Tunnel Construction Practices for Infrastructure Development in Nepal: A Survey-Based Review

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ABSTRACT

Tunnel construction plays a pivotal role in Nepal's infrastructure development. This survey-based paper presents a comprehensive review of tunneling practices in Nepal, focusing on historical milestones, current practices, challenges, and opportunities for sustainable development. Through a thorough examination of various aspects of tunneling like utility purpose, tunnel shapes and sizes, support system practices, geological challenges, instrumentation and monitoring, health and safety practices, and environmental impacts, this study offers valuable insights into the present state of tunnel construction in Nepal. The survey findings reveal diverse practices and highlight the importance of adopting sustainable approaches to address environmental concerns, ensure worker safety, and optimize construction methods. By emphasizing the need for collaboration, technological advancement, and continuous monitoring, this paper aims to offers valuable insights and guidance for policymakers, engineers, working professionals and stakeholders in promoting and navigating path towards sustainable tunnel construction practices for the socio-economic development of Nepal.

Keywords: Tunneling; Current Practices; Challenges; Safety

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1 Introduction

As a growing country, Nepal must hasten the development of essential amenities for the economic prosperity of its people. This is attainable through utilizing its major water resources, building short and efficient routes over the rugged mountain topography, extracting ore from mines, and offering cost-effective storage solutions. All of these critical facilities cannot be built until tunnels and underground caverns are built in Nepal (Panthi, 2002). To address the growing requirements of commercial and social activities in developing nations like Nepal, a large number of tunnels have been being developed to shorten physical distances and increase transportation efficiency. According to the Nepal Tunneling Conference 2017, 218 km of tunnel have been excavated in Nepal, mostly for drinking water, irrigation, mining, and road construction which proves that the tunneling has been an important part for infrastructure development in Nepal.

Thus, the construction of tunnels has made amazing strides in recent years that have transformed how infrastructure is created and incorporated into contemporary civilizations. Tunnels have become essential parts of transportation, water management, and energy distribution networks as governments try to overcome geographic obstacles and improve connection. This research article dives into the background of Nepal, a nation known for its difficult geography and the necessity for a strong infrastructure to sustain its socioeconomic development. This review intends to throw light on how Nepal might take advantage of these developments to promote sustainable development and satisfy its particular infrastructure requirements by analyzing the most recent tunnel construction methods and technology. A thorough investigation of these techniques gives priceless insights for decision-makers, engineers, and those interested in advancing Nepal's infrastructure development into the future, from cutting-edge tunneling techniques to new geological analyses.

2 Historical Overview of Nepalese Tunnel Projects

Nepal being a mountainous country and rich in surface water resources, the scope and importance of tunneling projects were earlier understood several decades ago in the sector of hydropower, irrigation and transportation. The history of Nepalese Tunnel construction project dated back to 1917 AD with the construction of Churia Tunnel which is also considered to be the first tunnel of south Asia. A 500m long Churia Tunnel is one of the earliest and oldest road tunnel projects which was constructed as a means of transport connecting Amlekhgunj and Hetauda under the design and construction supervision of Nepal's first civil engineer graduate Dilli Jung Thapa. At present, Churia tunnel is not in use and is preserved as a site of historical importance.

In recent years, modern tunneling projects in Nepal have reached an outstanding milestone through hydropower Tunnel development with ever increasing national and global clean energy demand. In the history of Nepal, modern tunneling and underground excavation started with the development of 2642m long tunnel waterways and a semi underground powerhouse for the Tinau hydropower plant commissioned in 1978 AD. The Tinau hydropower plant is thought to be important for training Nepali technicians and engineers in many fields such as tunneling and hydropower construction. Since then, approximately 110 small, medium to large scale hydropower plants have already been developed and currently operational generating approximately 1696 MW of electricity to cater the national demand. Only from the currently operational hydropower projects with a capacity greater than 10 MW, about 105 kilometers of headrace tunnel waterways have been constructed, excluding those added from projects generating less than 10 MW. Moreover, about 232 hydropower projects were under construction throughout Nepal aiming to produce approximately 8434 MW of electricity. Upon completion of planned and under construction Hydropower projects they will certainly add more than 850 km of headrace tunnel waterways (Panthi, 2006). The scope of tunneling and underground excavation for mining is very limited and still remains untapped in the context of Nepal except for a few small-scale local tunneling for coal mining purposes.

3 Tunneling practices in Nepal.

The current state of tunneling activities over Nepal was investigated by an online poll administered through a google form with well-structured questions. The study employed comprehensive sampling to cover a sample size of 55 geologists and tunnel engineers who are actively working or had worked within a two-year period on tunnel projects around the country. This allowed the study's findings to be broadly applicable. A period of 15 days, from February 5 to February 20, 2024, was designated for conducting the survey.

A detailed analysis was done on the survey data. This research used descriptive methodologies in its investigation. The self-completion questionnaire approach was employed to generate all of the data, which also included obtaining relevant information from published and unpublished studies and publications regarding Nepali tunneling methods.

3.1 Demographic profile and general information of respondents

There were 55 total respondents in this study. Among them 92.7% of those included were men and 7.3% of the interviewees were women. In order to facilitate analysis, the data was divided into the following groups: 20–25 years, 25–30 years, 30-35 years, 40–45 years, 45–50 years, and over 50 years. These categories were based only on Engineering Geologists, Geologists and Tunnel engineers engaged in tunnels. It was found that 76.4% of the respondents in the total samples are in the 25–30 age range. Likewise, 12.7% of those surveyed falls within the 30 -35-year-old age range. Additionally, 3.6% of respondents are in the 35–40 age group, while 1.8% of respondents are in the other age categories. The results also showed that the bulk of the subjects (90.9%) were master's degree holders, while the remaining 9.1% were bachelor's degree holders. Additionally, 65.5% of all responders had a background in engineering geology. Similarly, only 7.3% of surveyed one belong to tunnel engineers, compared to 27.3% of geologists. Furthermore, among those people engaging in Tunneling projects, only 27.3% individuals are employed with international developers while remaining 72.7% belong to the National companies in Nepal. On the Contractor side, the bulk of the populace (54.5%) is involved. Comparably, the Consultant team and client team comprises 21.8% and 20% respectively, while only 3.6% of individuals are on the subcontractor side.

The sample was carried out with thorough consideration and comprehension. Accordingly, 41.8% of the respondents fall into the category of those with between two - four years of experience working on tunneling projects. Rationale: Of

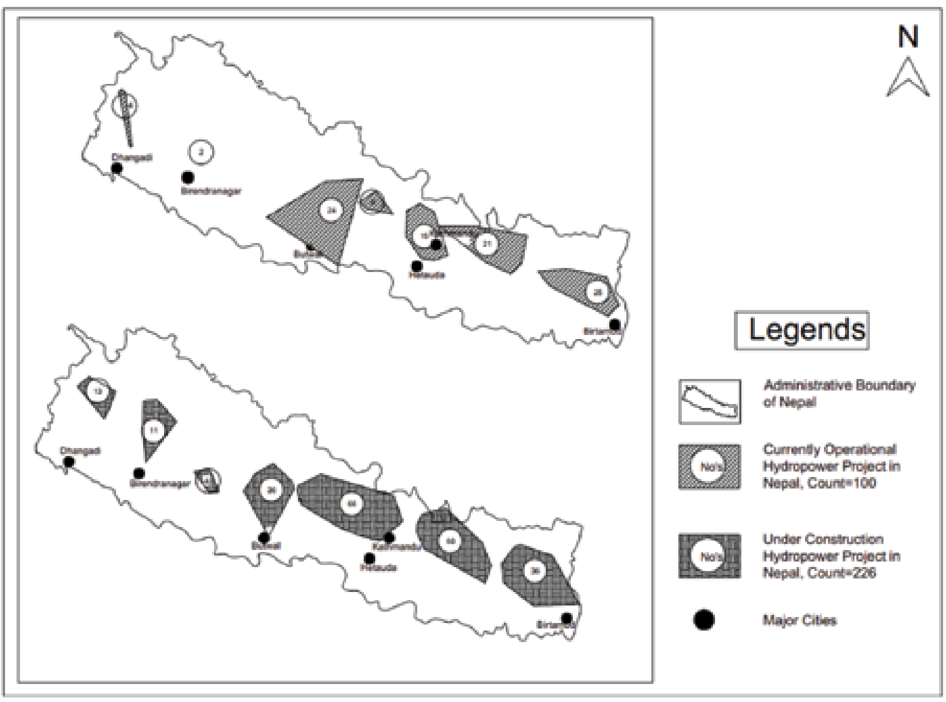


Figure 1: Current tunneling practices in hydropower sector

those surveyed, 27.3% had 1-2 years of experience. People with four -six years' experience make up 16.4% of the total. Subsequently, 7.3% of respondents reported having more than ten years of experience, 5.5% reported having less than one year of experience, and the remainder respondents had six - eight years of experience. The project in which the greatest number of people were involved was the hydroelectric tunnel. It was made up of 74.45% of those who were employed. Roadways make up the second-most projects, involving 21.8% of all involvement. With only 3.6% of participants, the drinking water and multipurpose project was the least active in Nepal.

3.2 Shape and size of tunneling in Nepal.

In Nepal, numerous rocks tunneling techniques have been used over the years, and these techniques have recently undergone some technological breakthroughs. Depending on the type of soil or hard rock and purpose of utility, different methods are used for the appropriate selection of shape, size and methods of tunneling. Hard rock is regarded as a totally self-supporting soil that doesn't need much support aside from the sporadic encounter with loose rock. On the other hand, soft soils like running grounds (such as sands that hold water) need for immediate support everywhere (Dhakal, 2021).

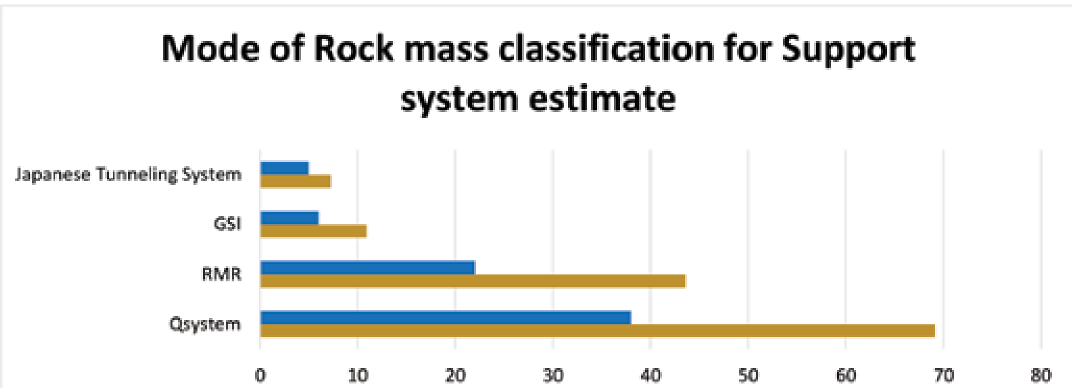
According to the survey, Inverted-D shaped tunnel projects make up the bulk of tunnel developments in Nepal which stands at 59.2%. At around 35.2%, the Horseshoe-shaped Tunnel comes in second place. Similarly, 1.9% of tunnels have an arc with straight sides, whereas 3.7% of tunnels are circular. Furthermore, it is clear that around 38.2% of Nepal's tunnels had a diameter of less than 4 meters, and 30.9% had a diameter between 4 - 6 meters. 12.7% of tunnels had a diameter more than 12 meters, compared to 14.5% of tunnels with a diameter of 10–12 meters. For 6 to 8 and 8 to 10 meters, the tunnel exhibits 7.3% and 5.5%, respectively. In Nepal, the tunnel is also heavily excavated using the drilling and blasting methods (96.4%). In certain locations, mechanical excavation is also practiced. Meanwhile, manual excavation is exceedingly rare, and TBM has only been used in one or two tunnels in Nepal.

3.3 Support system practices in tunneling of Nepal

Rock support that is appropriate for every site cannot be provided by general design principles based on rock mass classification methods. In order to accommodate the site-specific ground characteristics, such as the local rock mass and geological hazards various adjustments are therefore required (Sunuwar, 2007). In comparison to other sections, tunneling through fault zones is analyzed by frequently changing rock mass, groundwater conditions, and displacements.

It is always possible for below-ground construction or tunneling to provide unexpected engineering challenges due to the complex geology of the surrounding area. Due to the alteration in the tension condition of the ground in situ, earth movements toward the interior are caused by excavation actions on the ground during tunnel construction. Because of this, ground support is crucial while building of a tunnel. Some of them rely on keeping these forces contained by a physical barrier, while others aim to change the terrain's tensile-deformation and resistive properties (Monroy, 2021). That is why, certain support systems are assembled in the tunnel face, sidewall, and crown excavations. Common support elements include things like girders, reinforced sprayed concrete, rock bolts, etc. Using methods like pipe umbrella, fore poling, earth wedge, etc., loose ground and weak rock can also be stabilized in the rounds (Toma and Jodl, 2006).

According to the survey, the rock mass classification for support estimation was performed on the basis of different approach, i) empirical and ii) numerical, in different places, projects in Nepal. The majority of respondents, constituting 69.1%, voted in favor of using the Q-System for rock mass



	Qsystem	RMR	GSI	Japanese Tunneling System
No. of Respondents	38	22	6	5
% of respondents	69.1	43.6	10.9	7.2

Figure 2: Mode of Rock mass classification for Support system estimate

classification in support system estimation. This indicates a significant preference for this method among the surveyed individuals. While not the majority, a substantial portion of the 43.6% respondents favored RMR as their preferred method in their projects. A smaller but notable percentage, 10.9%, voted in favor of using the Geological Strength Index (GSI) for rock mass classification and 7.2% favored the use of Japanese Tunneling classification for support system.

During the tunnel project, a pattern of support system is always provided. In Nepal, a majority, constituting 54.5% of respondents, advocated for the immediate and strict implementation of both primary and secondary support measures (such as rock bolts, shotcrete, ribs, wire mesh, prefabricated support, and shields) before commencing the next tunnel cycle. This approach is widely embraced across all geological conditions. In about 32.7% of projects, respondents indicated that only the initial or primary support is immediately and strictly implemented before the next tunnel cycle across all geological conditions while, approximately in 38.2% of the Nepal's tunnel projects, the implementation of secondary support and considerations on gap of secondary support is often random and based on specific site geological conditions encountered in each excavated reach.

The survey highlights three distinct patterns of support system implementation in Nepal's tunnel projects: a predominant practice of immediate and strict implementation of both primary and secondary support, a significant portion implementing secondary support with a variable approach, and a subset focusing solely on the immediate and strict implementation of initial/primary support. These findings underscore the diversity in strategies employed by tunnel projects in Nepal.

Effective comprehension of tunnel support, stress distribution, and deformation is critical. Numerical approaches, particularly the finite element method, play a pivotal role in obtaining accuracy in these assessments. The survey asked if the individuals had used any computer-aided techniques such as simulation, modeling, and analysis tools to estimate the support system, or if it was entirely reliant on empirical methods (e.g., rock mass categorization). According to the poll, 42.6% of respondents do not use computer-aided approaches such as simulation, modeling, and analysis software to estimate the support system, while 29.6% choose an optimistic method. Meanwhile, 27.8% participated in both empirical and numerical approaches.

In the context of tunneling projects in Nepal, a detailed survey reveals the prevalence of various software tools. From the one that were positive in regard, it was found that the primary tool in use is the PHASE software, dominating with a substantial 61.1%, showcasing its significance in analyzing and simulating tunnel behavior under different conditions. Following closely is UnWedge at 30.6%, indicating its importance in specific aspects of tunneling projects. RocSupport and Tunnel CAD collectively contribute to 27.8%, highlighting their popularity and utility in tunnel-related applications. Furthermore, Slide and Slope/W are adopted in 16.7% and 13.9% of projects, respectively, underscoring their roles in addressing sliding and slope-related concerns during tunnel construction. Additionally, PLAXIS and other Roc Science packages make up 2.8% of the software landscape, demonstrating a diversified toolkit for addressing specialized challenges in tunnel engineering. This comprehensive array of software tools reflects the dynamic nature of tunneling projects in Nepal, where different tools are strategically employed to cater to the varied demands and intricacies associated with tunnel construction and design.

Effective management of extreme rock mass deformation is imperative to prevent displacement, damage, or total failure of the support structure. Controlling such deformations can be enhanced through meticulous selection of tunneling methods, improvement of support systems, and the strategic deployment of temporary supports. This understanding serves to minimize challenges encountered during excavation. Consequently, the likelihood of encountering issues leading to the initial failure of the support system decreases. In context of Nepal, present study (Figure 3) reveals that about 32.7% of the active

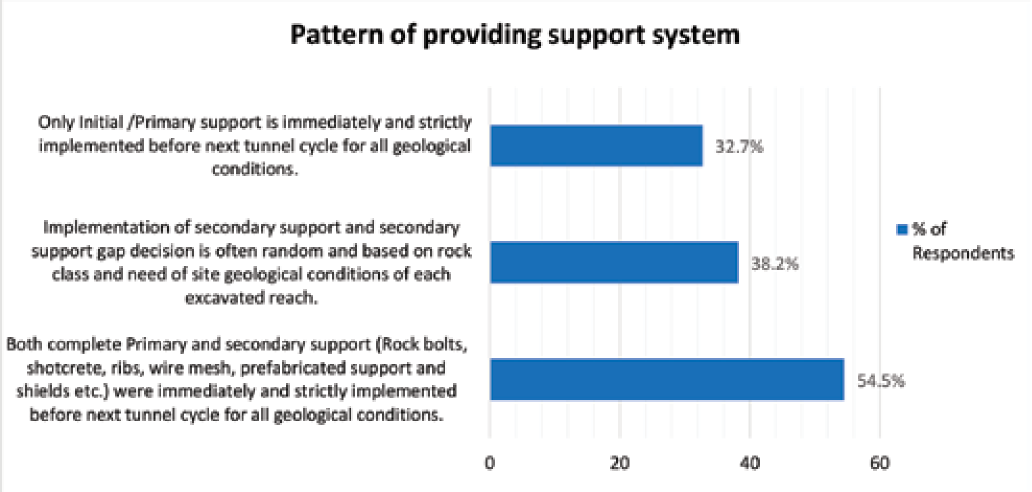


Figure 3: Pattern of Support system in Nepal's Tunnel

tunneling projects have the documented record of initially provided support system failure.

3.4 Geological problems in Nepal Tunneling Projects

The viability of tunnel construction is heavily determined by geological and geotechnical conditions that shape the fundamental foundations of these subterranean routes. The techniques and methodologies used in tunnel building are governed by the delicate interplay between the earth's geologic foundation and the fundamentals of soil and rock mechanics, which ultimately determines safety, stability, and project success. The assessment makes it abundantly evident that Nepal has performed exceptionally well when it comes to Lesser Himalayan tunneling. Similarly, the Higher Himalayan Zone is the site of 42.6% of tunnel building. While Siwalik accounts for 5.6% of all building in Nepal, even soft sediments only account for 3.7% of tunnel construction. The Himalayas are one of the world's most volatile regions. Because of the fragile geology, tectonic activity, and complicated geological features in this region, underground excavations are extremely difficult (KC et al., 2022).

i. Sheared and Faulted Zone.

The presence of small-scale shear-plane-like structures and faulted zone can lead to detrimental effects on the tunnel boundaries, serving as barriers that accumulate elevated stresses and may leads to heavily disturbed rock masses. In the context of deep excavations, the combination of a shear plane with high-stress conditions poses significant dangers.

In Nepalese projects, the likelihood of encountering Shear Zones is considered unavoidable. In response to inquiries, a

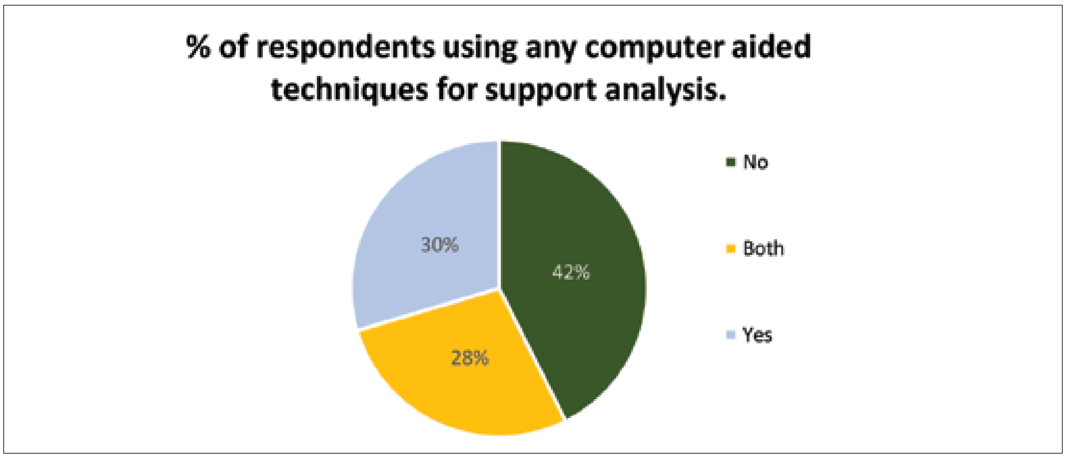


Figure 4: Use of computer aided techniques for Support Analysis

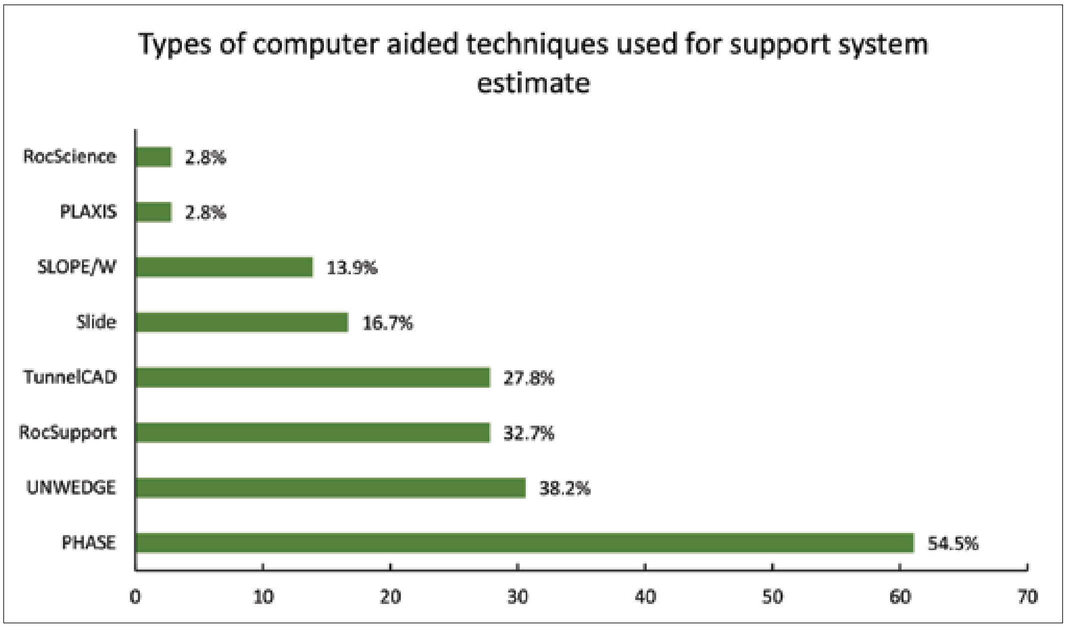


Figure 5: Type of Computer Aided Techniques used for Support System

majority of respondents have indicated that there are indeed a few instances of shear zones while 20 participants have reported a moderate presence of shear zones and 12 respondents have noted the frequent occurrence of such shear zones. Remarkably, only one respondent has asserted the absence of shear zones in their ongoing tunnel project in context of Nepal.

According to the survey findings (Figure 7b), it is widely acknowledged that in 66% of the surveyed tunnels, no mappable fault zone exists. Conversely, the remaining 34% of the tunnels are reported to have identifiable fault zones. The shear zone can be present in a variety of places, including the working face and the tunnel's side walls, resulting in a concentration of abnormal stress near these planes. These have varying degrees of influence on the tunnel's progression. The survey results show that the bulk of the project with shear zone, around 70.9%, had experienced a substantial impact on the project's progress. Meanwhile, 29.1% agreed that the shear zone had no effect on the tunnel's progress.

Among those who expressed a positive impact, considerations were given to the estimated time required to stabilize the shear zone and progress through it. The majority, constituting approximately 33.3% of the responses, indicated that it took less than a week to address and move forward from the shear zone. Similarly, 23.1% reported a duration of 15 days to a month for stabilization. Furthermore, 17.9% mentioned a timeframe of 7 to 15 days for stabilization. A smaller percentage, specifically 7.7% each, reported durations of 1 to 2 months and 4 to 6 months, respectively. However, 10.3% of tunnel projects required more than 6 months to effectively manage and proceed beyond the shear zone.

ii. Cavity

Cavities in tunneling pose significant risks to infrastructure stability and worker safety Thus, the knowledge about the cavity and its stability was crucial for advancing the project. The survey revealed that around 64.8% of tunnels in Nepal had suffered cavity formation, whereas 35.2% had not. Of the participants who encountered cavity formation, approximately 60.4% indicated that the existence of cavities in their project significantly impact the project progress. If the possibility of formation of cavity is not identified earlier and left untreated then it may pose significant challenges and may require large timeframe to make it stabilized. In context of Nepal, the expected duration, as per the respondents, indicated that a majority, approximately 33.3%, mentioned a timeframe of 7-15 days to effectively address and progress beyond the cavity. Similarly, about 24.2% of projects reported a duration between

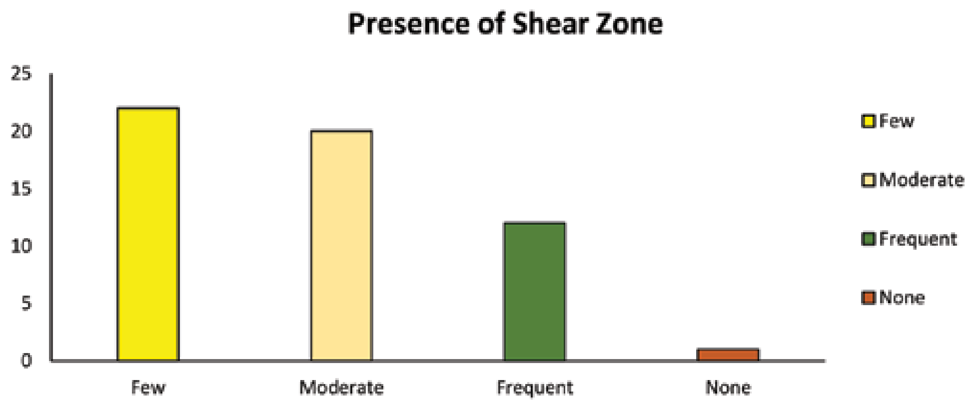


Figure 6: Presence of Shear Zone during Tunnel Construction

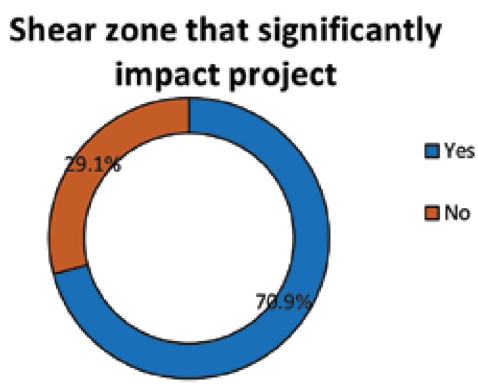


Figure 7(a): Shear Zone that impacts project

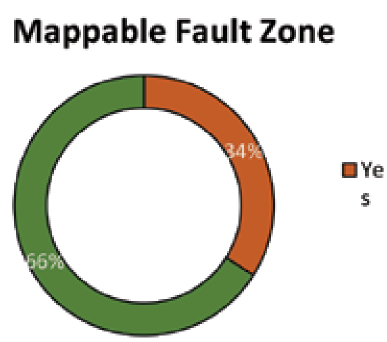


Figure 7(b): Mappable fault Zone in Tunnel

15 days to a month for stabilization. Additionally, 21.2% mentioned achieving stability within a week. Meanwhile, 12.2% of tunnel projects resolved cavity concerns within two months and 3% reported durations of 4-6 months. It's worth noting that 6.1% of tunnel projects required more than 6 months to comprehensively manage and surpass the challenges associated with the cavity zone.

iii. Tunnel squeezing and deformation.

Tunnel squeezing is a major geological disaster that frequently occurs during tunnel construction in weak rock types subjected to significant in-place loads. Redistributed stresses induced by tunnel excavation may exceed rock strength, resulting in severe plastic deformations known as tunnel squeezing. It occurs in soft or weak rock masses that are subjected to high in situ forces (Sun et al., 2018). It might lead to shield jamming, financial overruns, construction delays, tunnel instability, and even casualties. As a result, precise tunnel squeezing prediction or detection is critical during tunnel design and construction. In a survey involving individuals engaged in tunnel projects across Nepal, findings revealed that 55.6% of such projects encounter squeezing characterized by slight deformation, falling below the design diameter, with negligible impact on the overall project. Notably, 14.8% of tunnel constructions reported substantial deformation, exceeding the designated diameter and exerting a significant influence on the project. Additionally, 31.5% of respondents opted that the tunnel projects experienced no deformation. The survey also attempted to identify the primary causes of squeezing in Nepalese tunneling projects and found that 83% of the causes were posed by problematic geological conditions like shear zone, highly weathered and fractured zone while 42.6% reported rock types and properties, 31.9% reported tunnel depth and overburden pressure and a notable, 12.8% reported- under estimated support system are the primary causes of squeezing and deformation.

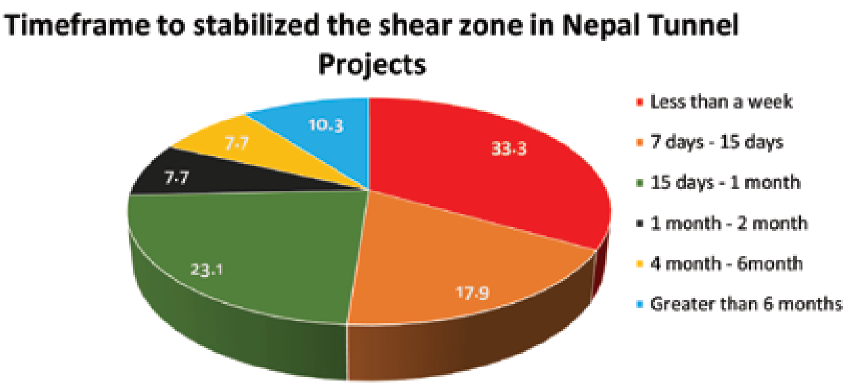


Figure 8: Timeframe to stabilized the shear zone in Nepal Tunnel Projects

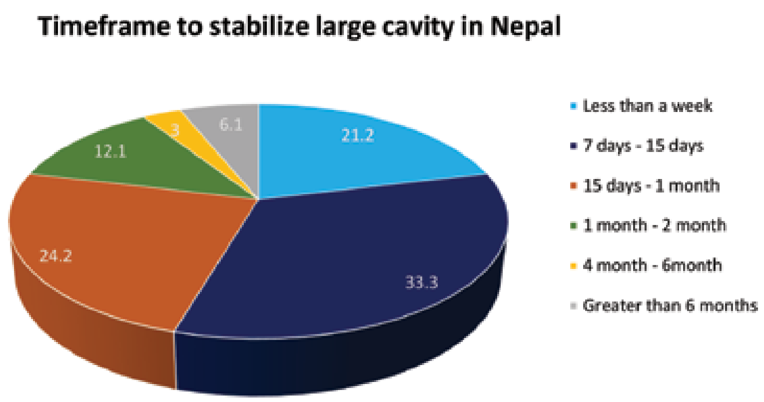


Figure 9: Timeframe to stabilized the large cavity in Nepal Tunnel Projects

3.5 Instrumentation and Monitoring Practices:

Instrumentation and monitoring in tunneling involves deploying sensors and instruments are considered as very important task to perform in order to track and monitor various parameters like ground movement, structural integrity, and environmental conditions during excavation. These tools provide real-time data crucial for ensuring safety, optimizing construction methods, and mitigating risks in underground projects. Therefore, to evaluate the overall scenarios and to understand its level of effectiveness under current tunneling practices in Nepal, the respondents were questioned about the general types of instrumentation adopted at their sites and the results were presented in the illustrations below (Figure 11). The survey also intends to understand the general execution pattern of instrumentation deployed at their respective tunneling sites. The results indicate that, about 29.4% of the respondent follows the definite patterns and interval for instrumentations as per designed and 17.6% of the respondents reported that the instrumentation is provided only in problematic zones. Furthermore, about 70.6% of the respondents voted that the instrumentation decision is made as per recommendations made by engineers and geologists at site and about 2% had no instrumentations.

3.6 Health and safety practices

Achieving optimal health and safety outcomes on tunneling sites, while preventing any undesirable incidents such as accidents, illnesses, and losses, arises from the effective identification, control and managing risks. This involves identifying the hazards, evaluating their potential impact, determining the level of risks and devising strategies for their mitigation. This process starts during the planning and design phases and continues throughout the construction stage till completion of the project. The potential hazards that can arises during any tunneling projects that can impose health and safety related risk are unstable ground condition, water, noise,

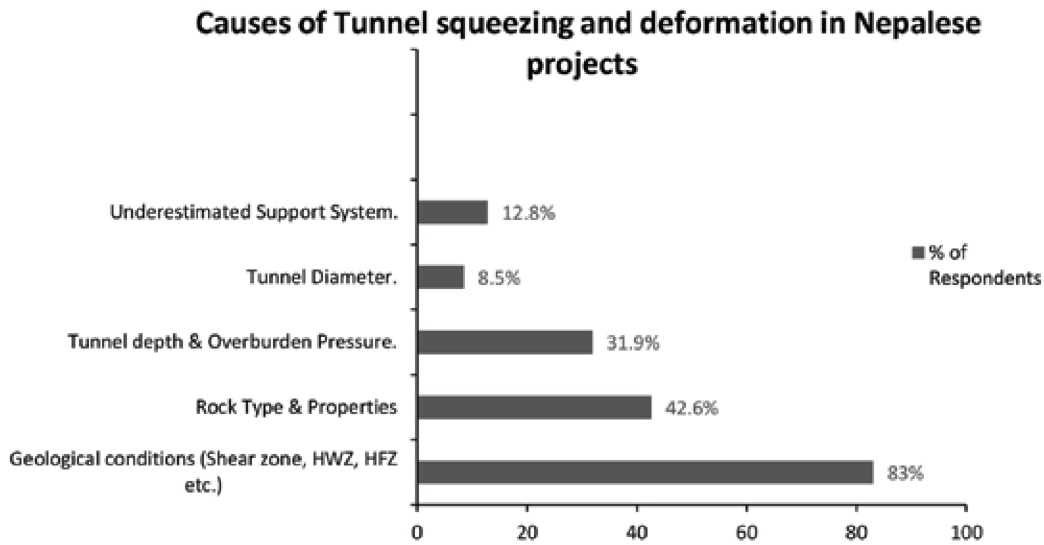


Figure 10: Causes of Tunnel squeezing and deformation in Nepalese projects

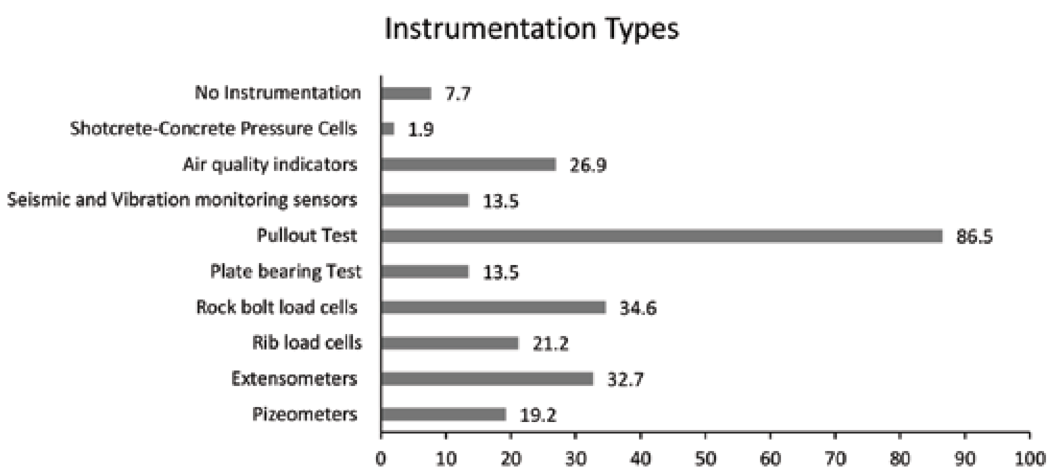


Figure 11: Instrumentation Types

blasting dust and smoke, moving machineries and electricity etc. Some hazards such as fall from height, injuries from machineries and equipment's etc. are likely to be encountered in everyday working shifts are well understood and can be easily minimized with proper safety related training to the workers, continuous monitoring and use of proper Personal Protective Equipment (PPE). However, some tunneling and underground excavation hazards are unpredictable and occur infrequently such as falling rock blocks from tunnel, ground collapse and subsidence, underground fires etc. but the consequences of such impact to the work force can be serious.

In this context, to grasp the actual situation regarding health and safety related issues and practices in tunneling projects in Nepal, the questionnaire section of the current research also included inquiries about health and safety concerns of the respondent's project area. From the present survey with 55 professional respondent populations, about 52.8% of the them reported experiencing of major mis happens like death of front liner and other co-workers on tunneling projects in Nepal. In simpler terms, this suggests that approximately one tunneling project in Nepal out of every two is associated with at least one fatality that leads to death. The pie chart below, illustrates the percentage of respondent populations encountered with specific number of deaths occurred in the tunneling projects in Nepal.

Injuries are another almost inevitable aspects of every major construction projects. About 88.9% of the respondents had reported that their tunneling projects are associated with mis-happens like injuries among which 74.1% are minor injuries, 19.0% are fatal injuries and 6.9% are the injuries that leads to disability. The frequency of occurrence of all types of injuries included, as reported by the respondents were shown in the illustration above (Figure 13).

Respondent populations were also surveyed with the question related to the major causes of mis-happens like death and injuries in their tunneling projects. From the survey it has been identified that the major cause of accidents is due to own's carelessness (34.5%) and compromised safety (28.6%) followed by technical and/or mechanical errors (19.0%) and unpredictive geological uncertainties (17.9%).

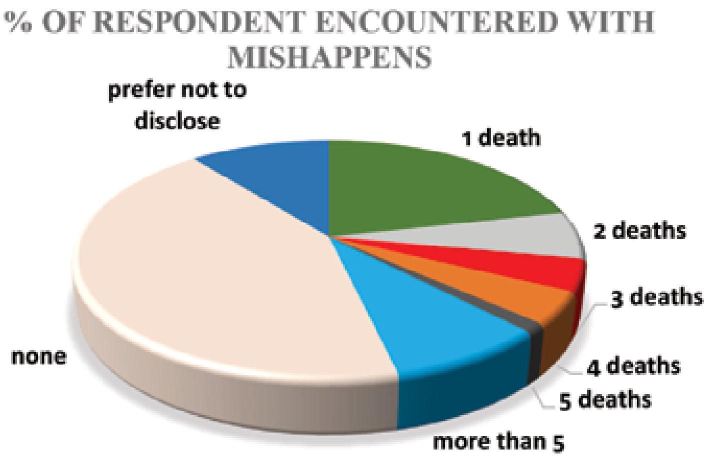


Figure 12: Percentage of respondent populations encountered with mis-happens like death in the tunneling projects in Nepal.

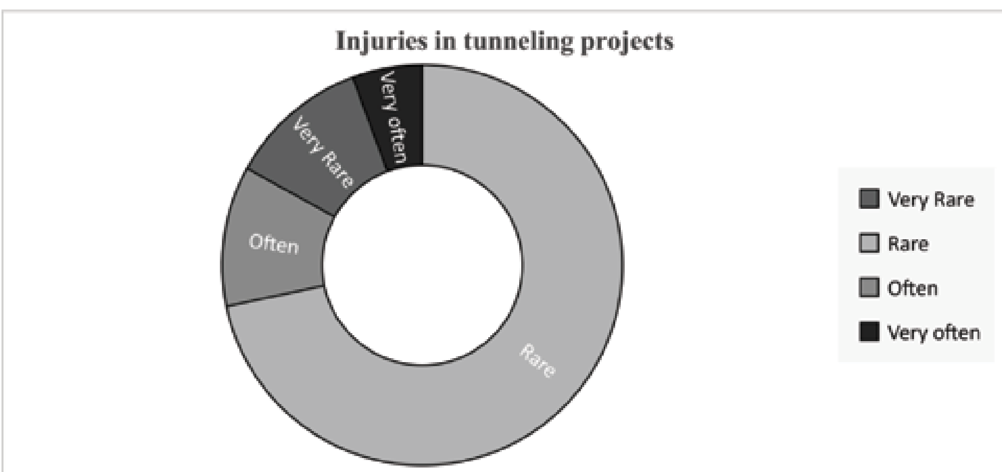


Figure 13: Illustration on frequency of occurrence of injuries in tunneling projects in Nepal.

The data presented highlights the prevalent risks associated with tunnel construction projects where death and injuries are alarmingly common occurrences in tunnel construction projects in Nepal. Personal Protective Equipment (PPE) emerges as a vital component to serve as a frontline defense against tunnel workplace safety from hazards. However, the survey reveals the mixed sentiment among respondents regarding the satisfaction level with PPE usage. While a considerable portion expresses moderate to high satisfaction levels, a notable percentage still remains dissatisfied or only fairly satisfied on the PPE equipment's given to respondents and their co-workers by their organization (Fig 14). This underscores the importance of not only providing PPE but also ensuring its adequacy, comfort, and effectiveness in addressing the specific challenges and concerns faced by workers in constructions environments.

On-site fatalities and injuries represent just one aspect of the health and safety risks in tunneling projects. Ensuring dust and smoke-free, breathable air quality within underground excavations projects is equally critical, as prolonged exposure can lead to chronic respiratory illnesses. The current survey aims to assess the quality of ventilation systems and air circulation within respondents tunneling projects based on their personal experiences, ranging from very poor to very good. Results indicate that 3.7% of respondents rated the quality as very poor, 13% as poor, 40.7% as fair, 38.9% as good, and only 3.7% as very good. These findings highlight that more than half of the respondents expressed dissatisfaction ranging from poor to fair with the ventilation systems and air quality in their projects.

Given the high-risk nature of tunneling work, insurance coverage is crucial to safeguard workers and their families in case of accidents or injuries on the job. Employers are generally responsible for providing this insurance coverage to their employees, ensuring compliance with legal requirements

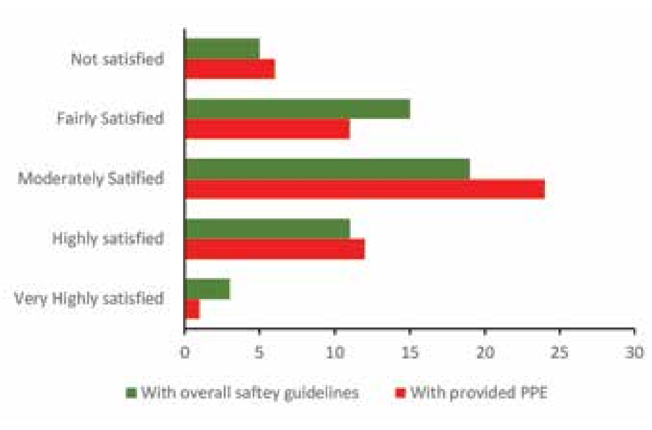


Figure 14: Level of satisfaction of respondents with overall safety guidelines of their organization and with the PPE equipment provided to them by their employer.

and industry standards for workplace safety and protection. Hence, to assess the insurance compliance practices among organizations involved in tunneling projects in Nepal, respondents were queried about the insurance provisions available to them and their colleagues. Results revealed that 41.8% of respondents were covered by comprehensive health and/or life insurance policies, while 18.5% were not insured at all. Additionally, 24.1% indicated uncertainty regarding their insurance status, and 9.3% were completely unaware. Respondents were also asked if they had purchased any insurance independently, with only 30.2% affirming that they were insured independently. The majority, constituting 69.8%, had not obtained any health or life insurance independently, making them uninsured on their own.

3.7 Environmental Impacts and Sustainable Practices

Tunneling projects play a vital role in infrastructure development, but it's essential to tackle the environmental challenges they may bring. Understanding and mitigating issues like air and noise pollution, ground vibration, land subsidence and loss of surface spring water bodies are key steps towards ensuring environmentally sustainable tunneling practices. This paper doesn't indent to provide the solutions to the various environmental problems that tunneling projects may pose. Instead, it was designed with the sole intention of gaining a general understanding of the environmental problems and their qualitative level of complexities associated with current tunneling practices in Nepal.

Table 1: Response of participants on various environmental problems caused by tunneling projects in Nepal.

Any records or complaints of *(i, ii, iii, iv, v) from local communities?				
Environmental Problems	**% Yes**	**% No**	**% Maybe**	**% Total**
i) Excessive Ground Vibration	44.4	44.4	11.2	100.0
ii) Household damage due to ground vibration	38.9	50.0	11.1	100.0
iii) Ground subsidence	17.0	77.3	5.7	100.0
iv) Loss of spring water body	56.6	37.7	5.7	100.0
v) Surrounding Air quality	17.0	67.9	15.1	100.0

In this context, the respondent populations were queried about any records and complaints related to excessive ground vibration, household damage resulting from ground vibration, ground subsidence, losses of spring water bodies, and the surrounding air quality as reported by local communities. The survey findings pertaining to these questions were summarized in Table 1. Focus on recycling or repurposing of excavated muck materials from underground excavation should have to be the primary concerns of every major excavation project for environmentally sustainable project development. With this

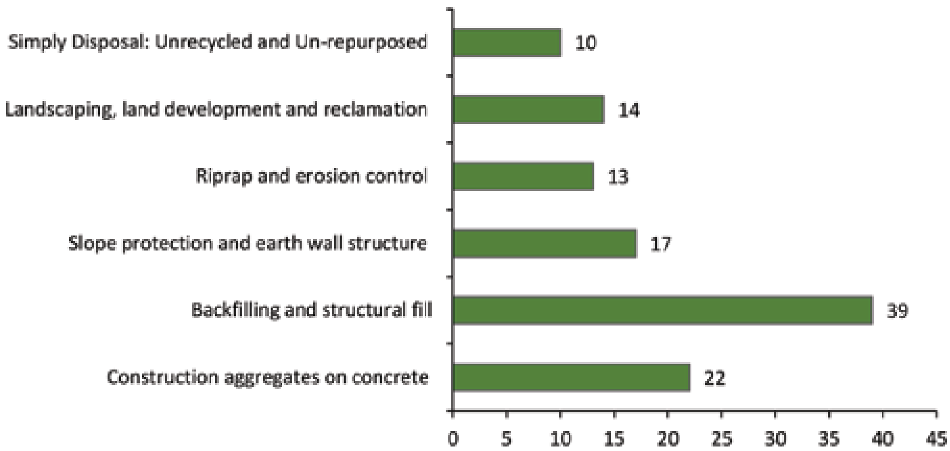


Figure 15: Illustration on mode of recycling and re-purposing practices of the excavated muck materials of tunneling projects in Nepal.

practice, the project not only benefits economically but also contribute to environmental preservation by reducing muck waste and minimizing the need for raw materials extraction for project.

To understand the effectiveness of this sustainable practices on tunneling projects in Nepal, the participants were asked about their muck recycling and repurposing efforts. Results revealed that about 62.3% of the participants voted 'yes' on focus of recycling and repurposing of excavated muck within the projects while 37.7% doesn't. The chart below illustrates the general use of excavated muck material within project environment for various construction purposes.

4 Way forward and Conclusion

Nepal offers a thorough picture of the current situation and challenges that the industry is facing in the country. Nepal is actively working to improve its tunneling techniques as it has identified areas for improvement that might be achieved by utilizing strategic resource use and technology developments. Despite the slow adoption of advanced technologies like Tunnel Boring Machines (TBMs), there is a noticeable upward trend in interest, suggesting a gradual transition towards the acceptance of novel approaches. Because of Nepal's distinct geography, building road tunnels presents its own set of challenges. Nevertheless, the country's progress toward the development of this crucial infrastructure is encouraging.

An important revelation from the survey is the conspicuous gender gap in the tunneling sector, with a mere 7.3% representation of women in these professions. Encouraging greater female participation is not only essential for gender equality but also holds the promise of bringing diverse perspectives to enrich the field. The geological complexities of the Himalayan belt, with its thrusts and folds, necessitate heightened awareness, as indicated by the survey's findings regarding common geological challenges like faulted, sheared, and fractured zones, affecting a significant portion of tunneling projects. This underscores the need for developers and tunneling professionals to exercise extra caution and preparedness when encountering such problematic geological scenarios in the challenging Himalayan terrain.

Furthermore, the term, tunnel; not only symbolizes significant infrastructure but also signifies challenges and safety considerations inherent in tunneling projects. The survey draws attention to a glaring lack of health awareness in the tunneling sector, resulting in approximately 6.9% of fatalities leading to disabilities. This highlights the urgent need to address health and safety concerns to ensure the smooth progress of major projects without disruptions. A key takeaway from the survey is the majority's confidence in the capabilities of Nepali engineering professionals, geologists, and frontline workers. This collective belief in local expertise underscores Nepal's commitment to cultivating indigenous talent for managing the technical complexities of large-scale tunneling projects without extensive reliance on foreign assistance. Simultaneously, the survey underscores significant gaps in gender representation and confidence in the resources of tunnel construction companies, emphasizing the necessity to address gender disparities and enhance overall industry practices for a more resilient and inclusive future.

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