Underwater ROVs in Dam & Tunnel Inspection: How Robotics is Transforming Hydropower Infrastructure Safety

Executive Summary

Dams, tunnels, and hydropower infrastructure represent some of the world's most critical and highest-risk civil assets. Yet for decades, the inspection of their submerged components headrace tunnels, pressure shafts, and penstocks has relied on costly dewatering operations or high-risk diver deployments. EyeROV's underwater robotics technology offers a safer, faster, and more data-rich alternative.

Over time, these hydraulic structures are subjected to high water pressures, sedimentation, corrosion, and geotechnical stresses, all of which can compromise their structural integrity and hydraulic efficiency. As these assets age, comprehensive condition assessments become essential for planning effective maintenance and rehabilitation strategies.

Remotely Operated Vehicles (ROVs) have emerged as a transformative solution for the inspection of submerged tunnel sections without the need for dewatering or diver intervention. Equipped with high-definition cameras, imaging sonars, and non-destructive testing sensors, ROVs can navigate confined spaces that are inaccessible to humans. These systems enable detailed visual and sonar-based assessments, reducing inspection time, cost, and operational risk.

By delivering high-resolution imagery and accurate mapping of defects such as cracks, voids, seepage zones, sediment buildup, and corrosion, ROV-based inspections significantly enhance diagnostic precision. The result: infrastructure owners gain actionable condition data without shutting down operations reducing inspection costs, eliminating dewatering downtime, and extending the operational life of critical hydropower assets.

Introduction

Dams and tunnels are critical infrastructures that support irrigation, flood control, and hydropower generation. Regular monitoring of these assets is essential to prevent potentially catastrophic failures. For hydropower plants to function efficiently and sustainably, submerged tunnel systems such as pressure shafts, penstocks, and headrace tunnels play a vital role in conveying large volumes of water from reservoirs to turbines.

The design, construction, and maintenance of these hydraulic structures directly influence their longevity, safety, and performance. Over time, prolonged exposure to high water pressures, sedimentation, corrosion, and geotechnical or environmental stresses can degrade their structural integrity, hydraulic efficiency, and

safety margins. Therefore, a comprehensive condition assessment is crucial for planning effective maintenance and rehabilitation strategies for aging assets.

Remotely Operated Vehicles (ROVs) provide an innovative solution for inspecting submerged tunnel sections without the need for dewatering or diver intervention. Their ability to access confined and hazardous environments allows for detailed visual and sonar-based assessments using high-definition cameras and advanced imaging sonars. By deploying ROVs, inspection time and costs are significantly reduced while improving data accuracy and minimizing operational risks. Equipped with high-resolution imaging, sonar mapping, and non-destructive testing instruments, ROVs enable the detection of defects such as cracks, voids, seepage paths, silt accumulation, and corrosion. As a result, ROV technology has become an indispensable tool in ensuring the safety, reliability, and extended service life of aging hydraulic tunnel infrastructure. EyeROV has been at the forefront of this transition in India and across international markets, deploying purpose-built underwater robotic systems for hydropower, dam safety, and critical infrastructure inspection missions.

Fig 1: EyeROV's Tunnel Specialist ROV - engineered for deep, narrow, and flooded tunnel environments without dewatering

Methodology & Results

Advanced, purpose-built Remotely Operated Vehicles (ROVs) are capable of efficiently navigating and operating within tunnels for extended range up to 10 kilometers without interruption. The tether system enables seamless data transmission between the ROV and the surface control station, where all collected information is processed, synchronized, and formatted for analysis.

When integrated with advanced payloads such as Imaging Sonar, ROVs can effectively navigate and acquire acoustic data even in low-visibility or turbid water conditions. Profiling sonar, another key payload, assists in generating accurate tunnel cross-sections and profiles. The fusion of data from multiple sensors enables a comprehensive assessment of tunnel conditions, enhancing the precision of inspection outcomes.

High-definition cameras mounted on the ROV capture detailed visuals of the tunnel interior, providing a clear view of structural conditions. Additional payloads such as Laser Scalers allow for precise defect measurement, enabling quantification of cracks, cavities, or material loss. In hydraulic tunnels, ROV inspections are increasingly used to monitor sedimentation in real time, particularly in submerged or inaccessible zones. Using sonar and visual data, the ROV maps sediment accumulation along tunnel walls and invert, enabling accurate spatial referencing for long-term sediment management and targeted de-silting operations.

Fig 2: High-definition footage captured inside a hydropower tunnel — enabling real-time visual assessment of cracks, sedimentation, and structural anomalies

By integrating profiling sonar data with existing tunnel geometry, the volume of deposited silt can be calculated, supporting condition-based maintenance and optimizing operational planning while minimizing downtime and safety risks. During inspections, high-resolution sonar or laser scanners generate tunnel cross-sections at regular intervals typically every meter referenced to chainage from the inlet or a defined datum point. These 2D profiles illustrate tunnel geometry and sediment distribution, while superimposing them on original design cross-sections highlights changes caused by silt deposition.
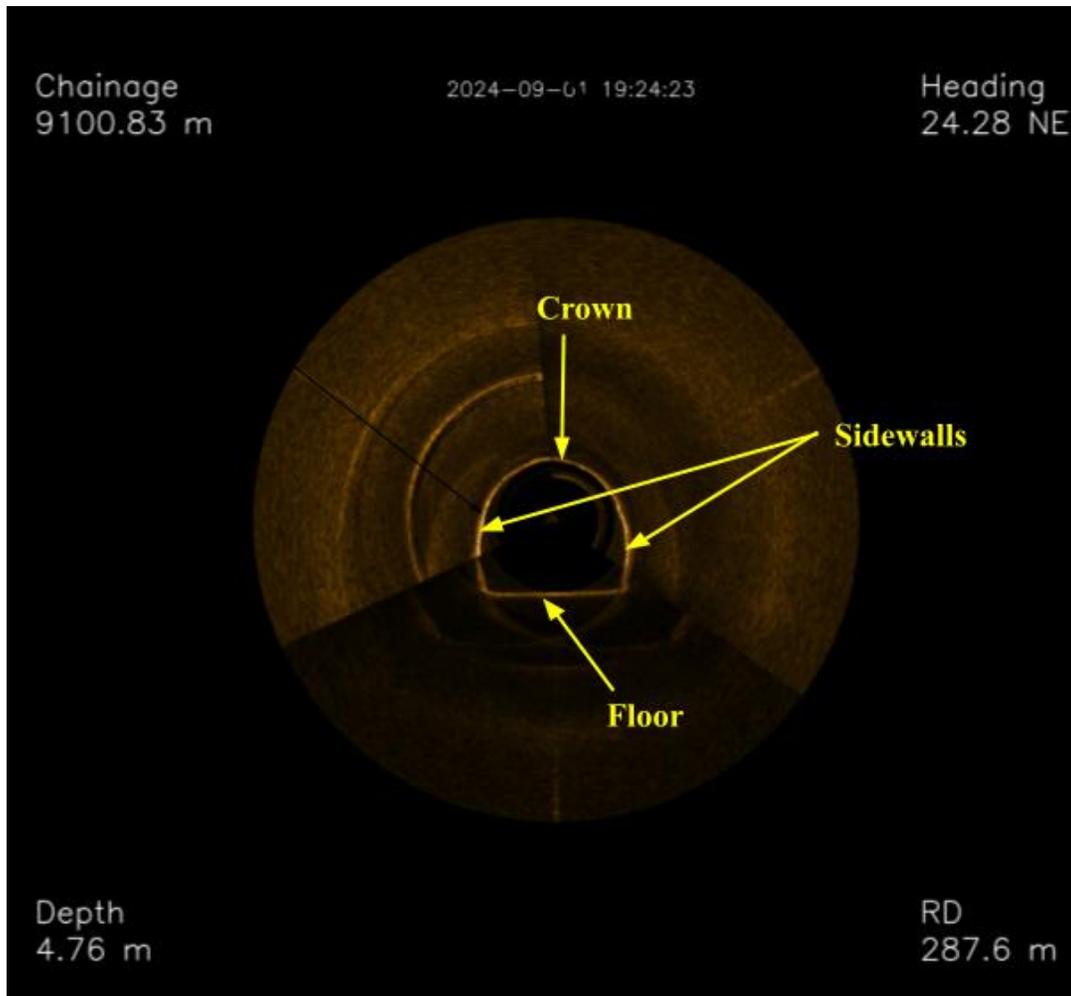
Fig 3: 2D cross-sectional profile generated by profiling sonar, showing tunnel geometry and sediment distribution mapped against the original design baseline

Profiling sonar data can also be utilized to create precise 3D models of submerged tunnels, offering a detailed visualization of internal geometry and sedimentation patterns. As the ROV traverses the tunnel, 2D cross-sectional slices recorded at regular intervals are georeferenced and merged to form a continuous 3D point cloud model. This modeling technique is invaluable for maintenance planning, trend comparison, and the development of digital twins for long-term tunnel health monitoring.

The inspection report generated from this data includes high-quality images, measurements of identified defects, and detailed documentation of all critical observations. Analytical reports can be delivered through cloud-based platforms or storage media, supplemented by hard copy documentation. Additionally, an interactive software-based report can be produced using EyeROV's proprietary EVAP (EyeROV

Visualization Analytics Platform), offering intuitive data visualization, fault mapping, and comprehensive assessment summaries.
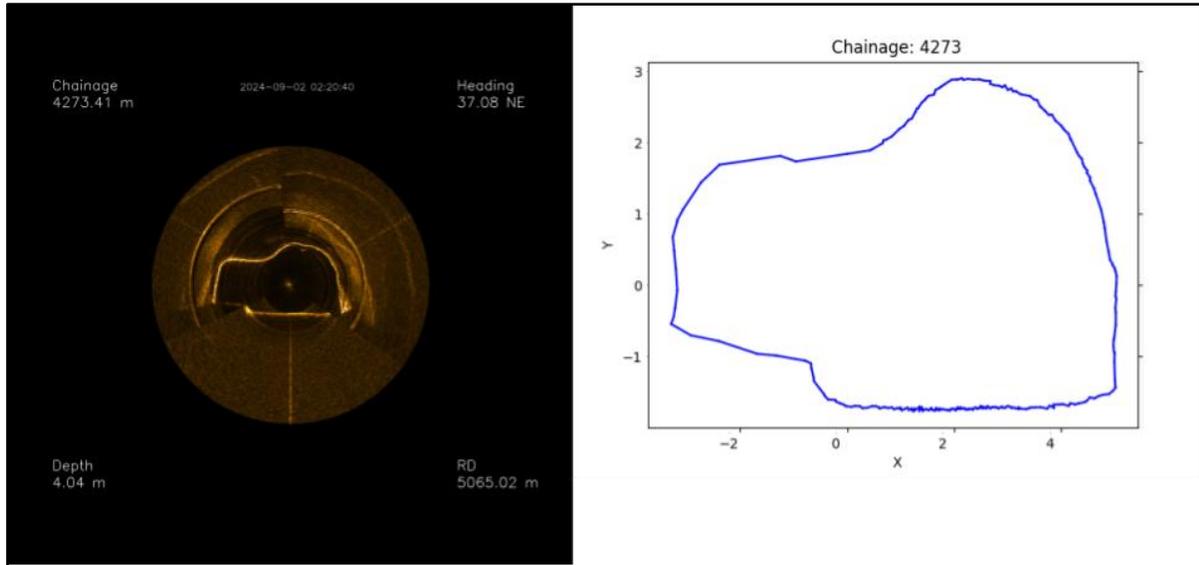
Fig 4: Imaging sonar output and point cloud data - enabling accurate defect mapping and 3D reconstruction of submerged tunnel geometry
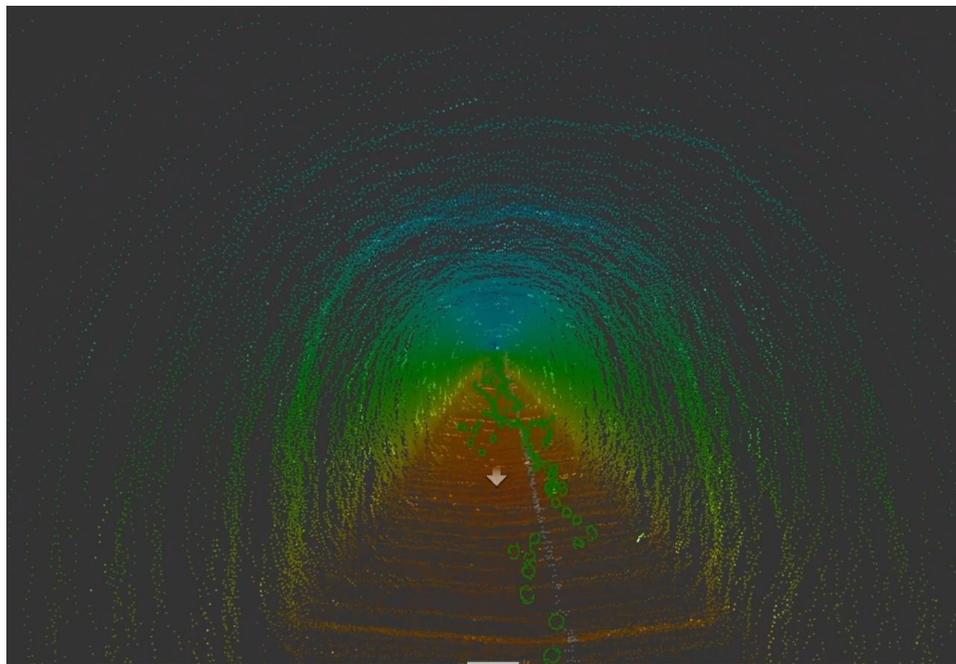

Fig 5: Full 3D point cloud model of a submerged tunnel, constructed from georeferenced sonar cross-sections - supporting digital twin development and long-term condition trending
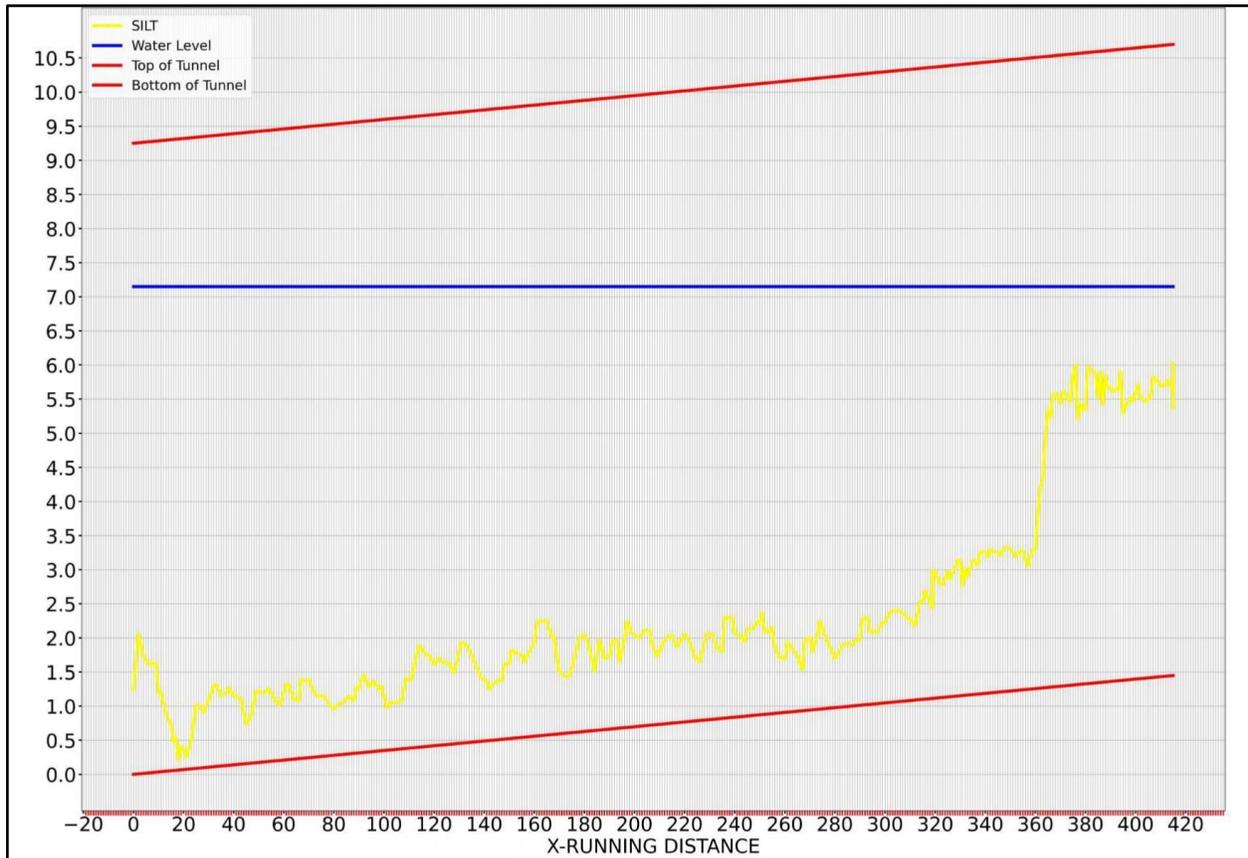
Fig 6: Siltation analysis graph showing sediment volume accumulation along tunnel chainage — used to prioritise de-silting operations and track deposition trends over time

Conclusion

The adoption of Remotely Operated Vehicles (ROVs) represents a transformative advancement in the inspection of tunnels within hydropower and other critical infrastructure sectors. These robotic systems offer a non-intrusive, efficient, and safe alternative to conventional inspection methods, particularly in flooded or confined environments where human access is hazardous or impractical. By enabling high-resolution visual assessments, sonar mapping, and real-time data acquisition, ROVs enhance the accuracy of condition evaluations and support timely, data-driven maintenance decisions that extend the operational life of tunnel systems.

As hydropower assets continue to age and the global demand for reliable energy grows, ROV-based inspections will play an increasingly vital role in infrastructure management. Continuous advancements in sensor technologies, artificial intelligence–based defect detection, and autonomous navigation are expected to further improve the precision and efficiency of these inspections. Ultimately, the integration of ROV technology not only enhances the safety and effectiveness of tunnel assessments but also contributes significantly to the long-term sustainability, resilience, and reliability of critical infrastructure systems.

About EyeROV

EyeROV is India's leading underwater robotics company, delivering Remotely Operated Vehicles (ROVs) and Unmanned Surface Vehicles (USVs) for critical inspection missions. Trusted by the Indian Navy, Coast Guard, and global oil & gas companies, EyeROV's systems operate at depths up to 400m and have been deployed across India, the GCC, and Southeast Asia. Products include the TUNA and TROUT ROV series, the iBoat Alpha USV, and the EVAP data analytics platform.

To learn more about EyeROV's underwater inspection solutions for dams, hydropower tunnels, and critical infrastructure, visit **www.eyerov.com** or write to **sales@eyerov.com**.