mumbai-Pune Expressway Missing Link, India

The Mumbai-Pune Expressway Missing Link is one of India's most complex highway engineering projects. Commissioned to address congestion and safety concerns on the ghat section between Khopoli and Khandala, the project comprises two major tunnels (1.75 km and 8.92 km), two large viaducts, including a 650 m cable-stayed bridge, and widening of the existing expressway. The project reduces the length of the ghat section to 13.3 km from 19 km, shortening the overall Mumbai-Pune journey by approximately 6 km and reducing travel time by 20-25 minutes.

Advanced digital surveying, geological investigations, BIM-enabled design coordination, drone-based construction monitoring and structural monitoring systems were employed to manage construction through the challenging Western Ghats terrain. These technologies helped improve project planning, construction safety and risk management while supporting efficient delivery of a technically challenging asset.



Annexure 1: References

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Time and cost overruns—tunnels

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Time and cost overruns—bridges

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Annexure 2: Key circulars issued by NHAI/MoRTH in recent years

S no	Circular	Date of issuance	Subject
1	RW/NH - 24036/27/2010- PPP	February 4, 2019	Clarifications with respect to provision of boundary wall and toe wall to be constructed along NH projects
2	NHAI/Bharatmala/EC/DPR/2016/143430	October 30, 2019	Policy for development of highways under Bharatmala Pariyojana
3	RW/NH- 29023/02/2019-S&R(P&B)	January 1, 2020	Guidelines for providing the type of median on NH network and guidelines for metal crash barriers (semi-rigid) to be installed on highways
4	8.3.36/2020	July 10, 2020	Guidelines for determination of cost of change of scope/reduction in scope/withdrawal and alteration of works in DBFOT projects
5	RW/NH/Tunnel zone/01 /2020-21	February 4, 2021	Constitution of an expert committee on tunnels by MoRTH
6	NHAI/Policy Guidelines/Management of Toll Plaza/2021	May 24, 2021	Policy circular number 17.5.82
7	RW/NH-33044/10/2021-S&R(P&B)	March 15, 2023	Reuse of materials reclaimed from pavement layers
8	NHAI/Policy Guidelines/Standard Documents/2023	October 10, 2023	Advanced traffic management system
9	IHMCL/Manual Transactions/FASTag/123819/269	May 25, 2024	Two-stage validation of manual FASTag transactions
10	RW/NH-33044/22/2020-S&R	June 4, 2024	Width of shoulder (paved and earthen) for NHs
11	NH- 12037/8/2024 / Tunnel/Misc/ North-I	September 6, 2024	Constitution of a panel of experts for tunnel projects
12	12.36/2024	December 12, 2024	Strengthening of incident management services (amendment to Circular 12.19, dated March 20, 2018)
13	RT-25035/07/2023-RS	December 24, 2024	Guidelines for provision of signages on expressways and NHs
14	RW/BNG/GENL/ROADSAFTY/112/2021	July 4, 2025	Inspection and maintenance of bridges/structures falling on NHs and expressways
15	NH-12037/3/2025/Tunnel/Zone-1	September 2, 2025	Standard operating procedure for NH tunnel alignment studies and approval
16	Policy Guidelines/O&M/2025/Policy Circular 9.4.31/2025	September 25, 2025	Maintenance manual of NHAI projects
17	NHAI/Policy Guidelines/Standard Documents/2026	June 20,2026	Policy circular number 11.95/2026
18	NHAI/Policy Guidelines/ Standard Documents/2026	August 07,2026	Policy circular number 11.102/2026—checklist for submission of proposals for long tunnel projects (length: 1.5 km)

Notes

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