

RESEARCH ARTICLE

HERITAGE AND INFRASTRUCTURE: THE CHURIYAMAI TUNNEL MAINTENANCE EXPERIENCE IN NEPAL

Sahadev Bahadur Bhandari and Krishna Kanta Panthi

^a Kathmandu Terai Madhesh Fast Track (Expressway) Road Project^b Norwegian University of Science and Technology (NTNU), Norway.*Corresponding Author Email: sbbhandari@ioe.edu.np

This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 17 September 2025
Revised 20 October 2025
Accepted 23 November 2025
Available online 31 December 2025

ABSTRACT

The Churiyamai Tunnel that was constructed in 1917 near Hetauda is the first highway tunnel in Nepal. Therefore, this tunnel holds significant historical and infrastructural importance. Over the time, the tunnel suffered structural degradation issues, including partial collapses, developed cracks in linings, material deterioration, and water leakage in various sections. This manuscript describes the ratification work carried at this tunnel with an aim to emphasize the historical and cultural significance. In addition, the manuscript evaluates construction techniques used during its original development, identifies the causes behind the structural anomalies in the tunnel and presents the countermeasures applied to restore the functionality. The maintenance work was conducted between 2021 and 2022 where combination of modern and traditional technologies was utilized to strengthen the structural deficiencies while preserving the tunnel as a heritage structure. The study involved investigating the anomalies inside the tunnel and documenting the restoration techniques applied. It was envisaged through investigations that the tunnel suffered with development of cracks, material degradation, and water leakage. The applied countermeasures successfully restored the functionality of Churiyamai Tunnel and maintained status as a heritage site.

KEYWORDS

Grouting; Heritage; Rock bolt; Shotcrete; Tunnel Maintenance

1. INTRODUCTION

Integrated heritage and infrastructure preservations are vital for balancing cultural legacy with modern development. Such preservations safeguard cultural identity, support economic growth through tourism, and promote sustainability of historical structures. In addition, heritage preservation enriches education, enhances community well-being, and demonstrates resilience, offering insights for durable modern designs. Legal and ethical obligations of a society further emphasize the importance of preservations and ensure heritage and progress coexist harmoniously while fostering sustainable development. Such preservation strategies should include thorough documentation, innovative and adaptive designs, stakeholder collaboration, and the use of modern technological tools.

The Churiyamai Tunnel, which was built in 1917, is the first highway tunnel in Nepal and among the earliest in the Asia. This tunnel played a vital role in reducing travel time between Bhimpheedi of Makawanpur District of Nepal and the border town Raxaul of Bihar, India (Poudel, 2021). The 500 m long, 2.7 m wide and 3 m high tunnel was originally designed by the team led by Colonel Dilli Jang Thapa during the rule of Rana Prime Minister Chandra Shumsher Rana. Initially, the tunnel construction was intended to drive horse-drawn carriages, which later was also used to drive through motor vehicles. The tunnel was in use until the beginning of 1960s. The Churiyamai tunnel remains a historic engineering landmark for Nepal regarding transport infrastructure advancement. Even though not in use for the transportation vehicles, the tunnel was accessible until the great earthquake of April 2015, which partially damaged the tunnel. Geologically, the tunnel lies in the foothills

of the Siwalik mountains of the Himalaya. The tunnel passes through conglomerate and upper Siwalik sandstone rocks. Due to presence of porous, fragile and low degree cemented rock mass the construction of this tunnel was not that difficult but posed challenges associated to the long-term stability. Originally, the tunnel was lined with wooden logs, but in 1980s the tunnel was reinforced with RCC pillars, beams and application of shotcrete. There remained some structural issues since cracks were developed in some locations and few collapses. Since the tunnel is a pathway to the Churiyamai Temple located near to its southern portal, which attracts pilgrims during Nepal's Dashain festival, preservation is crucial for both heritage and societal perspectives. Therefore, the Transport Infrastructure Directorate of Bagmati Provincial Government gave preference for the maintenance of this tunnel.

It is emphasized here that the tunnel maintenance depends on specific topographic and geological factors and requires rigorous inspections to identify level of degradation and damage caused by long-term leaching of groundwater that causes accelerated weathering to the support structures and earthquake effect. Hence, effective maintenance must address "visually distinguishable" anomalies such as cracks and lining dislocation and "visually indistinguishable" issues such as structural cavities that often require non-destructive testing. This article highlights about the strategy adopted for the maintenance of Churiyamai Tunnel so that the dual roles of this tunnel (heritage structure and infrastructure asset) is intact. The manuscript further outlines strategies adopted to address structural damages like cracks, water ingress, and overall tunnel stability so that preservation of cultural value and originality of the structure are protected. Balancing heritage conservation with modern reinforcements is essential to safeguard this landmark transportation legacy of Nepal.

Quick Response Code



Access this article online

Website:
www.gwk.com.my

DOI:
10.26480/gwk.01.2025.23.30

2. LITERATURE REVIEW

Tunnels differ significantly from above-ground structures, and their design conditions vary on a case-by-case basis (Lee et al., 2008). As a result, the deformation mechanisms of tunnels are complex compared to those of structures like bridges. Over the years of operation, existing tunnels may develop pathologies due to aging, weathering, or, in some instances construction defects stemming from improper techniques or challenging engineering geological and hydrogeological conditions (Sandrone et al., 2007). For example, a fiberscope inspection of the Mohale Tunnel in Lesotho revealed a loss of grout or pea gravel behind the lining, which significantly compromised structural integrity and necessitated remedial grouting work as part of maintenance efforts (Molapo and Lees, 2021). The Connaught Tunnel in the UK, which was built in 1878 using the cut-and-cover method, has suffered from lining delamination, corrosion of embedded ironwork, local spalling, loose debris, and persistent water ingress, all contributing to its structural deterioration over time (Wilde, 2019).

The common defects of aged tunnels include:

- Concrete structures: cracking, spalling, delamination, and leakage.
- Steel structures: corrosion, cracks, buckling, and protective layer failure.
- Masonry structures: damage to masonry units, mortar degradation, and leakage.
- Timber structures: decay, insect damage, and leakage (Balaguer et al., 2014).

Several researchers have proposed various methods for tunnel maintenance. A group researcher proposed Umbrella Arch Methods/Fore-pole methods for tunnel construction and maintenance in loose soil (Rostami et al., 2016). The umbrella arch approach is preferred for tunneling in soft rocks or overburden soil because of being quicker and less expensive than other pre-support techniques such as ground freezing, jet grouted columns, or pipe jacking (Gangwar et al., 2024). The traditional method of tunneling adopts strong and heavy structures to bear external loads, so damage is likely to occur if local stress exceeds material strength (Chiu et al., 2016). The tunnel lining based on the New Austrian Tunneling Methods (NATM) principles is implemented with a double-shell tunnels consisting of a primary lining (temporary) and a secondary (final) lining. The primary lining, usually composed of shotcrete, which facilitates the partial release of rock mass pressure and stabilizes the excavation so that a needed time is available for the secondary lining (Mohyla et al., 2020). The tunnel engineer should assess the service states and lifecycle of all structural components of the tunnel and should choose methods and intervention levels that balance performance and optimum maintenance cost (Yao et al., 2009). The in-situ stress state must be estimated to design the layout or support pattern of underground openings, thereby reducing the risk of rock-mass instability in and around these openings. Currently, four primary methods are employed in the study of tunnel stability and failure mechanisms: numerical simulation, field measurement, theoretical investigation, and model testing (Gao et al., 2025). A group researcher used numerical modelling method to estimate the regional stress state by considering topography, rock-mass heterogeneity, and tectonic stress near the facility, ensuring an accurate understanding of the regional stress state (Aoyagi et al., 2024; Panthi and Basnet, 2019). A group researcher utilized geogrids as reinforcing elements to enhance the poor tensile strength of soft soils, thereby increasing bearing capacity, improving stability, and reducing settlement (Faleigh et al., 2024).

Preserving historic transport infrastructure, like bridges, tunnels, and railways, requires balancing operational standards with historical significance (Salah et al., 2024). Key challenges include maintaining structural integrity, complying with modern regulations, optimizing costs while preserving authenticity, gaining public support, and addressing limited availability of traditional materials and techniques. Collaboration among historians, engineers, architects, and planners is essential to protect both the physical structure and its cultural value. The ongoing need to refurbish existing heritage tunnels presents a significant opportunity to rejuvenate these structures, addressing not only their structural integrity but also integrating sustainable practices into their restoration (De Feudis et al., 2024).

It is emphasized here that the Nepal Himalaya, located between the Indian and Eurasian tectonic plates, experiences compressional tectonic movements that have caused the rock mass highly folded, faulted, sheared, fractured, and deeply weathered. As a result, tunnels in this region often

face significant stability challenges, including squeezing, bursting, and tunnel collapses, which are associated with the presence of faults, fracture zones and very young geological formations having very weak and fragile rocks such as Siwalik mountains (Panthi, 2004; Piya et al., 2023).

3. MATERIALS AND METHODS

3.1 Project location and Site Condition

The Churiyamai Tunnel is situated within the Churiya Mai Formation of the Upper Siwalik region. Geologically, the area is characterized by young sedimentary formations, which play a critical role in understanding the subsurface conditions in the tunnel. The infiltration tests were conducted to assess the permeability conditions so that a proper construction and maintenance strategies were adopted. Figure 1 shows the location map of the Churiyamai Tunnel.

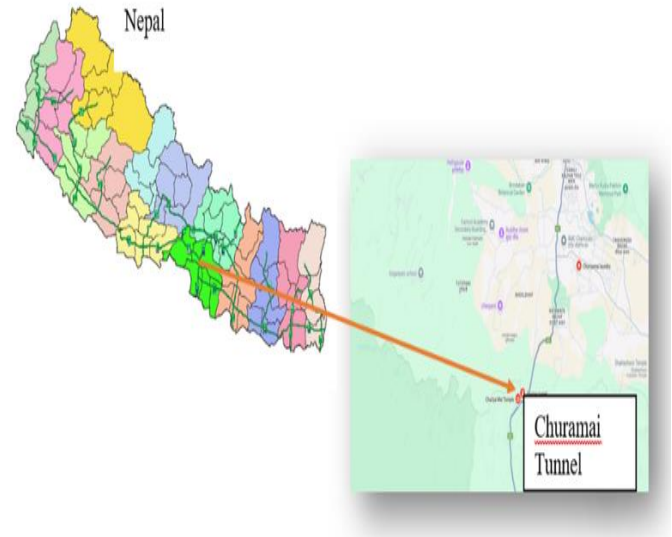


Figure 1: Location Map of Churiyamai Tunnel

3.2 Data Collection

Given the lack of documentation regarding the construction and maintenance of the Churiyamai Tunnel, historical data was sourced through discussions with senior citizens who had insights into the history of the project. To establish a robust geotechnical understanding of the construction medium and its surrounding environment (IRC:SP:91-2010, 2010), a field study was conducted by a multidisciplinary team comprising Geotechnical Engineers, Tunnel Experts, Engineering Geologists, Road Engineers, Tunnel Engineers, Geomatic Engineers, and Surveyors. The study aimed to guide for the rectification of the Churiyamai Tunnel and involved the following key activities:

- Detailed Topographical Survey: Conducted for the proposed project area.
- Existing Tunnel Survey: Performed at 1-meter intervals to capture comprehensive details.
- Geological Mapping: Completed at a 1:25,000 scale for the project area.
- Geological Investigation and Laboratory Testing: Included in-situ tests, shear tests, and remolding tests.
- Rectification Design: Developed for the tunnel and its associated facilities.

3.3 Data Sources and Collection

The study utilized preliminary data from various secondary sources, including topographic maps, Google Earth imagery, hydrological data, and regional geological maps, along with findings from past studies. Primary data collection followed established methodologies widely accepted in the field, including:

- Topographical Surveys

- Geological Studies
- Geophysical Surveys
- Geotechnical Surveys

3.4 Laboratory Testing

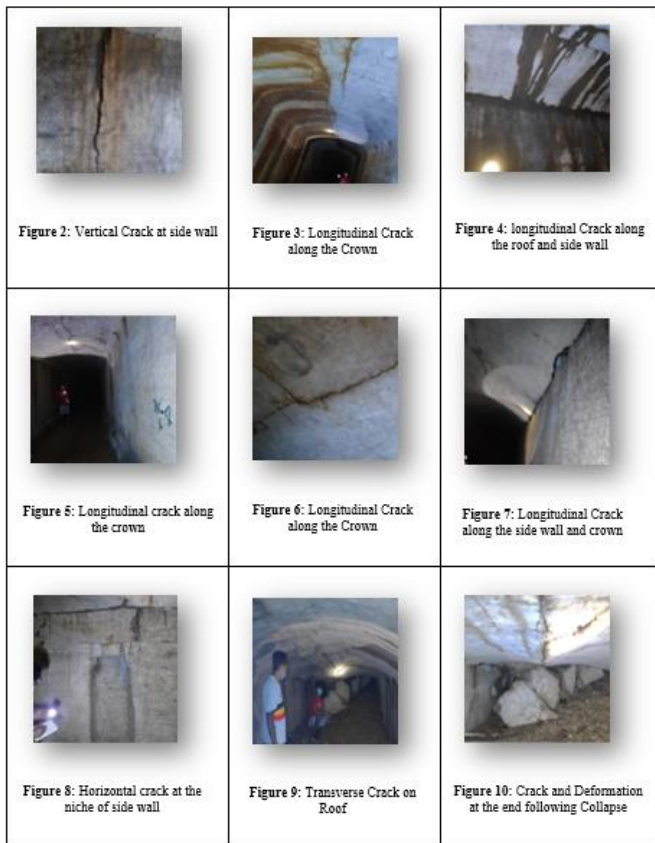
Laboratory tests were performed to evaluate soil and material properties, adhering to standard protocols:

- Engineering Soil Classification: As per the Unified Soil Classification System (USCS).
- Infiltration Tests: Conducted in accordance with ASTM D3385-09.
- Grain Size Analysis: Executed following ASTM C136-06.
- Atterberg Limits Tests: Conducted as per ASTM D4318-05.

The comprehensive and systematic approach provided critical insights and needed data, serving as a foundation for the tunnel rectification design and construction effort.

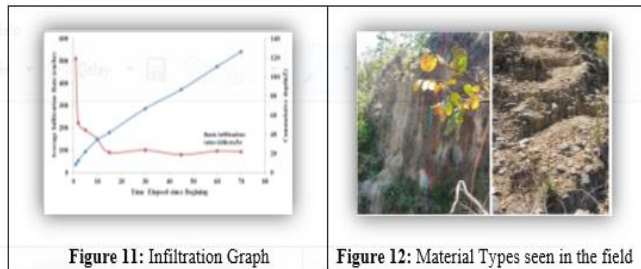
3.5 Documentation and Condition Analysis

The condition of the Churiyamai Tunnel was evaluated through detailed field observations. The features at the portal area near the Churiya Mai Temple and along the tunnel where the other end was buried during the construction of modern east-west highway and possibilities for preserving the northeast section of the tunnel were studied. It is noted here that significant portions of the tunnel were found in a collapsed condition leaving only a 198-meter section intact and accessible. Visual documentation of the general condition of tunnel is given below in Figure 2-10.



The observation, evaluation and overall condition findings are highlighted as:

Condition of shotcrete: The structural integrity of the shotcrete was found to be weathered and weak exhibiting low strength. Soil Characteristics: The soil and rock material in the area primarily consists of gravelly sand and weakly cemented conglomerate. The infiltration tests have indicated varying infiltration rates of 112 cm/hr and 108 cm/hr, respectively. The infiltration graph of the overburden material and the material types at the site are given in Figure 11 and Figure 12.



Grain Size Distribution and Strength: Analysis of the grain size distribution curve revealed two distinct soil layers, i.e. poorly graded gravel (GP) and thin layer of silty sand (SM). The friction angles of poorly graded gravel (GP) and silty sand (SM) was found to be 37.45 and 30.94 degrees, respectively.

The findings provide critical insights into the challenges associated with maintaining and preserving the Churiyamai Tunnel, including its structural integrity and drainage capacity.

3.6 Data Analysis and Evaluation

The geological and geotechnical studies of the tunnel alignment indicated that the tunnel was excavated through gravelly soil and weakly cemented conglomerate. The gravelly soil is composed of different sequences of clasts and matrices. The common variation was observed in vertical sequence beside that the lateral variation within a sequence was conceivable. The geotechnical tests at the field and laboratory of the gravelly soil were congregated and are given in Table 1, which gave basic guidance for the tunnel rectification.

Table 1: Parameters Used to Understand Ground Characteristics						
Sample no	Unit weight (γ)(kN/m ³)	Friction angle (φ)(°)	Cohesion ©(kPa)	Bearing value (kPa)	Young's Modulus (Mpa)	Hydraulic conductivity (m/sec)
A1	19.5	37	16	250	15	4.6x10 ⁻⁶
A2	20	31	18	400	18	3x10 ⁻⁴

Source: TID, Hetauda

4. USED RATIFICATION APPROACHES AND DISCUSSIONS

4.1 Challenges of Maintaining Historical Infrastructure

Maintaining historical infrastructure, such as tunnels and bridges, poses technical, cultural, and financial challenges. Aging materials, incomplete records, and prolonged use weaken structures, while modern safety standards often conflict with preservation goals. Restoration must balance modernization with historical integrity, adhering to strict legal protections. High costs arise from specialized materials, skilled labor, and conservation techniques. Projects like the Churiyamai Tunnel faced added difficulties, including undocumented construction, reliance on oral histories, and geological and geotectonic factors such as soil and rock mass conditions and seismic risks. By addressing these challenges through innovative diagnostic techniques and restoration strategies, the Churiyamai Tunnel project was upgraded in such a way that it provides a model for balancing preservation and functionality in historical infrastructure.

4.2 Diagnostic Methods and Assessment of the Tunnel's Condition

The study adopted a detailed case study approach, focusing on in-depth analysis to understand tunnel maintenance practices and challenges. This approach allowed for a comprehensive examination of real-time conditions, providing valuable insights and practical solutions. A thorough survey of the existing Churiyamai Tunnel, conducted at 1-meter intervals, alongside a topographical and engineering geological survey of the project area was found to be very helpful for the restoration work. Geological investigations and laboratory tests, including in-situ testing, shear testing, and remolding tests were further added the value of strengthened work.

The problems identified and the measures taken for the rectification of the tunnel are given in Table 2.

Table 2: The Problem Identified and measures taken in Churiamai Tunnel

Location	Problem	Measures taken
Beginning from south to 20m:	The overburden is very low, and the right-side wall cover is thin. At 8.8 m from beginning , a vertical crack on the right wall from the portal was observed. A 2.5m section with shotcrete was broken.	Dismantling of existing cement structure was done. 25 dia. 2.5 long Rock bolt @ 2m spacing, Grouting, Chipping, Wire mesh netting, and 20 cm thick fiber reinforced shotcrete were applied.
From 8.8m to 14.2m	A longitudinal crack along the crown was observed, continuing almost continuously.	
From 20m to 40m:	No prominent deformation was observed.	
From 40m to 60m:	No prominent deformation, minor but occasional longitudinal cracks along the crown were seen. The strength of support was very low and slightly separated from the ground, barely sustaining itself.	
From 60m to 80m:	A long longitudinal crack, with minor cracks from 60m to 63m , was observed. Muddy water leaked through the crack during the rainy season	Backfilling at the crown and support measures as mentioned above were applied.
From 61.5m to 80m:	The crown was separated from the wall, with varying degrees of separation. In some sections, the separation was prominent, while in others, it was minor. The longitudinal crack that separated the crown from the right wall was open, displacing the crown about 4 to 6 cm downward. This condition continues up to 75m, after which the crack disappears.	Dismantling of existing cement structure was done. 25 dia. 2.5 long Rock bolt, Grouting, Chipping, Wire mesh netting, and 30 cm thick fiber reinforced shotcrete were applied.
From 80m to 100m	No prominent damage and deformation was observed.	
From 100m to 120m	Longitudinal cracks were observed along the crown.	
From 120m to 140m:	Parallel longitudinal cracks in the crown were observed. The support at the tunnel crown was highly altered. No deformation was observed.	
From 140m to 160m:	Longitudinal and transverse cracks at the crown were observed. The cracks were seen prominent.	
From 160m to 170m:	The right-side crown was separated from the wall between 160m and 170m , with a prominent and open separation. The deformation of the crown was easily visible, displacing it about 8 to 12 cm downward. Similarly, near 167m , a crack on the right wall was observed. Transverse and longitudinal cracks were dominantly observed after from 167m . The support was weak and unstable.	
From 170 to 175m:	Both longitudinal and transverse cracks were observed between 170m and 175m . The cracks were prominent, but no deformation was observed.	Umbrella Arch Method was used with fore-polling, steel ribs, and 30 cm thick fiber reinforced shotcrete.
From 186m to 215m	Deformation in the tunnel intensified after 186 meters, with cracks and structural changes were seen more pronounced. This progression ultimately resulted in a tunnel collapse, characterized by a chimney-type failure, where debris from the tunnel roof accumulated at the invert.	
From 215m to 225m (northern portal)	Northern Portal has to be built.	

4.3 Tunnel Rectification Design

The rectification design for the tunnel was focused on preserving its originality and heritage value. General values were estimated from the data available and are presented in Table 3 to guide the rectification process.

Table 3: Parameters Used to Understand Ground Characteristics

Sample no.	Unit weight (γ)(kN/m ³)	Friction angle (ϕ)($^{\circ}$)	Cohesion (c)(kPa)	Bearing value (kPa)	Young's Modulus (MPa)	Hydraulic conductivity (m/sec)
A1	19.5	37	16	250	15	4.6×10^{-6}
A2	20	31	18	400	18	3×10^{-4}

For analytical evaluations, Vermeer's formula was applied. In addition, semi-empirical assessments were done using guidelines provided by the U.S. Department of Transportation. The used approaches ensured a comprehensive analysis for the rectification process. According to Franza & Marshall (2019), empirical and semi-analytical solutions may provide an efficient and reliable way of evaluating tunnelling related ground displacements and their characteristics.

Shape and volume of stressing ground was estimated based on ground span and failure angle of the soil. The failure angle (θ) was assumed to be $45^{\circ} - \phi/2$ in behavior mode-II and was increased to approximately 45° just before collapse occurs. This means, the failure angle became $45^{\circ} + \phi/2$ in behavior mode-III. The figure 13 below illustrates the relations of different modes of failure assumption.

The volume contributing to the stress on the upper part of the tunnel was

estimated using Equation 1.

$$V = \frac{\pi}{16} D \cdot \tan\theta \cdot RL^2 \tag{1}$$

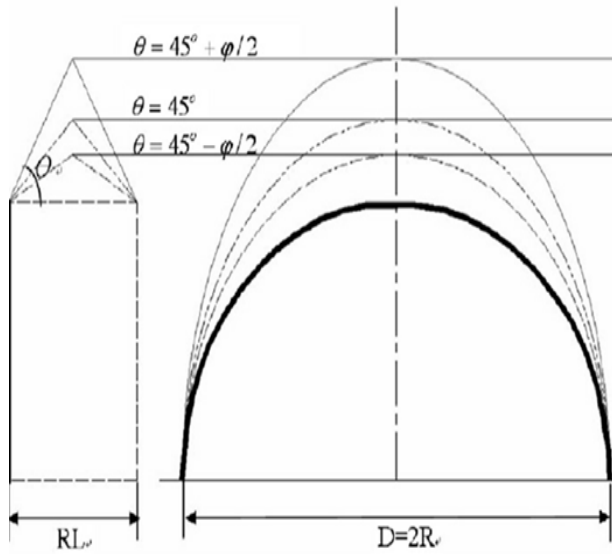


Figure 13: Estimating failure modes of the ground

Relative shear stress (RSS) is a parameter that can help to analyze the ground stress condition. Relative shear stress is the ratio between the maximum elastic stress and ground strength and can be considered as the reciprocal of the conventional safety factor at a specific location. Maximum relative shear stress (MRSS) was used for the analysis because it was found that the maximum relative shear stress has a relation to the behavior mode.

Estimation of the MRSS at the crown part with varying overburden stress was made. The safety factor was calculated by use of the concept of 'critical cohesion' using Equation 2.

$$FoS = \frac{c}{c_{critical}} \tag{2}$$

Where, C is cohesion of ground and Ccritical is the critical cohesion corresponding to the reference MRSS at the crown of the tunnel. The Critical critical cohesion was calculated using Equation 3.

$$C_{critical} = \frac{\sigma_1}{\cos\phi} \left[\frac{\alpha_2}{\alpha_1 \cot\phi + \beta_1} - \beta_2 \sin\phi \right] \tag{3}$$

where, $\sigma_1 = m\gamma(H + \frac{D}{4})$ which is maximum principal stress of the MRSS at a point of consideration.

$$m = 1.14, \alpha_1 = 0.009D + 0.522, \alpha_2 = 0.445 + 0.0045D, \beta_1 = 0.013D + 0.539, \beta_2 = 0.555 + 0.0045D$$

In some areas, tunnel overburden is relatively low. So, the settlement analysis was carried out to estimate the load calculation using Equation 4.

$$\delta_{mas} = V/2.5i \tag{4}$$

Where, $V = 3(\frac{Su}{E})e^{F-1}$ for $F > 1$; and, $F = (P_z - P_a)/S_u$, = air pressure above atmospheric on the tunnel face; P_z = overburden pressure; S_u = undrained shear strength; E = deformation modulus

The tunnel passes through relatively shallow overburden. Therefore, it was necessary to be aware of about the existence of any natural and anthropogenic activities of historic past. Similarly, the infiltrated water was responsible on reducing fine materials in the gravel composition. The change in fine matrix decreased the strength parameter of the gravel. Therefore, holding tunnel roof was an important task. In general, the gravel is a loose material so it can easily collapse and slide down to the tunnel so use of proper support was an important task. Table 4 shows the support work used to address the issues discussed above.

Table 4: Support used in the Tunnel				
Rock bolt	Rock bolting material	Grouting	Wire mesh	Shotcretes
25 mm diameter of 2.5 m length with 2 m spacing, 3 bolts in crown and 2 in walls	Resign capsules	Two component, high strength, chemical grouting	100 x 100 mm, 6mm thick wire diameter, welded wire mess	300 mm thick

Two-and-a-half-meter-long rock bolts were used for support, with a spacing of 2 meters. Three bolts were installed in the crown, and one bolt in each sidewall, as shown in Figure 14.

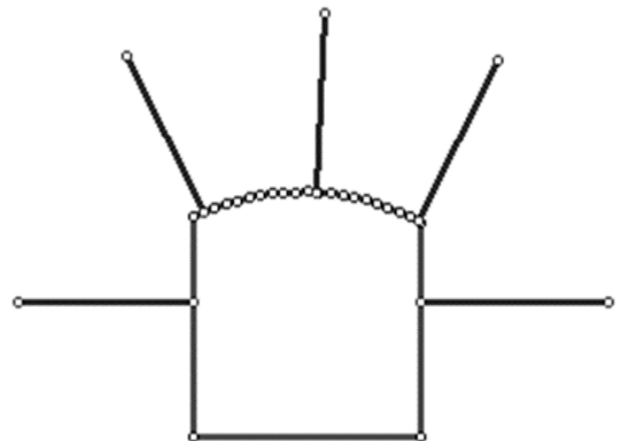


Figure 14: Rock Bolt Pattern

Resin capsules were used to cement the bolts. The initial setting time of the resin grout was 1.5 minutes immediately after mixing, and the final setting time was 2.3 minutes. The bonding strength was 60 MPa. Pre-polymeric grouting materials were used, which consisted of low-viscosity liquid mixtures capable of permeating through tiny pores. After mixing, the materials polymerized within 2-4 minutes to form a network molecular structure, effectively reinforcing the area. Approximately 15-18 liters of chemical grout were used in each hole. The wire mesh used had a 100 x 100 mm grid with a wire diameter of 6 mm. In addition, 200 to 300 mm thick fiber-reinforced shotcrete was applied in tunnel walls and crown. The properties of the grouting materials used are presented in Table 5.

Table 5: Properties of the Grouting Materials		
Component B	Component A	Physical Property
Physical Form	Liquid	Liquid
Odor	Strong	Pale
Density (kg/L)	1.30 - 1.40 at 25°C	1.1 - 1.30 at 25°C
Viscosity (mPas)	200 - 400 mPas at 25°C	200 - 400 mPas at 25°C
Solubility (Water)	Soluble	Insoluble
Solubility (Other)	Soluble in toluene, ethyl acetate or acetone	Soluble in toluene, ethyl acetate or acetone
Ratio	1	1
Flow Time (S)	60 - 600	60 - 600
Foam Expansion (Times)	1	1
Reaction Time (Minute)	12 to 18	
Compressive Strength	≥ 30 MPa in normal confining pressure	

The Specification of the support materials used in the maintenance of the tunnels are given in Table 6.

Table 6: Specification of Support Materials		
Material	Properties	Standard
Shotcrete concrete	Specified compressive strength after 28 days concrete grade M25, characteristic compressive strength $f_{ck} = 25 \text{ N/mm}^2$ Young's modulus: $E = 7500 \text{ MPa}$ Poisson's ratio: $\nu = 0.2$ Unit weight: $\gamma = 24 \text{ kN/m}^3$	IS 456:2000
Wire mesh	Grade: Fe 500D or Fe 500S Mesh width: 150 x 150 mm Bar diameter – 6 mm Minimum yield strength: $f_y = 500.0 \text{ N/mm}^2$	IS 1786:2008
Rock bolts	Grade Fe 500D or Fe 500S Yield strength: $f_y = 500 \text{ N/mm}^2$ bolt diameter: 25mm Minimum yield load: 200 kN	IS 1786 – 2008
Grouting material	Two component close cell pre-polymer grout specification should be of given table 6.	
Resin capsule	Final setting time should be of 2.5 min, after mixing UCS should be around 60MPa. 32mm dia and 10 to 15m length capsule will be used.	

The working sequence in the maintenance of tunnel from 0 (southern Portal) to 175 m is given in Figure 15.

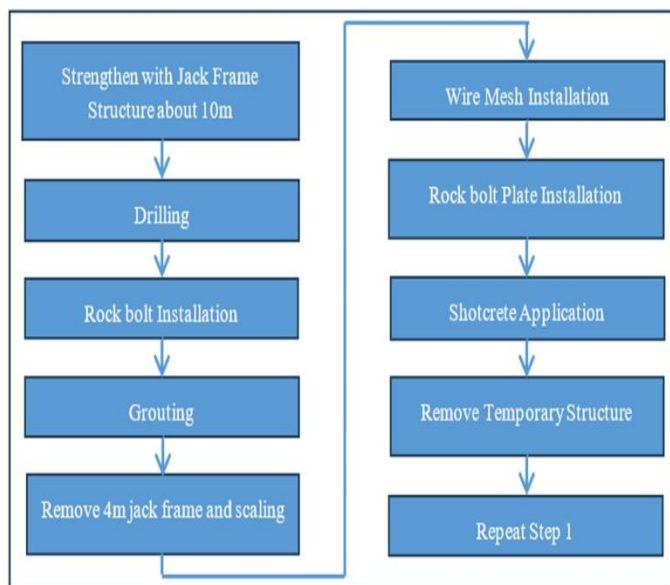
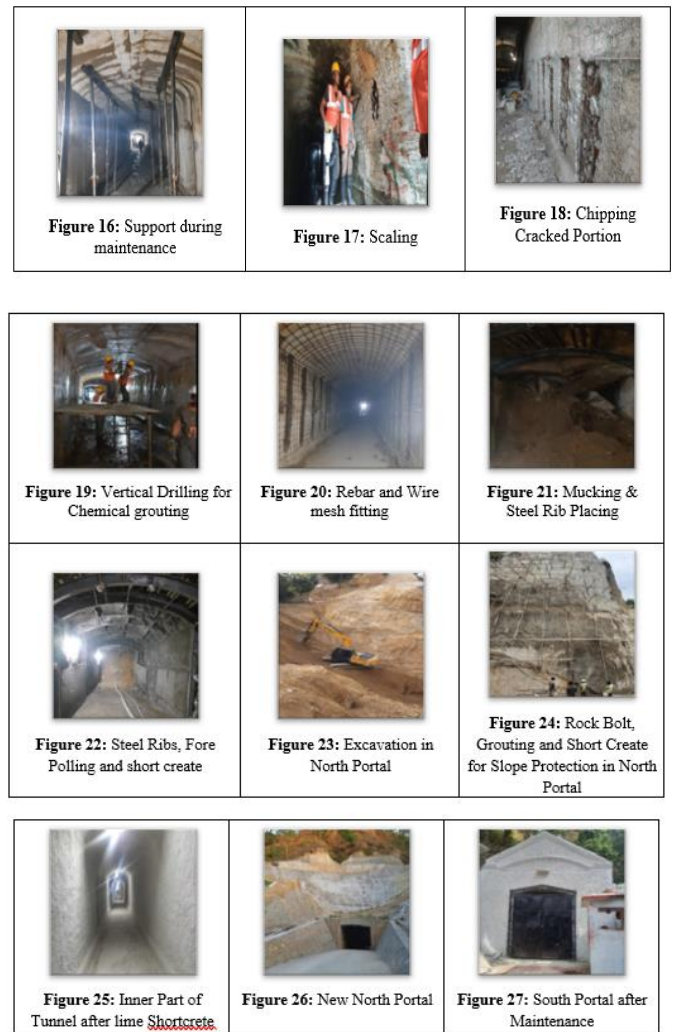


Figure 15: Working Sequence of the Tunnel Maintenance

Various stages of the tunnel maintenance process were used to ensure its structural integrity and functionality are shown below in Figures 16-27.



4.4 Outcomes and Broader Implications for Heritage and Infrastructure

The results of the Churiyamai Tunnel maintenance project have helped to the broader understand on the process to be used in preserving heritage while maintaining infrastructure functionality. The main conclusions of the ratification work are outlined as below:

- The damaged sections of the tunnel, including the northern portal and the crown, were successfully rehabilitated using advanced engineering techniques such as use Umbrella Arch, cut and cover methods and use of fiber reinforced shotcrete. The application of modern materials (e.g., resin capsules and chemical grouting) ensured long-term stability while mitigating risks associated with shallow overburden and water infiltration.
- The design incorporated materials like lime shotcrete on the outer surface to replicate the original appearance so that it was possible to preserve original historical value of this tunnel.
- Efforts to align modern modifications with the tunnel's traditional aesthetic reflect a commitment to cultural heritage preservation.
- The integration of support systems, including rock bolts, wire mesh, and shotcrete, enhanced the structural resilience of the tunnel against environmental and anthropogenic stressors. Water infiltration was mitigated to reduce long-term risks to both the structure and its surroundings.
- The detailed diagnostic approach used in the tunnel, including geological surveys and failure mode analysis, provided valuable insights for future restoration efforts of similar historical infrastructures.
- The project offers a replicable framework for diagnosing, analyzing, and addressing challenges in similar historical tunnels.
- Methods such as Vermeer's formula and settlement analysis can be

adapted to assess other infrastructure with complex ground conditions.

- The balance achieved between modern engineering practices and heritage conservation can serve as a benchmark for similar projects globally.
- The use of compatible materials and techniques demonstrated on how functionality and authenticity can coexist.
- The project aligns with SDG 9 (Industry, Innovation, and Infrastructure) by upgrading aging infrastructure to ensure reliability and sustainability.
- Additionally, it contributes to SDG 11 (Sustainable Cities and Communities) by preserving cultural heritage for future generations.
- Maintenance of such historical structures can boost local tourism and cultural pride, creating economic opportunities. The preservation of cultural landmarks reinforces community identity and history, enhancing societal resilience.
- Mitigating water infiltration and reducing material loss in gravel soil contributes to the environmental stability of the surrounding area. The project demonstrates the importance of integrating environmental impact studies into heritage conservation.

The Churiyamai Tunnel maintenance project underscores the possibility of harmonizing engineering innovation with cultural preservation. By addressing technical, aesthetic, and environmental challenges, it sets a precedent for similar heritage infrastructure projects. It highlights the necessity of interdisciplinary approaches, bringing together engineering, geology, architecture, and heritage management for sustainable development.

5. CONCLUSION AND RECOMMENDATION

This study underscores the historical and engineering importance of Nepal's first motorable Churiyamai Tunnel, emphasizing the necessity of integrating advanced geotechnical methods with heritage preservation strategies. Various tunnel maintenance techniques are highlighted, including the Umbrella Arch method for severely damaged soft soil tunnels and other solutions like rock bolting, chemical and cement grouting, and shotcrete for partial damages. Lime shotcrete is recommended for maintaining the tunnel's heritage value.

Future projects should adopt diagnostic methodologies and material-specific maintenance strategies, especially in seismically active regions with soft soil conditions. Detailed documentation and studies are essential for guiding long-term maintenance efforts. The Churiyamai Tunnel can function both as an archeological site and a transportation route, with local authority management ensuring its historical significance and operational utility. This balanced approach integrates conservation techniques with community involvement to preserve the tunnel's legacy.

ACKNOWLEDGMENT

The author acknowledges the Transport Infrastructure Directorate, Hetauda, Nepal, the client, for providing photos and data; Mountain Infra Pvt. Ltd., Kathmandu, the main contractor, for their project management; and Radiant Consulting Consortium Pvt. Ltd., Lalitpur, Nepal, for conducting structural condition surveys. Special thanks go to Er. Hari Prasad Ojha and Er. Bijaya KC for their supervision.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Aoyagi, K., Sugawara, K., Kamemura, K., and Nago, M. 2024. Estimation of stress state using measured tunnel convergence in loop galleries excavated in mudstone. *International Journal of Rock Mechanics and Mining Sciences*, 178(May), 105776. <https://doi.org/10.1016/j.ijrmms.2024.105776>

Balaguer, C., Montero, R., G. Victores, J., Martínez, S., & Jardón, A. 2014. Towards fully automated tunnel inspection: A survey and future trends. 31st International Symposium on Automation and Robotics in Construction and Mining, ISARC 2014 - Proceedings, 19–33. <https://doi.org/10.22260/isarc2014/0005>

Chiu, Y. C., Wang, T. T., & Huang, T. H. 2016. State-of-the-art of the tunnel maintenance in Taiwan and challenges to sustainable development. *Geotechnical Engineering*, 47(2), 7–13. <https://www.researchgate.net/publication/304890989>

De Feudis, S., Insana, A., & Barla, M. 2024. Seizing the opportunity of energy retrofitting of existing tunnels. *Tunnelling and Underground Space Technology*, 154(September), 106109. <https://doi.org/10.1016/j.tust.2024.106109>

Faleih, Z. H., Al-Gharbawi, A. S. A., & Baqir, H. H. 2024. The Behavior of the Tunnel Reinforced with Geogrid in Soft Soil Under the Effect of Axial Load. *Civil Engineering Journal (Iran)*, 10(8), 2471–2484. <https://doi.org/10.28991/CEJ-2024-010-08-04>

Franza, A., & Marshall, A. M. 2019. Empirical and semi-analytical methods for evaluating tunnelling-induced ground movements in sands. *Tunnelling and Underground Space Technology*, 88(June), 47–62. <https://doi.org/10.1016/j.tust.2019.02.016>

Gangwar, A., Handa, S., Kumar, J., Singh, M., & Dwivedi, R. D. 2024. A Case Study of Tunnel Stability in Quaternary Deposits Using Pipe-Roof Supports. *Indian Geotechnical Journal*, February. <https://doi.org/10.1007/s40098-024-00892-y>

Gao, D., Shen, Y., Zhou, P., Gou, A., Chang, M., Dong, J., & Wu, K. 2025. Failure mechanism of deep-buried and large cross-section subway station tunnel: Geo-mechanical model test and numerical investigation. *Tunnelling and Underground Space Technology*, 155(P1), 106148. <https://doi.org/10.1016/j.tust.2024.106148>

IRC:SP:91-2010. 2010. Guidelines for road tunnels, 2010. <https://law.resource.org/pub/in/bis/irc/irc.gov.in.sp.091.2010.pdf>

Lee, C.-H., Wang, T.-T., Han, C., & Tien, T. 2008. Rock Tunnel Maintenance in Taiwan. 6th Asian Young Geotechnical Engineers Conf. Dept. of Civil Engineering, Indian Institute of Science, Bangalore, India., December 2008, 205–217. <https://www.researchgate.net/publication/308048607>

Mohyla, M., Vojtasik, K., Hrubesova, E., Stolarik, M., Nedoma, J., & Pinka, M. 2020. Approach for optimisation of tunnel lining design. *Applied Sciences (Switzerland)*, 10(19). <https://doi.org/10.3390/APP10196705>

Molapo, R., & Lees, D. 2021. Lesotho Highlands Water Project-Mohale Tunnel-Maintenance Inspection and Review. Australasian Tunnelling Conference, Melbourne. <https://www.researchgate.net/publication/353443879>

Panthi, K. K. & Basnet, C. B. 2019. Evaluation of earthquake impact on magnitude of the minimum principal stress along a shotcrete lined pressure tunnel in Nepal. *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 11, pp. 920-934. <https://doi.org/10.1016/j.jrmge.2019.06.003>

Panthi, K. K. 2004. Tunnelling challenges in Nepal. Proceedings of Norwegian Tunnelling Conference, 25–26. <https://www.researchgate.net/publication/261614229>

Piyya, B., Panthi, K. K., & Neupane, N. R. 2023. Stability assessment for proposed Hemja-Patichaur road tunnel using empirical and analytical methods, western Nepal. *Journal of Nepal Geological Society*, 65(August), 49–56. <https://doi.org/10.3126/jngs.v65i01.57746>

Poudel, K. P. (n.d.). Statue of Late Dilli Jung Thapa Cause For Recognition. Spotlight VOL. 14 No. 15, April 02, 2021 (Chaitra 20, 2077). <https://www.spotlightnepal.com/2021/04/04/statue-late-dilli-jung-thapa-cause-recognition/>

Rostami, A., Dehkordi, P. K., Ziarati, M. A., Jahani, S., & Lotfi, K. 2016. The Types of Tunnels Maintenance in Umbrella Arch Method. *Open Journal of Civil Engineering*, 06(02), 156–162.

Salah, R., Szép, J., Ajtayné Károlyfi, K., & Géczy, N. 2024. An Investigation of Historic Transportation Infrastructure Preservation and Improvement through Historic Building Information Modeling.

Infrastructures, 9(7).

of the Institution of Civil Engineers - Engineering History and Heritage, 172(2), 46–56. <https://doi.org/10.1680/jenhh.18.00028>

Sandrone, F. L., Labiouse, V., & Mathier, J. F. 2007. Data collection for Swiss road tunnels maintenance. In *Geomechanik und Tunnelbau* (Vol. 25, Issue 1, pp. 8–14).

Yao, X., Yuan, Y., Weng, Q., & Zhao, Q. 2009. Service-state monitoring system field test for tunnel preventive maintenance. *Proceedings of the 2nd International Conference on Transportation Engineering, ICTE 2009*, 55–62. [https://doi.org/10.1061/41039\(345\)10](https://doi.org/10.1061/41039(345)10)

Wilde, D. 2019. Connaught Tunnel, UK: Condition and repairs. *Proceedings*

