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Ministry of Road Transport and Highways

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CDRI
Coalition for Disaster Resilient Infrastructure

Regional Workshop on Building Climate and Disaster Resilient Roads/Bridges in Mountainous Regions

Workshop Proceedings


Date: 26th – 29th November
Venue: Hotel Hyatt Regency, Chandigarh

Disclaimer:

This outcome document serves as a comprehensive knowledge resource dedicated to strengthening the climate and disaster resilience of road and bridge infrastructure in mountainous terrains. It synthesizes the technical expertise and operational insights shared by participating nations, subject matter experts, and transport authorities. The strategies and perspectives documented herein are attributed to the respective contributing entities and do not necessarily reflect the official policy, position, or endorsement of the Coalition for Disaster Resilient Infrastructure (CDRI).

Acknowledgement:

Coalition for Disaster Resilient Infrastucture (CDRI) and The World Bank expresses their sincere gratitude to the Ministry of Road Transport and Highways (MoRTH), Government of India, and the Himachal Pradesh State Roads and Infrastructure Development Corporation Limited (HPRIDCL) for their invaluable support in hosting this regional workshop. Special thanks are extended to the distinguished guests, including Shri Anbamuthan M.P. (IAS), Government of Assam, and Mr. Paul Procee of the World Bank, whose keynote addresses and special remarks provided a strategic vision for building climate-resilient mountain infrastructure. We also acknowledge the contributions of the expert presenters and moderators from the World Bank, CDRI, and various technical institutions, whose insights into the "Five Pillars of Resilience" and practical engineering solutions formed the core of the workshop's technical success.

Furthermore, we extend our appreciation to the delegations from Bhutan, Mongolia, Nepal, Papua New Guinea, Sri Lanka, and Vietnam for their active participation and for sharing their unique national perspectives on managing disaster risks in mountainous terrains. The success of this event was greatly enhanced by the collaborative spirit shown during the technical group exercises and the experiential learning gained through the field visit to the Himachal Pradesh State Road Transformation Project sites. This collective effort has established a vital foundation to safeguarding vital mountain lifelines against the challenges of an uncertain climate future.

Executive Summary:

The Regional Workshop on Building Climate and Disaster Resilient Roads/Bridges in Mountainous Regions was held from November 26th to 29th, 2025, in Chandigarh, India. Organized by the World Bank and the Coalition for Disaster Resilient Infrastructure (CDRI), with support from MoRTH and HPRIDCL, the event convened over 60 participants from seven countries: India, Bhutan, Mongolia, Nepal, Papua New Guinea, Sri Lanka, and Vietnam. The workshop addressed the critical vulnerabilities of mountain infrastructure which cover 27% of the Earth's land surface against escalating climate-induced hazards like landslides, floods, and glacial lake outbursts. It served as a regional platform to move from reactive maintenance to proactive resilience planning by fostering knowledge exchange and regional collaboration.

The technical sessions were anchored in the World Bank's "Five Pillars of Resilience": Network Planning, Design and Engineering, Operations and Maintenance (O&M), Contingency Planning, and Institutional/Financial Capacity. Discussions highlighted that creating a resilient ecosystem could globally generate 150 million jobs, while inaction risks losing 230 million. Key technical shifts proposed included transitioning from static mapping to dynamic multi-hazard risk assessments and adopting hybrid "green grey" solutions, such as bioengineering, to balance structural integrity with ecology. Experts emphasized that infrastructure should be designed to be "fail-safe," ensuring that even if assets fail during extreme events, they do so without catastrophic consequences.

Technical insights showcased a high return on investment for resilience, where every dollar spent can yield a return of four to seven dollars in avoided losses. The workshop demonstrated the efficacy of these measures through the HPSRTP (Himachal Pradesh) case study, where climate-resilient roads suffered less than 2% damage during severe monsoons compared to 30–40% damage on conventional roads. Digital tools like Kerala's iRoads platform for climate-informed maintenance and CDRI's Resilient Cost-Benefit Analysis (RCBA) tool were highlighted as essential for prioritizing limited resources toward high-risk segments. Participating nations also shared common challenges, including fragmented data systems and the high cost of resilient building relative to limited budgets.

The workshop concluded with a strategic roadmap for systematic implementation. Key recommendations include co-developing a specialized training curriculum for engineers on mountain transport systems and establishing a Community of Practice (CoP) or "Road Clinic" to maintain regular regional engagement. Participants committed to updating national design standards with future climate parameters and exploring dedicated Climate Resilience Funds. Furthermore, the DRI Task Force will be mobilized to provide ongoing, targeted technical assistance to coalition members to ensure that regional expertise is leveraged to solve local infrastructure challenges.

Contents

1. Introduction

1.1 Background

Climate change has significantly increased the frequency and intensity of catastrophic events, such as cyclones, storm surges, extreme heat, and flooding. These climate-induced disasters have far-reaching impacts on socio-economic stability, severely affecting critical infrastructure, including transportation networks, healthcare facilities, and water supply systems. Mountain regions cover approximately 27% of the Earth's land surface and are home to about 14% of the global population. Although ecologically fragile and environmentally significant, these regions are highly susceptible to a range of natural and climate-induced hazards—such as floods, landslides, avalanches, rockfalls, wildfires, and earthquakes. Such hazards not only threaten lives and livelihoods but also disrupt vital infrastructure and services, causing cascading downstream impacts that extend far beyond mountain communities.

Data from CDRI's Global Infrastructure Risk Model and Resilience Index (GIRI) platform indicates significant economic exposure to these risks. Nepal faces an Average Annual Loss (AAL) of US$ 765 million, Bhutan US$ 127 million, and Sri Lanka US$ 985 million. In Kazakhstan, a mountainous country in Central Asia, the transport sector alone faces an AAL exceeding US$ 32 million.

Road networks form the lifeline of mountain economies by facilitating trade, tourism, and access to essential services such as healthcare and education along with connecting the last mile communities. However, constructing and maintaining road infrastructure in mountainous terrains presents complex challenges due to steep gradients, unstable geology, limited accessibility, and environmental sensitivity. Design standards that fail to account for changing climate scenarios, combined with poor drainage or insufficient slope stabilization, can accelerate erosion, trigger landslides, and lead to repeated structural failures. The lack of climate- and disaster-risk-informed planning further increases vulnerability. Additionally, constraints such as limited technical capacity, complex working conditions, and restricted maintenance budgets make both routine and emergency interventions demanding.

The impacts of climate change and extreme weather on mountain road infrastructure have become increasingly evident in recent years, resulting in road washouts, bridge collapses, and prolonged service disruptions. Given the interconnected nature of infrastructure systems, such failures amplify social and economic losses. Consequently, ensuring safe, sustainable, and resilient road systems in mountain regions requires a flexible and adaptive approach, integrating robust engineering with continuous feeding of learnings and adopting local innovations.

Building on the World Bank's investment in road infrastructure, CDRI's work around mountain resilience and the Himachal Pradesh Road and Infrastructure Development Corporation Limited's (HPRIDCL) experience in constructing resilient mountain roads, a regional workshop was convened. The World Bank and CDRI, with support from the Ministry of Road Transport and Highways (MoRTH) and HPRIDCL, jointly organized this in-person event in Chandigarh from November 26th to 29th, 2025.

1.2 Workshop Objectives

1.2.1 Overall objective:

Recognizing that climate change and disasters severe damage on road infrastructure resulting in substantial economic losses, this workshop aims to serve as a platform bringing expertise across the countries having mountainous geography to exchange knowledge on learnings and good practices further fostering regional collaboration. Furthermore, the workshop also seeks to identify challenges and learn/explore about solutions that has been practiced in the various countries (across various pillar) that address the impacts of both extreme weather events and long-term climate change.

1.2.2 Specific Objectives:

In line with the sessions from the workshop some of the specific objectives were to:

- Enhance shared understanding on mountain hazard and characteristics of transport resilience along with Five Pillars of Climate- and Disaster-Resilient Transport
- Identify, hazards, vulnerabilities and exposure to have risks informed plannings specific to mountainous road networks and integrating insights from participating countries' experience
- Learn integration of climate resilience into mountain road design and implementation through reflecting on lessons learned from the GNHCP (MoRTH) and HPSRTP (HPRIDCL) projects
- Learn about Operations and Maintenance (O&M) strategies, specifically the use of Road Asset Management Systems (RAMS) featuring in-built Climate Modules to enable climate-informed planning and inspection
- Strengthen learnings on contingency planning and integration of DRM in transport sector
- Promote knowledge on strengthening governance and institutional and financial capacities for resilient infrastructure, including climate financing for road resilience and demonstration of the Resilient Cost-Benefit Analysis Tool.
- Provide hands on experience through Field exposure from Himachal Pradesh State Road Transformation Project

1.2.3 Outcomes of the workshop:

- Increased understanding on mountain hazard and characteristics of transport resilience along with Five Pillars of Climate- and Disaster-Resilient Transport.
- Peer-to-peer knowledge sharing on the past/ongoing successful and learning intervention in India, South and Central Asia mountain region road network initiatives.
- Strengthened Knowledge on institutional and financial capacities for resilient infrastructure, including climate financing for road resilience and demonstration of the Resilient Cost-Benefit Analysis Tool.
- On ground field experience through the exposure visit organised by the Himachal Pradesh State Road Transformation Project on mitigation and social enhancement measures

2. Workshop participants and Method

2.1 Agenda

- The three days regional workshop held from November 26-28, 2025, brought together officials from Transport and related departments, and Disaster Risk Management agencies/authorities Coalition member countries from the South and Central Asia.
- The agenda featured inaugural session, introductory video for the event followed by welcome and opening remarks, keynote address and special remark from CDRI, GoI and WB respectively. The regional workshop also included fifteen technical sessions over 2 days that explored key themes such as characteristics of transport resilience focusing around Five Pillars of Climate- and Disaster-Resilient Transport sector. The Session on Network planning focused on understanding hazards, vulnerabilities

and exposure for risks informed plannings, prioritizing climate resilience in transport sector. Pillar 2 focused on design and engineering aspect focusing on climate sensitive design and planning, slope stabilization, reflecting on lessons learned from the GNHCP (MoRTH) and HPSRTP (HPRIDCL) projects. Similarly, pillar -3 was dedicated on Operations and Maintenance (O&M) strategies focusing on Road Asset Management Systems (RAMS) with Climate Modules to enable climate-informed maintenance and inspection. Pillar 4 contributed towards contingency planning and integration of DRM in transport sector whereas pillar 5 focused on strengthening governance and institutional and financial capacities for resilient infrastructure, including climate financing for road resilience and demonstration of the Resilient Cost-Benefit Analysis Tool.

- The final day included field visit of participants to Himachal Pradesh State Road Transformation Project. The field visit contributed to observe mitigation and social enhancement measures in mountain road (See Annex 1 for detail workshop agenda)

2.2 Participants

The regional workshop convened over 60 participants from 7 countries including India. The participants comprised of road sector professionals (including engineers with hands-on experience across all five pillars) representing department and ministries responsible for transport, roads and physical infrastructure, Disaster Management Authority alongside Indian experts in the road sector (See Annex 2 for the participant list.)

2.3 Facilitation team

i) **Moderators:** Mr. Kiran Gowda, Nicolas Ziv (CDRI), Arnab Bandyopadhyay (World Bank)

ii) **Expert Presenters:** Mr. Arnab Bandyopadhyay, Ms. Vijetha Bezzam, Dr. Kishore Kumar, Mr. Anup Karanth, Ms. Yeshika Mallik, Mr. Goverdhan Lal Verma, Mr. Nikhil Narang, Mr. Pawan Kumar Sharma, Mr. Bhavesh Jain, Mr. Binu Mathew, Mr. Empati Uday Kumar, Mr. Jagan Shah, Mr. Raj Vikram Singh

2.4 Methods

The three days regional workshop adopted a comprehensive, and multiple approach designed to explain the concept of climate and disaster resilience, presentation and discussion around 5 pillars of Climate and Disaster resilient transport followed by practices carried out in the sector of mountain roads from MorTH, HPRIDCL along with private sector actors. The three-day workshop methodology was structured to facilitate combination of theoretical foundations and experiences sharing, case study exercise (Days 1–2) followed by experiential learning on day 3 through onsite visit to understand both technical and social aspect of mountain road resilience carried out by HPRIDCL with support from World Bank.

In terms of session delivery both in person and hybrid model were used. The in-person sessions and field exercise along with Q/A sessions after the experts' presentations has supported in maximization of engagements, facilitating spontaneous peer-to-peer exchange. A dedicated sessions for participants were provided to present case studies, from their country's experiences. This includes discussing failures and successes in similar topographies along with institutional and financial capacity and gaps.

The third day focused from theory to practice, allowing participants to witness the application of the concepts discussed during the technical sessions. Workshop participants visited the selected project sites that demonstrate successful implementation of climate-resilient roads, effective slope stabilization techniques along with drainage and flood mitigation structures. The field visit also supported the participants in understanding the role of local communities in road resilience, specifically how community participation is leveraged for maintenance in remote mountainous regions along with showcasing of social enhancement measures across community infrastructures (See Annex 4 for the map of sites visited).

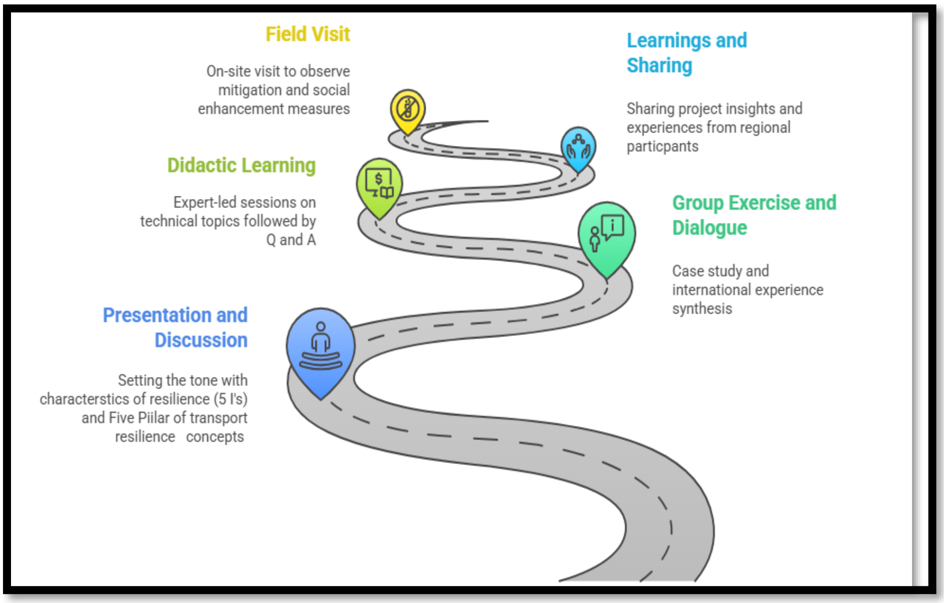


Fig 1. Workshop Method

3. OPENING SESSION

3.1 Inaugural session:

- The three-day regional workshop on building climate and disaster-resilient mountain roads and bridges began with a welcome address by Mr. Kiran Gowda, Transport Advisor for CDRI and moderator of the session. Mr. Kiran provided a brief overview of the agenda, with the key sessions and field visit activities. The workshop was formally inaugurated with a traditional lamp-lighting ceremony. The dignitaries present at the inaugural ceremony were Mr. Ramraj Narasimhan, Deputy Director General (DDG) of CDRI; Shri Anbamuthan M.P, (IAS) Government of Assam, the Chief Guest; Mr. Pawan Sharma, the Director of Projects from HPRIDCL; Anil Kumar Kushwaha, CE-RO Shimla, MoRTH, Govt. of India and Mr. Arnab Bandopadhya, Transport team Lead from the World Bank. This symbolic gesture reflected their collective commitment to resilient roads in mountainous regions. The inauguration concluded with a brief introductory video outlining the workshop's objectives and expected outcomes, setting the tone for the three-day event.

3.2 Key address

3.2.1 Welcome and Opening Remarks- Mr. Ramraj Narasimhan, DDG, CDRI

- Mr. Ramraj Narasimhan, DDG, CDRI welcomed all the delegates from all seven countries. He acknowledged that presence of such a committed and diverse group to contribute towards shaping resilience of mountain roads. Mr. Narasimhan also provided a brief introduction to CDRI to the participants. He also shared about the CDRIs multi-pronged approach focusing on Program and technical assistance, Capacity development, Knowledge Management and global collaboration. He also highlighted CDRI support in access to funding, technical expertise, capacity building and research opportunities, along with providing a strong platform for partnerships. He touched base on the importance of climate and disaster resilience especially for mountains and how this capacity building matters in shaping resilient mountain road sector. Additionally, he also emphasized that building the resilience of infrastructure systems requires agencies and asset managers to strengthen not only the capacity to absorb disasters but also the ability to respond to shocks and recover quickly.
- His address also provided a brief overview on World Bank and CDRI's joint effort which seeks to foster practical, peer-to-peer learning and exchange across South Asian and Central Asian countries, advancing regional collaboration for safer and more resilient road infrastructure. His address also emphasized that the collaborative efforts will further result in the co-creation and dissemination of knowledge products, and learning materials. He also thanked the good practices initiated by Government of India (GoI) and Himachal State Government for leading the frontline showing its capabilities in including disaster resilience measures, that include bioengineering or nature-based solutions into Schedule of Rates (SoR) making it quantifiable measure and ease of adoption by designers and engineers. DDG, Narasimhan reiterated CDRI commitment in strengthening multi-hazard risk-informed decision-making, risk-sensitive institutional capacities buildings, and integrating nature-based solutions and indigenous knowledge into infrastructure planning and management. At the end, while talking about the way forward the speaker highlighted that the workshop would serve as a foundation for developing training guidelines and formation of Community of Practice for resilient mountain roads and believed that the He shared that real-world knowledge and collective expertise of (engineers, planners, disaster managers, sector specialists) will guarantee that the training materials co-develop will be applicable, scalable, and applicable throughout mountainous nations. Lastly, he thanked GOI especially for MoRTH and HPRIDCL and wished everyone a successful workshop full of knowledge, deep conversations, and enduring relationships.

3.2.2 Keynote Address by Chief Guest - Shri Anbamuthan M.P, (IAS) Government of Assam

- The keynote address sets the context for the workshop by emphasizing that mountain road networks are not merely infrastructure, but vital lifelines that sustain biodiversity, culture, and economic engines like tourism. Acknowledging the increasing frequency of climate-induced hazards such as cloud bursts and landslides in Himachal Pradesh and Uttarakhand the Mr. Anbhamuthan called for an urgent paradigm shift from reactive maintenance to proactive resilience planning. Mr. Anbamutham highlighted the value of the collaborative partnership between HPRIDCL, CDRI, MoRTH, and the World Bank, stressing that conventional engineering approaches are no longer adequate to protect these critical arteries against the current reality of climate change. Building on the economic rationale, the speaker noted that investing in resilience is a necessity rather than a luxury, citing that every dollar invested in resilient infrastructure yields a return of four dollars by minimizing loss and service disruptions. His address also detailed concrete steps being taken to mainstream resilience, including the adoption of nature-based solutions like bioengineering for slope stabilization, Full Depth Reclamation (FDR) technology, and the development of robust policy frameworks such as Early Warning Systems. Concluding with reference to the "Five Pillars of Resilience," Mr. Anbamuthan encouraged delegates to leverage the three-day workshop and site visit to co-create actionable knowledge and forge stronger regional partnerships.

3.2.3 *Special Remarks -Mr Paul Procee, Acting Country Director India, The World Bank*

- The special remarks by Acting Country Director India Mr. Paul Procee emphasized that transport infrastructure in mountainous regions must be viewed not merely as engineering assets, but as national development imperatives and community lifelines. Mr. Procee commended the collaborative leadership of CDRI, the World Bank, MoRTH, and HPRIDCL. He highlighted that the region faces the climate risks that our transport systems are facing due to escalating of disaster both in frequency and intensity, with heavy rainfall events, glacial lake outbursts, and shifting slope dynamics affecting entire region. His special remarks emphasized that at the same time, technological and institutional innovations are opening new pathways for us to act more decisively and this workshop, therefore, offers a platform for collective thinking, cross-country learning, and co-creation of resilient solutions that transcend national boundaries.
- To guide the discussions, his remarks outlined three strategic priorities: risk assessment, design innovation, and institutional capacity are critical, and they form the foundation for unlocking finance at scale to support long-term adaptation. He also noted that collective challenge and opportunity is to maintain resilience through system to people, lens i.e policy frameworks to engineering standards to project financing and community engagement. Further, Mr. Procee also linked the transport sector's resilience with local communities who are entirely dependent on connectivity for their basic needs and livelihood. At the end, during these special remarks he emphasized that resilience is ultimately a moral responsibility to the people who depend on these networks, with a call to action for participants to use this opportunity to ignite a "regional movement" that safeguards development pathways against an uncertain climate future.

  The inaugural session ended with the group photograph (Please see Annex 3 for event photographs).

4. Summary of Technical Sessions

4.1 Session 1: Introduction

4.1.1. *Five I's of Resilience – Characteristics*

Presenter: Mr. Arnab Bandyopadhyay, Lead Transport Specialist, World Bank

Following the inaugural ceremony, the first technical session began with a foundational presentation by Mr. Arnab Bandyopadhyay on the World Bank's "Rethinking Resilience" framework. He introduced the "Five I's"—Income, Information, Insurance, Infrastructure, and Interventions as the overarching characteristics necessary to build comprehensive community resilience. Mr. Bandyopadhyay stressed that resilience is a key ingredient for economic development, not just a safety measure. Arnab shared striking figures: creating a resilient ecosystem has the potential to generate 150 million jobs globally. Conversely, inaction could result in the loss of 230 million jobs.

A significant portion of the Mr. Bandyopadhyay session focused on the underutilized power of insurance. The speaker highlighted a stark contrast in asset management: while contractors are mandated to have "all-risk insurance" during construction, public assets (roads and bridges) are rarely insured once open. Using examples like the USDA Crop Insurance Program (a success story) and catastrophic bonds in Asia, he argued for innovative financial models. He also cited an Indian case study where a policy shift from flood protection (2006) to drought protection (2010) left farmers without coverage for extreme events, highlighting the need for insurance products that align with actual climate risks. Mr. Bandyopadhyay addressed the engineering dilemma of cost-benefit analysis. He argued that making infrastructure 100% "climate-proof" is often impossible or expensive. Instead, the goal should be to design systems that are "fail-safe" meaning that if they fail during extreme events, they do so safely without catastrophic consequences.

He highlighted that while developed countries struggle with retrofitting infrastructure, developing nations have a unique advantage, as they are currently building the bulk of their infrastructure, which can integrate resilience from the foundation. On his concluding statement, he stated that - While the workshop is primarily focused on Infrastructure, Mr. Bandyopadhyay emphasized that this must be supported by the other four pillars (Income, Information, Insurance, Interventions). This holistic "Five I's" framework serves as the conceptual anchor for discussions over the next three days.

4.1.2. Introduction to Climate & Disaster Resilient Transport: WB's Five Pillars of Resilience

Presenter: Ms. Vijetha Bezzam Senior Transport Specialist, The World Bank

Building on the 5 I's resilience in the beginning of technical session, Ms. Vijettha Bezzam shifted the focus introducing the World Bank's "Five Pillars" approach to transport resilience. She outlined the roadmap for the workshop, noting that the next two days would be dedicated to unfolding each pillar to understand challenges and strategies for building resilient infrastructure and communities along with sharing learnings from the delegates.

Ms. Bezzam highlighted the critical nature of the discussion with key data on disaster risk, climate change, and its impact on the economy.

- **Disaster Risk:** India ranks 32nd out of 191 countries on the INFORM Risk Index, ranking 7th globally for landslide risk and 13th for flood risk.
- **Climate Trends:** There has been a drastic increase in hazards, with heat events rising by nearly 78%, floods by 57%, and landslides by 32%.
- **Economic Impact:** In South Asia, climate change could reduce GDP by 1.8% by 2050, affecting 800 million vulnerable people. In India specifically, infrastructure disruption costs approximately 1.8% of the annual GDP, with 30–40% of the road network exposed to floods or landslides.

She also stressed the financial imperative for resilience with the National Infrastructure Pipeline (NIP) projecting 40,000 transport projects worth $1.5 trillion USD, integrating resilience is essential to protect these massive investments and prevent compounding disruption costs.

She touched base on five pillars of resilience i) Network Planning ii) Design & Engineering iii) Operations & Maintenance iv) Contingency Planning v) Institutional & Financial Capacity Ms. Bezam distinguished between "Resilience of the Asset" (technical durability) and "Resilience through the Asset" (ensuring community survival and service continuity).

Linking with the five pillars, Ms. Bezam also shared findings from a recent survey of central, state, and local bodies, revealing that agencies possess a reasonable understanding (~40%) of the technical pillars (Planning, Design, O&M), alarmingly low (<20%). Ms. Bezzam concluded with a commitment to bridge these gaps through collaboration with CDRI through development of training curriculum for engineers, contractors, and supervisors, institutionalizing resilience knowledge across the transport sector.

4.1.3. Overview of the Mountainous Hazard and challenges faced by mountainous road network

Presenter: Dr. Kishore Kumar, Ex-Chief Scientist, CSIR - Central Road Research Institute (CRRI)

Dr. Kishore Kumar, drawing on decades of field experience in the Himalayas, presented a critical overview of the disconnect between static highway engineering and the dynamic geological reality of mountain regions. His address argued that the current "manageable connectivity" approach is insufficient for the geologically active and climatically volatile Himalayan terrain.

Dr. Kumar emphasized that while the Himalayas vary drastically from foothills to high peaks in terms of geology (thrusts, faults, and plates) and ecology, the design standards for highways often remain dangerously uniform. The Himalayas are still rising (5–6 mm/year), making them inherently unstable. Citing 2025 as the wettest year since 1901 (with 699 heavy rainfall events and over 12,000 landslides recorded), he underscored that rainfall is often blamed as the "sole cause" when it is merely a trigger. The retreat of glaciers and the formation of unstable moraine-dammed lakes pose increasing threats to downstream infrastructure. Dr. Kumar outlined a structured technical approach to risk management, emphasizing that risk identification must happen prior to construction, not just post-disaster through comprehensive hazard mapping, realignment, if possible, to reduce likelihood and opt for engineering interventions to prevent failure and reduce consequences. He also shared that in many cases failure is inevitable, hence minimizing the impact along with regular monitoring of the landslide. From his experience and practice Dr. Kishore also shared budgets covering the road surface but not the slopes above or below and underscored that highway Slopes must be treated as part and parcel of the Road Asset. Further he argued the adoption of a dedicated Highway Slope Management System (like systems in France, USA, and New Zealand) to institutionalize slope maintenance, ensuring that slopes receive the same budgetary and technical attention as the pavement. Dr. Kumar underscored that the continued reliance on outdated 1:50,000 scale maps (where 1 cm = 500 meters), which are insufficient for engineering design. He encouraged the transition from academic use to national policy implementation of modern technologies like LiDAR, UAVs need to be taken into consideration. He stressed the need for a transparent, GIS-based national landslide inventory to enable evidence-based prioritization of vulnerable stretches. The session concluded with a strong appeal to policymakers to move from a "reactive" approach (repairing after failure) to a "proactive" approach (predicting and preventing failure) by integrating multi-hazard risk assessment into the core of road development policy.

Key Take Aways:

- **Resilience is not merely a safety measures but a critical economic driver**
- **Slope needs to be treated a part of road assets and adoption of a dedicated Highway Slope Management System to institutionalize slope maintenance**
- **Capacity building in Contingency Planning and Institutional/Financial investment needs to increase**
- **Resilience needs to be integrated across the entire transport lifecycle from planning to emergency response.**

4.1.4. Reflections from Participating Countries

Following the technical sessions, delegates from participating countries were requested to share the reflection from their respective countries to build climate and disaster resilient mountain roads.

i) Sri Lanka

- The delegate expressed gratitude to the organizers (WB and CDRI) for inviting them in the workshop. With two distinct monsoon seasons affecting different parts of the country (including sugar cane regions), minimizing disaster-induced costs remains a priority despite budget limitations. He shared that there has been very limited allocation for new projects due to financial constraints and government of Sri Lank has been prioritizing Operations and Maintenance (O&M) to reduce vulnerability.

ii) Papua New Guinea (PNG)

Mr. Kenneth Yamu started with the unique context as a diverse nation with over 800 languages and 600+ islands/atolls, characterized by complex terrains ranging from coastal areas to rugged highlands. He underscored that flash floods and landslides frequently disrupt access to government services for mountain communities. He also shared about the ongoing initiatives of the government has allocated significant budget (approx. 5.6%) specifically for roads and highways to connect economic corridors (Gold, LNG, Agriculture). He also shared about collaboration with ADB on a $1 billion USD project for a 500km economic corridor in the Highlands. In relation to challenges he emphasized on the lack of an integrated data system for informed decision-making. He also acknowledged CDRI's support for the implementation of the "IRIS" program to update specifications, standards, and climate-resilient assessment frameworks.

Lastly, he expressed his keen interest in learning and adopting the "Five Pillars" and exploring insurance models for public assets that can be replicated to PNG.

iii) Nepal

Ms. Alka Prasapati, Senior Divisional Engineer from MoPIT, emphasized Nepal's fragility as a high-seismic zone with unplanned urbanization and scattered settlements. She mentioned about the recent destruction caused by the Roshi River (2024) along the BP Highway as a stark example of climate impact. She shared about the policy framework DRRM strategic action plan and NAP in place to support implementation of DRR and climate related initiatives, In addition to that share also emphasized about the fragmented data systems, lack of insurance for public assets, and inadequate geohazard mapping are some of the areas where Nepal can improve. Along with that she also shared the importance on integrating bioengineering in vulnerable areas and developing Early Warning Systems for monsoon preparedness.

iv) Bhutan

Ms. Yeshey Choden from the Ministry of Infrastructure and Transport highlighted that 80-90% of Bhutan's roads traverse mountainous terrain, making slope stability a primary concern. While highlighting the challenges she emphasized on the lack of geo technical inputs budget constraints. She also shared about the absence of an in-house geotechnical lab and design decisions often rely on visual observation rather than technical investigation. Lastly, share shared that Bhutan has taken initiatives to establish a robust management and database system, which serves as a foundation for future improvements.

v) Vietnam

Ms. Thai Min Huong from the Vietnam Disaster and Dyke Management Authority shared that of at least three quarter of Vietnam is mountainous, making roads essential lifelines for economic growth and community access. She highlighted that Vietnam is facing 12-15 typhoons annually leading to frequent landslides and flash floods. She also noted that roads in vietnam are often narrow, low quality, and poorly maintained due to high investment. Ms. Huong highlighted that adopting a risk-based planning and design approach, leveraging international technology and seeking sustainable financial solutions to ensure long-term resilience would be key to address and make infrastructure resilient to climate shocks and stress.

vi) Mongolia

Ms. KHOSGEREL Tsogkhuu, delegate from the Ministry of Road and Transport highlighted a distinct climatic challenge than other participants. Mongolia being a country with mountainous terrain snow coverage is high Permafrost coverage has dropped from 63% (1971) to 29% (today). The melting ground causes severe road damage, compounded by more frequent floods and heavy snowfall. The cost of recovery is increasing annually. The delegation viewed the workshop as a critical opportunity to gain knowledge on managing road damage caused by these rapid climatic shifts.

All delegations' members highlighted on the need for better information management system, financial constraints (high cost of resilience vs. limited budgets), and emphasized on more focused learning exchange, capacity building and collaboration for technological transfer to address specific local hazards faced by different countries.

4.2 Session 2: Resilience Concepts and Case Studies – Pillar 1

4.2.1 Risk-Informed Planning and Mountain Road Networks: Assessing Hazards, Vulnerabilities, and Exposure

Speaker: Mr. Anup Karanth, Senior Disaster Risk Management Specialist, The World Bank

Mr. Anup Karanth presented Pillar 1 as the cornerstone of resilience, arguing that the only way to move from emergency response to proactive mitigation is through effective planning. Sharing the recent images from Dharali floods he highlighted that how mountain ecosystems have "tipping points," where untreated minor damage combines with extreme weather to cause massive cascade failures that defy conventional hazard maps. He underlined that understanding hazards in mountainous areas needs going beyond historical data, which frequently fails to forecast "surprises" like the recent debris flows in Himachal Pradesh. Additionally, he pointed out that how mountain ecosystems have "tipping points," where untreated minor from previous years (e.g., 2024 s) combine with extreme weather (106% above average rainfall) to cause massive cascade failures, unleashing boulders "the size of autorickshaws." The presentation highlighted the failure of a vulnerable road network also make difficult to access critical energy infrastructure (HEPs) and halting emergency response.

He stated that planning needs to change from static mapping to dynamic vulnerability and exposure assessments. The presenter further shared the example of Tamil Nadu PWD after the change in zoning maps are carrying out the assessment how their infrastructures will perform and which needs to be prioritized for retrofitting. Adding on to that he highlighted that knowing where the earthquake might hit is less useful than knowing which specific bridge will collapse. Linking this example he also underscored that y in the mountain's user exposure will changes as seasonal tourism spikes in the mountains and pilgrim season, highlighting the needs of real-time data integration. Mr. Karanth also shared that, a "copy-paste culture" while preparing Detailed Project Reports (DPRs) that lack site-specific risk analysis frequently makes assets and infrastructure more vulnerable. Risk data exists (bore logs, sensor data) but is siloed.

Lastly, to address this, Mr. Karanth urged the delegates and experts in the room for a rigorous, multi-hazard approach that democratizes data access allowing planners to see the risks "below their feet" with a click of a button through multiple layers consisting of Hazard, vulnerabilities and exposure.

Question: Mr. Anil Kuswa (Chief Engineer, Shimla) raised a question about the challenge in Mountain Road as in cloudburst events, roads often turn into drains, washing away completely. He asked - if retaining walls were sufficient?

Response: Responding to Mr. Kushwaha's - Mr. Karanth stated that retaining walls are often insufficient for cascade failures. He suggested for avoidance of geologically unfit sites for reconstruction. He also stressed for the creation of a slope stabilization/special Cell within PWDs, staffed by geologists and seismologists, not just civil engineers.

4.2.2 National Adaptation Plan (NAP): Prioritizing Climate Resilience in the Transport SECTOR AND Reflection from Nepal

Presenter: Ms. Yeshika Malik, Climate Change Specialist, The World Bank

Ms. Yeshika presented the strategic importance of National Adaptation Plans (NAPs) as tools and guiding document for resilience planning from systemic lens. Focusing on the transport sector, National Adaptation Plan (2021-2050) of was used as a case study to illustrate how a mountain and most vulnerable to impact of climate change is addressing climate risks. Ms. Malik highlighted that NAPs are not merely planning documents but powerful financing engines countries with robust NAPs typically access 2 to 3 times more adaptation finance.

She underlined Nepal's Approach to Resilient Transport given that Nepal is the 4th most climate-vulnerable country globally and 80% of its population relies on road connectivity, their NAP focuses on three critical pillars:

1. Resilient Engineering: The plan mandates climate-proofing for roads and bridges. Specific technical interventions include increasing drainage capacity by 20–40% and attempting to realign roads away from slopes greater than 35 degrees.
2. Institutional Coordination: Nepal employs a harmonized "whole-of-system" approach. While the Ministry of Forests leads the NAP, sector-specific implementation falls to the Ministry of Infrastructure. This is cascaded down to 753 municipalities, ensuring national goals meet local realities.
3. Community-Led Maintenance (LAPA): A standout success is the Local Adaptation Plan of Action (LAPA). This bottom-up approach utilizes Gender Inclusive Community Road Maintenance Groups to manage rural connectivity.

Ms. Yeshika highlighted Nepal's innovative financial governance where she shared that approximately 7% of the national budget is tagged for climate-related activities across 22 ministries. She also highlighted that Nepal will mobilizes funds from the Green Climate Fund (GCF) with Technical Assistance from UNDP and explores Public-Private Partnerships (PPPs) for transport projects.

Ms Mallik session drew direct similarities to India, which possesses the world's second-largest road network (6.3 million km) and faces similar Himalayan risks. During her presentation she mentioned the 2021 Uttarakhand disaster (which caused estimated road infrastructure losses of $2.8 billion), the speaker shared that India could adopt similar strategies like integrating climate risk assessments into major schemes like Prime Minister Gati Shakti and National Highway projects along with ensuring budgets are optimized and allocated for resilience works.

In the conclusion, Ms. Yeshika Mallik emphasized that resilience requires a dual approach: a top-down National Adaptation Plan for policy and finance, combined with bottom-up community engagement for execution and maintenance. Investing in resilience today is the only way to avoid catastrophic economic losses tomorrow i.e. with every dollar invested generating $4 to $7 in avoided losses.

Question by Mr. Tanish Sri Varma, SDC: Despite the consensus that risk is a dynamic phenomenon changing rapidly even within a single year as seen in Uttarakhand effective risk screening is not translating into practice. Current Detailed Project Reports (DPRs) and District Disaster Management Plans (DDMPs) often resemble 'school geography books' with generic descriptions rather than technical risk assessments. What are the specific institutional challenges preventing effective risk screening? Furthermore, could the PM Gati Shakti program, which integrates data from various ministries, serve as a platform to institutionalize this risk management?"

Response: Ms. Yeshika identified the primary hurdle as institutional fragmentation. She explained that necessary data (rainfall, temperature, infrastructure specs) exists but is scattered across different agencies, requiring a "whole-of-economy" leadership approach to coordinate. She noted that even when screenings are conducted, they are often "one-time" exercises kept in files rather than utilized as dynamic public models.

Key Take Aways:

- **Risk-informed network planning should integrate hazard, vulnerability and exposure assessments and should transition to dynamic risk assessments**
- **Multi-hazard assessment methods, including probabilistic approaches, help accommodate uncertainty and future climate conditions in mountainous regions.**
- **NAPs are not merely planning documents but powerful financing engines that can increase access to adaptation finance**
- **Institutional frameworks for mandatory risk screening, and inter-agency coordination are essential to mainstream climate and disaster resilience.**

4.2.3 Group Exercise/Case Study – Pillar 1

Group exercise n°1: Network planning

The following tables consolidate all technical and socio-economic criteria identified by participants during the Pillar 1 group exercise. Working across three different mountain road segments, participants assessed which factors should guide the prioritization of resilient transport investments in mountainous regions. The consolidated list reflects recurring themes raised by multiple groups and provides a basis for developing a standardized assessment framework for future resilience planning.

a) Technical criteria

The technical criteria identified by participants cover engineering, geotechnical, hydrological and operational considerations that influence road performance in mountainous terrain. These criteria reflect the physical processes driving risk, such as slope instability, rockfalls, inadequate drainage, and seismic exposure, as well as the condition of existing infrastructure and the data requirements needed for informed planning and design. Together, they form the backbone of a technical assessment framework for resilient mountain roads.

Category	Criteria Identified by Participants
Geotechnical / Geological	- Seismic exposure zone / seismic zoning - Jointed rock, wedge failures - Slope stability / slope geometry - Shear strength parameters, rainfall-driven instability - Information on seismic zone & geophysical investigations missing
Slope Hazards	- Rockfall susceptibility / missing rockfall protection - Landslide-prone areas (slips, mass slides) - Toe cutting due to undersized drains - Overflow of drainage causing soil destabilization
Hydrology & Drainage	- Undersized drains - Blocked culverts (risk of washout) - Drainage system collapse in Segment 1 - Design of runoff / drainage density requirements - Water table considerations
Road Infrastructure Condition	- Weak retaining walls - Road materials condition - Collapsing drainage system - Poor road safety - Ageing structures (bridges, walls) - Inventory of existing assets & physical infrastructure
Traffic & Operations	- Existing traffic mix & volume - Travel time - Traffic blockage impacts emergency response
Data Requirements & Missing Information	- rainfall records (intensity and variability)
Financial / Engineering Planning	- Cost and financing constraints - Engineering approach for upgrades - Challenges of designing for high flows / runoff

b) Socio-economic criteria

Category	Criteria Identified by Participants
Accessibility & Mobility	- No alternative route (major socio-economic disruption) - Accessibility for communities - Accessibility & economic impact - Loss of accessibility and mobility during closures
Population & Community Factors	- Villages dependent on the road - Vulnerable communities & protected areas - Child & school access - Population unaware of local hazards
Livelihoods & Economic Activity	- Agriculture & market connectivity - Footfall of visitors / tourism flow - Strategic importance

	(economic corridor) - Points of interest (tourist, religious, heritage sites)
Public Services & Emergency Response	- Access to health and education services - Emergency response accessibility - Rescue & emergency operations delay
Environmental & Social Impact	- Environmental assessments - Resettlement plan considerations - Impact on local area from quarries / construction
Cost–Benefit & Strategic Evaluation	- Cost–benefit analysis for different options - Information on economic profile of area (missing)

c) Analysis of the results

- **Strong focus on hazards, weaker focus on exposure and vulnerability**

Participants were highly consistent in identifying geotechnical and hydrological hazards, but gave comparatively less weight to population vulnerability, service disruption, and sectoral dependency. This indicates a tendency to prioritize the technical causes of risk over its human consequences, suggesting an opportunity to strengthen multi-dimensional risk thinking.

- **Limited articulation of economic valuation**

While several groups mentioned “economic impact” or “cost–benefit analysis,” none translated this into quantifiable metrics (e.g., users affected per day, value of freight, agricultural dependency). This suggests that economic evaluation is recognized as important but remains conceptual rather than operational for most practitioners.

- **Emergency response considerations appeared, but not continuity of operations**

Participants noted emergency access and rescue delays, yet continuity of essential services (supply chains, medical logistics, fuel supply, functional recovery time) was largely absent. This indicates that resilience is still viewed primarily as reducing hazard impacts rather than ensuring continuity of critical functions.

- **Institutional complexity recognized, but governance quality not assessed**

Participants mentioned accessibility, hazard awareness, and emergency response roles, yet no group assessed institutional performance criteria such as coordination mechanisms, maintenance regimes, accountability, or regulatory enforcement. This reveals an opportunity to integrate governance diagnostics more explicitly into future exercises.

The strong emphasis on geotechnical hazards, drainage performance, material condition, and other engineering-related aspects is consistent with the profile of the audience, which was composed primarily of engineers and technical officers from different government departments. Their training and daily responsibilities naturally orient them toward diagnosing the physical causes of slope instability and road failure, rather than toward broader socio-economic, governance, or long-term climate considerations. This helps explain why criteria such as climate projections, institutional performance, or continuity of essential services were less prominent or absent in the group outputs. The results therefore reflect both the professional strengths of the participants and an opportunity to introduce more multidisciplinary perspectives into future exercises.

4.3 SESSION 3: Design and Engineering – Pillar 2

4.3.1 Embedding Climate Resilience in Transport Design and Implementation

Presenter: Mr. Goverdhan Lal Verma Senior Road & Bridge Engineer - EPC Consulting Firm

Mr. Goverdhan Lal Verma, drawing on a lifetime of experience as a practitioner, delivered a critical analysis of the current gaps in the Detailed Project Report (DPR) and design phases of hill road projects. His presentation focused on the disconnect between standard investigation practices and the specific realities of geologically fragile, climate-vulnerable mountain terrains.

Mr. Verma highlighted a systemic failure in the initial stages of project formulation. He noted that senior designers often do not conduct reconnaissance surveys personally, leaving critical investigations to third-party survey teams. These teams frequently treat mountain sites like plains, conducting standard cross-sectional surveys (500m upstream/downstream) that fail to capture the broader geological risks. Mr. Verma urged bridge and highway engineers to visit the site before survey teams are deployed to define a specific scope of investigation based on visible risks and vulnerability. Mr. Verma illustrated the danger of "reactive" solutions with a specific example of a slope failure that grew from a 5-meter slide in 2014 to a massive hillside collapse by 2023. Mr Verma shared an example where consultant proposed a 5-meter breast wall based on a localized borehole investigation. However later, broader investigation revealed that the upper road network lacked drainage. Runoff from the upper road was destabilizing the lower slope. A simple catchment drain on the upper road would have prevented the collapse, whereas the expensive structural wall at the bottom failed. Further, Mr. Verma also shared a scientific analysis of the devastation in Dharali village, Uttarakhand, highlighting the consequences of ignoring geological realities. Sharing the images from Dharali he revealed that the village and road infrastructure were constructed on a debris cone, a temporary landform created by sediment from the Kirganga tributary merging into the Bhagirathi river. He emphasized that designs ignored the river’s natural domain. Retaining walls artificially constricted the Kirganga waterway to a mere 9–10 meters, and hotels were constructed directly within the tributary’s natural pat resulting in burying 20 hectares of land under 10 meters of muck.

At the end of his presentation, Mr. Verma advocated for the establishment of "Hill Regulatory Zones," like Coastal Regulatory Zones, to strictly prohibit infrastructure encroachment into vulnerable riverine and mountain ecosystems. From an engineering perspective, he emphasized that bridge designs must exceed standard parameters by incorporating additional span lengths and vertical clearances to accommodate unpredictable high flood levels and debris flows. Finally, he stressed investing in robust Early Warning Systems (EWS) and targeted public education to ensure that tourists and local communities avoid occupying dry riverbeds.

4.3.2 Sharing Slope Stabilization guidelines and experiences from various countries

PRESENTER: Dr. Kishor Kumar Ex-Chief Scientist CSIR - Central Road Research Institution, New Delhi

Dr. Kishore’s presentation focused on slope management practices and the review of work carried out globally along with 25 CDRI’s member countries, while preparing the slope stabilization guideline. He shared the difference between developed and developing countries where countries like Hong Kong, Japan, and the US have strong, legally required slope management systems that keep track of every slope, tree, and potential hazard online. However, India and its neighbours mostly work alone with incomplete data. He used Hong Kong as an example because it hasn't had any deaths since 2008 thanks to a strict system that keeps track of more than 60,000 slopes and strict laws that require geotechnical investigations even for private land development. He highlighted the absence of a unified, national-level database and legal support for slope management in India. He acknowledged that Indian agencies (academic, R&D, and state bodies) perform high-quality work in silos without national coordination. Dr. Kishore emphasized that current "Road Asset Management" manuals focus on pavement but dangerously ignore the slopes above and below the road.

He discussed a fundamental shift to treat "slope management" as an integral part of infrastructure policy, backed by a verified, GIS-based national inventory that is accessible to all stakeholders, from ministers to private landowners. In addition to that he shared that establishing highway management system will take 3-4 years from scratch and can be started focusing on pilot corridors. He concluded stressing that technology
(LiDAR, AIbased warnings) is no longer a constraint; the real challenge lies in policy integration, where slope management is embedded into the national road development policy rather than focusing on maintenance related tasks.

4.3.3 Reflections from GNHCP Project by Ministy of Road Transport and Highways (MoRTH)

PRESENTER: Mr. Nikhil Narang, IES, Executive Engineer, MoRTH

Mr. Nikhil Narang presented a detailed overview of the Green National Highway Corridor Project (GNHCP) where he highlighted that climate-induced disruptions (floods, landslides, heatwaves) cost India approximately $10 billion annually, necessitating an urgent shift from reactive repairs to proactive, resilience-focused design. After that he shared a brief introduction on the GNHCP as a flagship initiative supported by a $500 million loan from the World Bank (total project cost ~$1.28 billion). The aim of the GNHCP is to develop 781 km of climate-resilient highways across four states: Himachal Pradesh, Rajasthan, Uttar Pradesh, and Andhra Pradesh. The project is divided into 23 construction packages focusing on two-lane and four-lane configurations. The key objective of this initiative is sustainability, adoption of green technology, social safeguards, and institutional capacity building. Mr. Narang emphasized that resilience must be embedded in the "paperwork" before it hits the ground.

He stressed that for DPR consultant selection, there should be mandated experience in climate-resilient design, geotechnical engineering, and hydrological modelling and further contracts should require mandatory climate risk assessments, hazard mapping, and slope stability plans and payments are linked to the quality of assessment and the submission of a "Resilient Integration Plan." He highlighted that the project prioritizes "Green Technologies" over conventional grey infrastructure, aiming for a 15% reduction in carbon emissions. specific interventions validated through risk screening including Use of coco fibre, Jute, and erosion control blankets with shrub/grass plantation. Mr. Narang detailed several innovative bio-engineering solutions currently being adopted to balance structure with ecology. He highlighted the use of Hydro Seeding for rapid vegetation growth on cut slopes and Geocells combined with hydro seeding for robust slope protection. Structural techniques were also discussed, such as Shotcrete Crib Walls, which integrate vegetation with structural support. A notable example from the Araku region in Andhra Pradesh involved Green Fascia Retaining Structures, where walls are covered with greenery to reduce heat islands and improve aesthetics.

Mr. Narang also compared Indian standards with Scandinavian models during his presentation to identify key areas for improvement. He encouraged for Advanced Modelling to predict road surface temperatures and freeze-thaw cycles crucial for managing thermal stress zones in Central India. While talking about policy and governance, he proposed moving away from fragmented policies toward Regional Climate-Resilient Transport Cells to centralize data and coordination. Additionally, he shared that MoRTH is compiling a Compendium of Green National Policies to unify these standards. He concluded by stressing that resilience is a deliberate choice, not a chance occurrence, leaving the audience with a quote from John Ruskin: *"When we build, let it not be for present use alone. Let it be such work as our descendants will thank us for."*

4.3.4 Reflections from the HPSRTP (Himachal Pradesh State Roads Transformation Project) by HPRIDCL

PRESENTER: Mr. Pawan Kumar Sharma, Director (Projects) HPRIDCL

Mr. Pawan Kumar Sharma presented a case of climate-resilient infrastructure sharing about the performance of World Bank-funded HPSRTP roads during the severe monsoons of 2023 and 2024. He highlighted that while conventionally constructed roads suffered 30–40% damage and remained closed for months during the 2023–24 disasters, the World Bank-funded HPSRTP roads experienced less than 2% linear damage and were restored within hours. He underscored that the bioengineering was incidental in road projects. Additionally, he added - to institutionalize resilience, HPRIDCL created a bio engineering manual and also included a separate Bill of Quantities (BOQ) in contracts. This ensures contractors are paid for green measures, incentivizing implementation for slope protections.

Mr. Pawn Kumar Sharma highlighted the urgent necessity for climate-resilient infrastructure in Himachal Pradesh, noting that recent monsoons have shifted from predictable seasons to frequent, high-intensity cloudbursts. Mr. Sharma presented HPRIDCL breaking away from previous practices where bioengineering was often treated separately, HPRIDCL institutionalized a Bio-engineering Manual with its inclusion on specific Bill of Quantities (BOQ) items. This ensured that contractors were financially incentivized to rigorously implement slope protection measures. Further, sharing the pictures during the presentation he emphasized that the project’s technical success was possible due to hybrid of "grey" and "green" interventions, including the use of bamboo crib walls, hydro seeding, and jute netting for slope stabilization. Additionally, surface runoff was not just drained but controlled through surface drains to rehabilitate existing ponds, to support groundwater recharge. Mr Sharma also highlighted that the project also supported circular economy principles by recycling cut-debris into Gabion walls and prioritized community ownership through plantation drives (over 10,000 plants), along with social enhancements measures like noise barriers, bus stands among others.

Comment for Professor Ashutosh Kumar, IIT Mandi: Prof. Ashutosh Kumar from IIT Mandi offered critical academic insights for the way forward. He emphasized that with the increasing frequency of cloudbursts, engineers must shift their focus from simply blocking landslides to managing them. He suggested modeling how debris moves so that designs can dissipate, or reduce, the energy of high-velocity mud and rocks rather than trying to stop them abruptly. Prof. Kumar also highlighted the golden rule of geotechnical engineering: "Never stop water." He argued that drainage systems must be sized and designed according to the specific rock and soil conditions to channel water effectively. Finally, he warned against the "rush to fund" syndrome, where project reports are prepared in a hurry just to secure budgets, often leading to poor design solutions. He encouraged bridging the gap between scientific research and field practice, noting that IIT Mandi has introduced a new specialized course on "Disaster Resilient Mountain Hill Road Engineering" to train future engineers.

Key Take Aways:

- **Attend the disconnect between standard investigation practices and the specific realities of geologically fragile, climate-vulnerable mountain terrains**
- **Institutional and contractual mechanisms are critical to enforce resilient design standards, require climate-adjusted specifications, and ensure proper implementation.**
- **Like forest and coastal regulatory zones hill regulatory zones needs to be prepared**
- **Need for slope management inventory and system to support mitigation of slope failure**
- **Promotion of both Gray and Green Infrastructure to reduce the cost and damage**

4.3.5 Group Exercise/Case Study – Pillar 2

Group Exercise n°2: Design and Engineering (Pillar 2)

Group exercise 2 aimed to immerse participants in practical decision-making for designing resilient road infrastructure under real-world constraints. Working in five small groups, participants were asked first to select two feasible engineering solutions for three distinct road segments in a hypothetical Himalayan corridor, and then to determine how they would adapt their strategy if the available budget were reduced by 40%. The objective was to understand how practitioners prioritize interventions, balance technical effectiveness with cost considerations, and manage trade-offs between structural, nature-based, and maintenance-oriented options when resources are limited.

Across all groups, two clear patterns emerge:

1. **Drainage and slope stabilization dominate the proposed engineering solutions** reflecting a strong consensus on the primary drivers of road failure in mountainous terrain.
2. **When budgets are reduced, participants shift toward hybrid, lower-cost, or nature-based solutions**, and toward prioritizing the most critical hazards rather than maintaining full intervention scope.

The results are consistent with engineering logic but also reveal blind spots and opportunities for improving decision-making frameworks.

Engineering Solutions Chosen (Before Budget Cut)

Participants most frequently selected two types of interventions:

a) <u>Drainage upgrades (very high frequency)</u>

Appeared in multiple forms:

- Catch drains (roadside surface runoff control)
- Lining of channels

- Drainage cleaning, maintenance & clearing blockages
- Undersized culvert correction
- Cross-drainage improvements
- “Proper gradient” and “pre-monsoon drainage maintenance”

Rationale expressed by participants:

“Runoff water is the trigger for landslides”

“Better drainage increases road longevity”

Drainage was clearly perceived as the most cost-effective and essential measure.

b) Slope stabilization measures (high frequency)

Types selected:

- Retaining walls (masonry, gabion, reinforced)
- Boulder pitching
- Crib walls
- Shotcrete
- Slope regrading
- Rockfall nets and protection systems
- Bioengineering or hybrid structures (engineering + vegetation)

Participants demonstrated familiarity with multiple stabilization techniques and often combined structural and natural methods.

c) Hybrid or nature-based engineering solutions (medium frequency)

Mentioned several times:

- Bamboo crib walls
- Bioengineering + local vegetation
- Combined “small engineering structures + bioengineering”
- “Nature-based solutions (50%) + retaining wall (50%)”

These appear especially when cost becomes a constraint.

d) Segment-specific preferences

Some groups adapted solutions to slope types:

- **Segment 1** (foothills): drainage upgrades, small structures, vegetation
- **Segment 2** (steep metamorphic slopes): retaining walls, rockfall nets
- **Segment 3** (river gorge/alpine zone): rockfall protection, shotcrete, gabions

This indicates that participants applied context-specific engineering judgment rather than generic solutions.

Strategies Proposed When Budget Is Cut by 40%

Participants were asked: “What do you do if the budget is cut by 40%?” Three dominant strategies emerged.

e) Prioritization of drainage as the first investment (highest consensus)

Multiple groups explicitly stated:

- “Drainage would be the first focus.”
- “Drainage upgrade is the most important measure.”
- “Mapping susceptibility → identify critical sections → reduce cost.”

This shows a nearly universal understanding that drainage improvements provide maximum risk reduction per dollar spent.

f) <u>Shift toward lower-cost or hybrid engineering options (high frequency)</u>

Examples:

- Replace full retaining wall with crib wall
- Use bamboo crib wall instead of RRM
- Reduce rockfall net length coverage + combine with vegetation
- “Hybrid solution: shotcrete + rock net + bioengineering”
- “Use bio-engineering measures if budget cut”

This reflects:

- adaptation to financial constraints
- preference for solutions that maintain functionality while reducing upfront cost

g) <u>Reduce intervention length or scope (medium frequency)</u>

Participants recommended:

- Applying measures only at the most critical sections
- Prioritizing “high-risk portions”
- Using mapping (LIDAR/UAV) to locate “susceptibility zones”

This indicates an intuitive understanding of risk-informed spatial prioritization, even without formal tools.

h) <u>Increase maintenance efforts when capital investment is limited (medium frequency)</u>

Participants wrote:

- “Better maintenance system”
- “Regular cleaning and clearing drains”
- “Cross-drainage cleaning increases longevity”

This shows that when capital budgets shrink, practitioners compensate with operational strategies.

The results from Exercise 2 revealed several patterns in how participants approached engineering decisions for resilient mountain roads. Across all groups, drainage improvements, retaining structures, and rockfall protection consistently appeared as preferred solutions, showing the strong technical grounding of an audience largely composed of engineers. It is particularly noteworthy that drainage emerged as the single most common and widely agreed upon solution, both under normal conditions and when the budget was reduced.

What is particularly striking, however, is how participants reacted when the budget was cut by 40%. Instead of rethinking the intervention strategy, most groups shifted toward scaled down or hybrid versions of their original proposals, such as combining small engineering structures with bio engineering, prioritising specific high-risk points, or choosing less costly materials like shotcrete instead of full retaining walls. This indicates a tendency to preserve the same conceptual approach while reducing scope or quality rather than exploring alternative design pathways or applying explicit cost benefit reasoning. Only a few groups used prioritisation logic, for example focusing first on drainage as the most cost-effective measure, lifecycle cost thinking, or re sequencing of works. Another notable observation is that many proposed solutions were relatively generic across the three segments, reflecting reliance on familiar engineering tools rather than segment specific or risk differentiated design.

Overall, the exercise highlights both the technical strengths of participants and an opportunity to strengthen decision making frameworks that help engineers adjust strategies more strategically rather than proportionally when major financial constraints arise.

4.3.6 Closing Remarks - Day 1

SPEAKER: Ms. Jen JungEun Oh - Practice Manager, Transport, South Asia, World Bank

Ms. Jen virtually concluded the first day of the workshop by expressing appreciation to the delegations from India, Bhutan, Mongolia, Nepal, PNG, Sri Lanka, and Vietnam, as well as partners MoRTH, HPRIDCL, and CDRI for a rich exchange of challenges and solutions.
Drawing from her previous experience in Vietnam, she highlighted a critical paradigm shift - the importance of using meteorological and hydrological data to change the narrative of resilience from a "cost" to a "strategic economic investment." Reflecting on the day's deliberations, she summarized the key takeaways from the first two pillars of the framework:

- **Pillar 1 (Network Planning):** The most cost-effective resilience measures occur *before* construction. Risk-informed planning is not just about where to build but knowing where not to build.
- **Pillar 2 (Design & Engineering):** Technical solutions (such as bioengineering and slope stabilization) already exist. The challenge lies in consistent application by embedding risk clauses into contracts and designing for future climate conditions rather than past records.

Looking forward to Day 2, Ms. Oh encouraged participants to consider how to bridge these technical designs with institutional and financial mandates (Operations, Maintenance, and Contingency Planning) to ensure resilience is integrated not just occasionally, but systematically.

DAY 2

4.4 Session 4: Operations and Maintenance – Pillar 3

4.4.1 Introducing RAMS and in-built Climate Module: A tool for climate-informed planning; Maintenance and Inspection Regimes

Presenter: Mr. Bhavesh Jain Principal Transport Specialist, TRL, India

Mr. Bhavesh Jain's session focused on pillar 3, exploring the integration of climate risk into Road Asset Management Systems (RAMS) to ensure safer, more resilient networks. Mr Jain shared the case study of Kerala where he emphasized that the robust infrastructure faces failure risk with out maintenance and monitoring regimes. With the changing climate change there is an increasing frequency of landslides, rockfalls, flash floods, and slope instability. Further, extreme rainfall and weather variability also has accelerated pavement deterioration rates beyond standard lifecycle predictions which has high impact on the rehabilitation costs and severe socio-economic consequences due to scarcity of alternative routes required for rescue and relief.

In his presentation Bhavesh shared on the salient features of RAMS as a unified, cloud-based platform maintaining a digital inventory of physical assets (pavements, bridges, markings, slopes) integrated with institutional data (deterioration patterns, budgets, and policies). The core module of RAMS contains inventory management establishing a geospatial database of assets, monitoring current performance and service levels and strategizing maintenance interventions to maximize service levels within financial constraints. Bhavesh underscored that the standard RAMS facilitates predictive maintenance based on asset condition and with the learnings RAMS is to transition towards risk bases climate informed predictive maintenance. Mr Jain shared that this approach would modify maintenance plans by accounting for specific environmental risk factors rather than relying solely on physical deterioration data. He also focused that the climate resilience module ensures network resilience against changing climatic events by identifying high-risk segments: importing hazard data (e.g., historical flood lines, landslide zones) to pinpoint critical network links which will prioritize the directing of maintenance resources and resilient material upgrades to these high-risk segments.

Mr. Jain highlighted the three key components of the assessment framework listed below.

1. hazard identification: integrating multi-hazard maps (landslides, floods, coastal surges) from disaster management authorities.
2. Exposure Determination: identify specific road segments, structures, or slopes located within hazard zones.
3. vulnerability assessment: evaluating physical, geotechnical, and socioeconomic factors (population density, traffic volume, demographics).

He further shared that the synthesis of these factors generates a risk score, enabling agencies to prioritize limited funds for the most critical, hazard-prone assets.

The case study of Kerala (iroads)

Mr. Jain shared about the Kerala public works department (PWD) implementing a customized RAMS, known as iroads, across a 31,000 km network traversing coastal, plain, and mountainous terrain.

He shared the key features like historical flood data (specifically the 2018 flood event) overlayed onto the road network GIS. This supported in visualization of risk the system categorized segments into high (red), medium (blue), and low (green) risk zones. This has resulted in facilitating preventive maintenance planning in flood-prone districts like alappuzha and Kottayam. He also shared that the system integrates real-time weather feeds (rainfall, temperature) from the India Meteorological Department (IMD). high-rainfall alerts trigger automated notifications to regional engineers, prompting immediate asset inspection. Further, Iroads also engage the citizens through the pwd4u mobile app. A distinct feature of the Kerala project is the pwd4u mobile application, designed to crowdsource asset data. Some of the function shared by Bhavesh from his presentation are provided below:

- citizens utilize the app to photograph and geo-tag issues such as potholes, waterlogging, or damaged barriers.
- data is routed directly to the ministry, ensuring transparency. the app has facilitated over 50,000 complaints with a target resolution window of 48–72 hours.
- the tool holds significant potential for post-disaster reporting, allowing the community to assist in rapid damage assessment.

Lastly Mr. Jain shared economic efficiency between 2021 and 2024 where Kerala PWD realized savings of approximately $2.63 million USD on maintenance and rehabilitation by optimizing planning through iroads. He also emphasized on the scalability of the framework which is adaptable to Himalayan regions and other Indian states facing similar climatic challenges as roads has successfully demonstrated a shift from reactive repairs to a proactive, data-driven, and risk-based maintenance regime.

Q&A and Discussions:

Clarification on the Kerala Project Scope Participant (Project Team Member): I would like to add some context regarding the Kerala case study, as I was part of that project. The state identified a **Critical Road Network (CRN)** of approximately 7,000 kilometers based on 19 distinct parameters.

From that larger network, a pilot of 550 kilometers was selected for intense scrutiny. This segment underwent physical data collection and ground verification. It included a diverse mix of terrain: coastal

roads, flood-prone sections, and landslide-prone areas in the northern districts. The objective was to determine how climate data and Detail Project Report (DPR) systems could be effectively integrated.
Comment on Predictive Modeling and Vulnerability (Participant): This type of study is vital. However, it is important to emphasize that we must not limit the assessment to existing landslides. The focus must also be on vulnerable slopes of areas that have not yet failed but are at risk. Identifying these "potential" hazards is where predictive modeling becomes essential.
Response (Mr. Bhavesh Jain) Agreed. That is the goal of incorporating risk factors.

Observation on Meteorological Data Limitations in the Himalayas (Participant): This is an excellent initiative, and it is good to see TRL's research on infrastructure aging and future prediction being applied. However, applying this to the Himalayan landscape presents a specific challenge regarding meteorological data.
We have observed in Uttarakhand, Jammu & Kashmir, and recently near the Vaishno Devi temple that standard rain gauge density often fails to capture cloudburst scenarios. These are highly localized events. Therefore, relying solely on standard meteorological station data might not capture the full risk scenario in mountainous terrain. This limitation needs to be acknowledged.

Response (Presenter): Thank you for that suggestion. I completely agree; the density of data collection points and the ability to capture localized events like cloudbursts is a critical challenge that needs to be addressed as we scale this to mountain regions.

Key Take Aways:

- **Climate-informed RAMS, supported by tools such as iRoads, allows agencies to evaluate condition, risk, and socio-economic relevance to prioritize maintenance more effectively.**
- **Resilience must be embedded in the "paperwork" through mandatory hazard mapping and "Resilient Integration Plans" before construction begins to avoid massive long-term recovery costs.**
- **Reliable data on slopes, drainage systems, rainfall patterns, and asset condition are essential to moving from reactive to preventive O&M.**
- **Preventive maintenance, including clearing drains, stabilising slopes, and systematic inspections, reduces long-term costs and service disruptions.**
- **Hybrid approaches integrating engineering measures with nature-based solutions enhance slope stability and reduce maintenance burdens.**

4.4.2 Reflections from Bhutan and Sri Lanka

A) **PRESENTER:** Ms. Yeshey Choden Deputy Executive Engineer Design & Geotech Division, Govt. of Bhutan

Ms. Yeshey Choden started her presentation with brief introduction of Bhutan and its road connectivity which spans roughly 18,000 kilometers. She shared that Bhutan has achieved significant development of road from 2000 KM (in 2003) which has increased by seven folds reaching 18000 KM support with of the Government of India, the Asian Development Bank (ADB), the World Bank, and the Royal Government of Bhutan. She touched upon having nine regional offices responsible for implementing

construction and maintenance, supported by five specialized divisions at headquarters for planning and management.
She also shared the maintenance framework which has evolved significantly over the years, i.e. 1988 & 2005. The original manuals established the concepts of Routine, Periodic, and Restoration/Emergency maintenance. Similarly, she also shared about the maintenance plan to align with World Bank standards and is being reviewed. She also shared that fixed cycle maintenance is executed via Performance-Based Management System (PBMS) using their internal workforce daily and in relation to larger repairs and emergency clearance. Due to a lack of internal skilled labor and equipment, these are typically contracted out.
She shared good practices and strengths on operation and maintenance where they utilize specific maintenance calendars for low altitude versus high-altitude roads. In addition to that Some of the activities focus on cleaning drains and prepping cross-drainage structures to handle debris are prioritized pre monsoon and engineering teams assess damages to prioritize structural repairs for the next budget cycle.
She acknowledged that with increasing climate variability, slope management has been critical for Bhutan. She shared that Bhutan lacks a comprehensive landslide hazard map, and currently working together with World Bank in developing a landslide risk assessment. Further, she also added that JICA is also supporting us with projects focused on rockfall and debris flow mitigation and plans to set up a geotechnical lab. Ms Choden also shared a Case Study from In Kaguchin (South-Central Bhutan), where they aced chronic sinking issues due to a high groundwater table. With support from the Green Climate Fund (GCF) project, they implemented a 5-meter-deep trench drain to lower the water table, which has successfully stabilized the road while using reinforced earth structures like Paralink and Paragrid.

Ms. Choden shared about the digital tools and data management that Bhutan have adopted to streamline operations i.e Bhutan Road Watch which provides real-time roadblock information to the public. Similarly, Road Slope Failure Inventory (RSFT) that catalogs slope failures by cause, history, and mitigation status, assigning a criticality rank to prioritize funding and utilize a Bridge Maintenance System, drone technology for preliminary investigations, and social media (Facebook) for rapid public dissemination. For Emergency Response and Winter
station machinery permanently for immediate clearance winter maintenance remains a challenge. She acknowledged that mechanized de-icing systems are lacking, and laborers work manually to spray salt and clear snow in high-altitude areas to keep passes open.
She shared that like other mountainous countries Bhutan also faces significant challenges i.e. difficult terrain, climate variability, financial constraints, and a shortage of skilled manpower. Further, she recognized that the system is often reactive, prioritizing emergency maintenance over preventive measures. In relation to the plans and policies she highlighted that to address high roughness levels ADB has helped formulate a master plan. And a 3-year master plan (2025-2028) a targeted maintenance blitz to bring critical roads to an acceptable state. She also stated that Bhutan is currently piloting a shift from internal force account work to Output and Performance-Based Road Contracts (OPBRC). If the pilots are successful, they will transition fully to this model.

She concluded that Bhutan is striving to evolve their O&M practices from reactive solutions to preventive strategies, ensuring a more resilient transport network for Bhutan in mountain regions.

B) PRESENTER: Mr. R.M.W.R Eheliyagoda, Provincial Road Development Authority, Sri Lanka

Mr. Eheliyagoda provided an overview of the road infrastructure in Sri Lanka, a country spanning approximately 65,000 square kilometers with a total road network of 120,000 kilometers. He shared that the Road Development Authority (RDA) is specifically responsible for Class A and B roads (National Roads), comprising roughly 12,000 kilometers, along with approximately 10,000 bridges and 150,000 culverts. Provincial councils manage the remaining road classes (C, D, and E). The RDA operates under

a Director General, supported by Provincial Directors across 10 provinces, Chief Engineers in 25 districts, and Executive Engineers at the divisional level.
Mr. Eheliyagoda highlighted that Sri Lanka faces distinct challenges based on terrain flat, flood-prone coastal areas and a central hilly region prone to landslides. During his presentation the country was experiencing heavy rainfall (due to cyclone Ditwah), rendering many roads impassable. He shared that the RDA possesses strong design and maintenance capabilities but lacks in-house geotechnical expertise. He also highlighted that RDA relies heavily on the National Building Research Organization (NBRO) to assess slope stability before deploying crews to clear landslide debris.
He shared that a major cause of flooding in urban areas of Sri Lanka is identified as unauthorized construction and lowland filling. Additionally, he shared about RDA implementing early warning systems (flash flood alarms) in town areas to protect lives and resources along with public awareness initiatives encouraging villagers to maintain "go-bags" (backpacks with valuables) to facilitate rapid evacuation during flash floods. At the end of his remarks, Mr. Eheliyagoda acknowledged a critical gap in their current system: the lack of a comprehensive database on unstable slopes. He proposed the development of such a database as a priority to align with best practices discussed during the workshop.

4.4.3 Group Exercise/Case Study

Group Exercise n°3: Operations & Maintenance (Pillar 3)

Exercise 3 focused on strengthening participants' ability to plan risk-informed Operations & Maintenance (O&M) for mountainous road networks across the monsoon cycle. Working in small groups, participants were asked to:

(1) build a simple six-step O&M workflow covering the *pre-monsoon*, *monsoon*, and *post-monsoon* phases; and

(2) identify three practical, low-cost monitoring solutions that can be realistically implemented by road agencies.

The objective was to understand how practitioners organise seasonal preparedness, integrate community-based processes, and leverage low-cost technologies to enhance road safety and service continuity during extreme weather.

Across all groups, three clear patterns emerged:

1. Participants recognised the monsoon as the defining driver of O&M planning, and consequently structured workflows around preparedness, response, and restoration.
2. Community involvement and decentralised reporting were consistently highlighted, demonstrating strong appreciation for local knowledge as a monitoring asset.
3. Low-cost, technology-light monitoring methods—particularly rainfall tracking, remote sensing, and UAV use—were widely proposed, reflecting a pragmatic approach suitable for resource-constrained agencies.

The results show a grounded understanding of monsoon-driven road risk but also reveal opportunities to formalise workflows and integrate monitoring tools into institutional O&M systems.

a) O&M Workflow Proposed Across the Three Phases

i) Pre-Monsoon Phase (Preparedness)

Participants almost unanimously prioritised pre-monsoon activities as the most critical stage of O&M. The most frequent actions included:

- Risk assessment and mapping of vulnerable locations, including identification of critical slopes, drainage choke points, and exposed road sections, bridges & culverts.
- Engagement with local communities to identify high-risk segments and gather experiential knowledge.
- Preparation of community search & rescue plans, including resource inventories and identification of emergency shelters.
- Clearing drains, cross-drainage structures, and natural waterways before the onset of rainfall.
- Training of volunteers and delegation of staff for monsoon-season operations.
- Condition assessment of the road network, especially in sections historically affected by landslides.
- Development of technology tools like Mobile application, establish WhatsApp groups for incident reporting and information dissemination

Participants demonstrated strong consensus that early preparedness reduces both operational burden and rainfall-induced failures.

ii) Monsoon Phase (Response & Continuous Monitoring)

During the monsoon, groups emphasised continuous vigilance and rapid response. Key actions included:

- Request for special weather bulletins from regional and national weather monitoring agencies
- Ensuring 24×7 operation of emergency centres, with ready deployment of machinery, equipment, and rescue teams.
- Dissemination of early warnings to travellers and communities in upper-slope locations.
- Traffic Management, Maintaining and securing diversion routes for stretches prone to blockage or collapse.
- Use of surveillance systems such as EWS, imagery analysis, remote sensing, UAVs, and other low-cost monitoring tools.
- Strengthening coordination mechanisms between road, disaster management, police, and local authorities.
- Community partnership for reporting, including trained volunteers sharing real-time field information.

This phase highlighted the importance of operational readiness and information flow to prevent local disruptions from escalating into prolonged road closures.

iii) Post-Monsoon Phase (Restoration & Learning)

Following the monsoon, participants focused on restoring functionality and capturing lessons. Major actions included:

- Risk-informed O&M planning for the next cycle, including budgeting, manpower allocation, and equipment mobilisation.
- Extensive field inspections, especially for slope instability, drainage blockages, and structural distress.
- Review the efficiency of codes/standards, sops and manuals on their effectiveness

- Post-Disaster Needs Assessment (PDNA), including rainfall data analysis, damage assessment, and loss estimation.
- Identification of infrastructure failures and documentation of lessons learned.
- Preparation of mitigation and repair plans, including slope stabilisation and drainage rehabilitation.
- Upgrading Early Warning Systems based on observed gaps during the season.

Overall, participants displayed a strong understanding of post-event learning and its role in strengthening preparedness.

b) Low-Cost Monitoring Solutions Identified

Participants proposed a range of low-cost, practical monitoring solutions that agencies can adopt with minimal investment. The most common included:

1. Community-Based Monitoring Systems
    - Local reporting networks using trained volunteers.
    - Structured information-sharing with road users and hillside communities.
2. UAVs / Drones for Rapid Assessments
    - Low-cost micro-UAVs for post-rainfall inspections and mapping.
    - Quick visual checks of slopes, drains, and inaccessible terrain.
3. Open-Source GIS & Remote-Sensing Platforms
    - Free imagery (Sentinel, Google Earth) to detect changes in slope and drainage conditions.
    - Simple rainfall tracking using open-data portals and manual rain gauges.

These solutions reflect a pragmatic balance between technology and community resources consistent with the realities of mountainous states.

Observation

The exercise revealed that participants possess strong practical knowledge of monsoon-driven road risks and rely heavily on community engagement and low-cost monitoring approaches. The workflows developed were logical and comprehensive, covering preparedness, response, and restoration. However, the responses also suggest the need for more formalised O&M systems, clearer standard operating procedures, and stronger integration of monitoring data into decision-making. There is also scoped to introduce structured prioritisation tools so that agencies can better sequence interventions and allocate limited resources more strategically.

4.5 Session 5: Contingency/Emergency Planning – Pillar 4

4.4.1 TRANSPORT EMERGENCY MANAGEMENT PLAN & TRAFFIC EVACUATION PLAN

PRESENTER: Mr. Binu Mathew, COO and PARTNER, Tarutium Global Consulting

Mr. Binu Mathew presented a comprehensive framework for a Transport Emergency Management Plan, specifically tailored to the challenges faced in Himachal Pradesh. While acknowledging other modes of transport (railways, helipads), the focus remained primarily on the road network. The presentation highlighted the reality of relief and restoration timelines, citing that damages from June 2025 were still visible in November, underscoring the need for a more robust system. He shared that working in association with HPRIDCL, the team has identified high-exposure zones and specific road sections vulnerable to disasters. This involves prioritizing roads based on mobility, village connectivity, and traffic volume. Mr. Mathew outlined a step-by-step process to reduce risk listed below:

i. **Preparatory Phase:** This involves inventory management (fuel, machinery) and knowing exactly where assets are located to minimize mobilization time. It also includes establishing alternative communication systems (satellite phones, radio) for when mobile networks fail.
ii. **Early Warning Phase:** Treating "data as infrastructure." This involves aggregating data from various sources (weather, police, social infrastructure) into a single portal to make risk visible.
iii. **During Disaster:** The activation of a Transport Emergency Operations Center (TEOC). This unit receives data from State/District Disaster Management Authorities (SDMA/DDMA) and coordinates the deployment of experts, police and fire services.
iv. **Response Phase**: Immediate clearance of routes to minimize congestion and allow access.
v. **Restoration Phase**: Long-term recovery and retrofitting.

While discussing institutional arrangements and gaps he identified “custodianship" of sensors and early warning infrastructure as a challenge. He emphasized that there is a need for clear policy on who owns, maintains, and pays for the repair of these systems to ensure sustainability. Highlighting the incorporation of resilience in the detailed project report, he shared that 19 parameters have been identified for landslides and 26 parameters for floods in terms of existing roads. Mr. Mathew also shared that the team is working on identifying threshold levels for road quality to help insurance sectors gauge premiums, a concept gaining interest among private operators and tourist roads.
Mr. Mathew closed his presentation stating that system integration bringing road safety, medical response, and transport infrastructure data into a unified synergy is the most critical component of a successful emergency plan.

Q&A and Discussion
Question (Arnab): Have you investigated integrating the existing road safety response (108 ambulance service, Golden Hour concept) into this emergency plan to optimize resources?
Response (Binu Mathew): Yes, this is being investigated. The Road Asset Management System (RAMS) should ideally function as a central dashboard that hosts all these factors.
Comment (Project Official from HPRIDCL): The 108-ambulance service is well-entrenched in HP. The project is currently developing an incident reporting app for common citizens that will integrate the 108-response system directly.
Comment (Shabir, HP Road Safety Project): Mr. Shabir highlighted a custom-made "Wrecker Vehicle" developed under the World Bank project for the police. He shared that vehicles combine search, rescue, extrication, and accident site clearance capabilities (including pneumatic bags capable of lifting 40 tons). He emphasized that road safety enforcement and disaster rescue operations should not operate on silos. The police, Home Guards, are being trained to operate these vehicles as first responders.

Smart Emergency Operations

- **Comment** (Sachin): Suggested the inclusion of "Smart Emergency" protocols, which utilize telematics and "Click & Collaborate" software to upgrade peripheral hospitals and first aid centers, ensuring efficient distress call support during evacuations.

4.4.2 INTEGRATING DISASTER RISK MANAGEMENT INTO THE TRANSPORT SECTOR

PRESENTER: Mr. Empati Uday Kumar, Specialist, Technical Studies, CDRI

The presentation from Mr. Empati Uday Kumar described the Coalition for Disaster Resilient Infrastructure's (CDRI) technical assistance provided to the Himachal Pradesh State Disaster Management Authority (HPSDMA) following the 2023 floods. This assistance was delivered through the DRI (Disaster Resilient Infrastructure) Task Force, which mobilizes experts from CDRI member countries (in this case, experts from Nepal and India) to provide targeted interventions.

He shared the engagements, which were divided into four-stage processes, starting with a Post-Disaster Needs Assessment (PDNA) in 2023. He further shared that the PDNA was followed by strategic and detailed missions that provided specific engineering solutions, ultimately enabling the state to secure bilateral funding for implementation.

He underscored that a critical road analysis was conducted in two segments co-identified by the HPSDMA with the support of DRI task force. He shared findings from the analysis of an urban road, characterized by complex land tenure and multiple stakeholders, and a forest road. The study pointed out that instability was driven by natural factors such as steep terrain, fragile geology, and intense rainfall, exacerbated by human factors like construction waste dumping and culverts blocking natural drainages. These blockages were identified as major triggers for slope failure, leading to hydrological disruptions like debris flows and shallow slides caused by water accumulation.

Finally, Mr. Empati emphasized that the initiative extended beyond report generation, fostering capacity building and catalyzing a policy shift toward investigating root causes, resulting in a state request for formal Slope Maintenance and Stability, initiating with a comprehensive landslide inventory.

Here is the refined Q&A and discussion section for the workshop proceedings.

Q&A and Discussion

Question: Following the 2023 disaster, specific roads were restored based on CDRI's recommendations. Given that 2025 brought similar disasters, effectively serving as a "litmus test," is there a report analysing whether these restored roads withstood the recent events better than the general network?

Response (Mr. Uday Kumar, CDRI): The initial CDRI study was site-specific. While funding was secured for implementation, a formal performance audit analysing the specific outcomes of those suggestions post-2025 has not yet been made public.

Intervention (Mr. Pawan Kumar Sharma, HPRIDCL): The roads upgraded under the current project serve as that testimony. While the general road network suffered significant destruction during the recent events, the project roads implemented with climate-resilient measures such as rock bolting, concreting , and nature-based solutions witnessed less than 2% damage. This low damage rate validates the efficacy of the interventions.

Question: The presentation included imagery of a forest fire. Considering recent discussions at COP regarding forest fires destabilizing mountain slopes a major issue in East Asia and Papua New Guinea has CDRI conducted specific work in this area?

Response (CDRI Representative): Forest fires have emerged as a critical risk area for CDRI. This was initially identified during work on telecom resilience, specifically regarding backhaul lines crossing forested areas. It is now recognized as a significant threat to all infrastructure sectors globally, and CDRI is receiving increasing requests from member countries for vulnerability assessments regarding fire risks.

Comment: Mr. Ramraj Narasimhan provided further elaboration on the Disaster Resilient Infrastructure (DRI) Task Force referenced in the technical presentation. He described it as a rapid-response mechanism designed to remain relevant across diverse global contexts.

He shared that CDRI member country may submit a specific, targeted request for technical assistance. He also highlighted the mechanism where CDRI brings together a specialized team of experts, drawn from both the requesting country and the broader coalition of membership. The strategic goal is to match the specific problem with experts who have successfully tackled similar challenges elsewhere. He shared an example where experts were mobilized from Nepal to apply their experience with Himalayan Mountain infrastructure. Following a severe cloudburst that threatened bridge integrity, a team was deployed that included experts from India alongside local specialists.

Key Take Aways:

- **Effective emergency management requires shifting from ad-hoc reactions to a structured 5-phase lifecycle: Preparatory, Early Warning, During Disaster, Response, and Restoration**
- **Disaster response and road safety enforcement need to go together rather than in Silos**

4.4.3 REFLECTIONS FROM PAPUA NEW GUNIEA (PNG)

PRESENTER: Mr. Kenneth Yamu, Deputy Executive Engineer Design & Geotech Division, Govt. of PNG
Mr. Kenneth Yamu shared a comprehensive update on Papua New Guinea's (PNG) infrastructure progress since 2019, centering his reflections on the "Connect PNG" 20-year strategic plan. He highlighted the program's ambitious goal to connect the entire country via road, expanding the current 32,000 km network to 35,000 km by addressing critically missing links. To support this mandate, he noted that the government has legislated 5.6% of the national budget to the program, a vital move given that 60-70% of the population resides in mountainous regions often isolated from economic opportunities.
Mr. Yamu outlined the Department of Works' alignment with the Paris Agreement and the National Adaptation Plan. He underscored key milestones, including the 2020 development of the Climate Resilient Infrastructure Policy and strategic partnerships with the Australian transport sector and CDRI (IRIS Program) to develop resilient guidelines and codes.
On the engineering front, Mr. Yamu detailed specific interventions to combat extreme weather. He described projects in Lae City, the industrial hub, where roads are being reconstructed with rigid concrete pavement to withstand heavy rainfall, alongside upsized drainage and concrete culverts to prevent corrosion.
He also showcased the Highlands Highway, a $1 billion ADB investment where 72 bridges are being upgraded, featuring a case where a collapsed abutment was temporarily restored with a Bailey Bridge. Concluding his reflections, Mr. Yamu identified the lack of accurate data systems and the "incremental costs" of resilient building as primary challenges. He emphasized a way forward focused on capacity building for engineers, utilizing CDRI guidelines for network-wide vulnerability assessments, and establishing a Dedicated Climate Resilience Fund.

4.4.4 GROUP EXERCISE/CASE STUDY

Group exercise n°4: Contingency/Emergency planning

The objective of this exercise was to familiarise participants with the practical steps required to organise an effective emergency response when a landslide, flash flood, or road blockage occurs along a mountain corridor. Working in small groups, participants were asked to define a Standard Operating Procedure (SOP) outlining who does what, when, and how, and then to sketch a simple command chain while identifying likely weak points in coordination among agencies. The exercise aimed to help participants articulate clear responsibilities, visualise inter-agency coordination flows, and recognise bottlenecks that often delay response operations in real mountainous regions. The purpose was not only to design an ideal response system but also to reflect on organisational realities and the improvements needed for more resilient emergency management.

a) Structure of the SOPs Proposed by Groups

Across all groups, the SOPs followed a broadly similar structure, demonstrating a shared intuition of how emergency response should be organised. Most SOPs began with incident detection, followed by decision-making by district authorities, and then activation of relevant emergency support functions.

Common elements observed include:

- **Activation of district administration**

Most groups placed the District Disaster Management Authority (DDMA), the District Magistrate (DM) or District Collector (DC) at the centre of decision-making.

- **First responders as the initial action layer**

Groups consistently involved police, road departments (PWD/NH/BRO), and local community volunteers as the first to react on-site.

- **Clearance of debris as the primary engineering response**

Multiple sticky notes emphasised clearing debris, road reopening, or creating temporary diversions, which is particularly aligned with the river gorge and steep slope scenarios.

- **Health and rescue services integrated early**

Participants referred to hospitals, health departments, ambulances, and relief teams as part of early-stage activation.

- **Importance of communication systems**

Nearly all groups highlighted communication with the public, information sharing across departments, and receiving information from villages and traffic authorities.

This indicates that participants fully understood the multi-sectoral nature of emergency response and were able to map operational roles relatively clearly.

b) Command Chain Observations

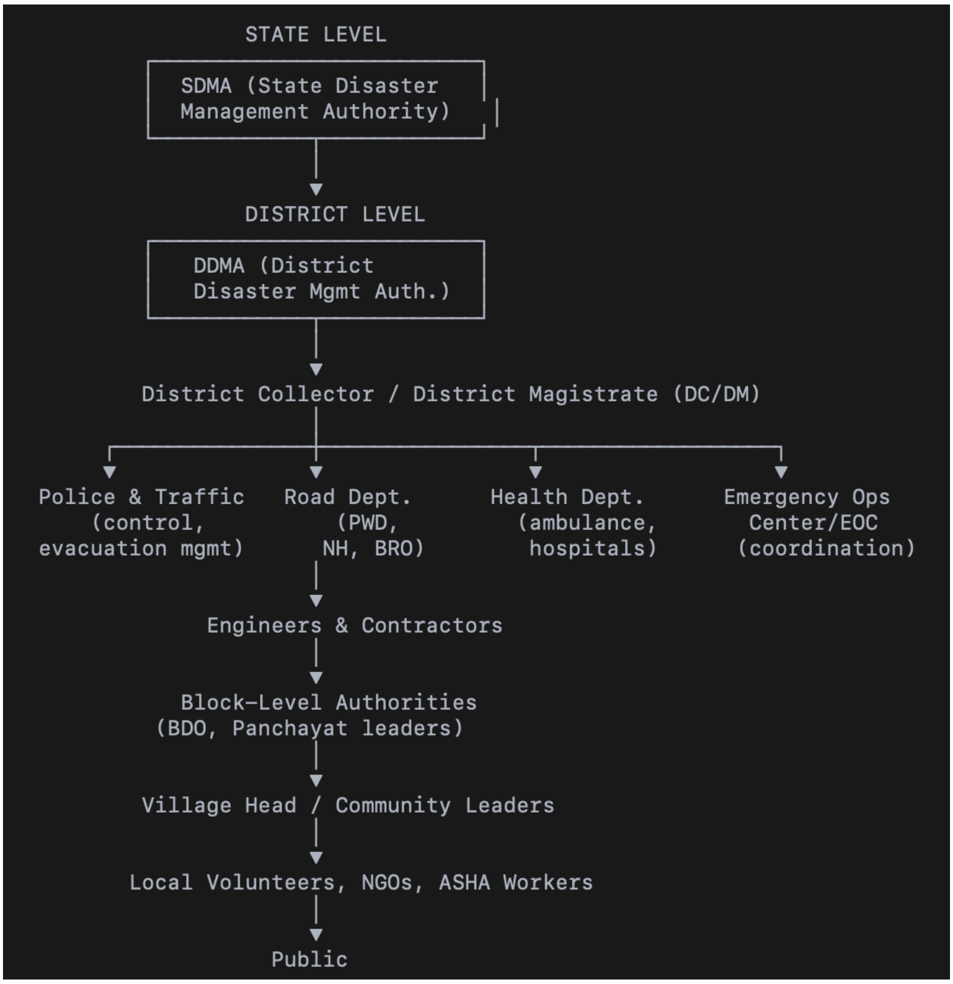


FIGURE 2 – CHAIN OF COMMAND FOR MOSTLY ALL THE GROUPS

c) What All Groups Agreed On

Across all groups, participants converged on a similar emergency command chain centred on the District Magistrate and the DDMA as the primary coordination hub. Police, road agencies, and health services consistently appeared as the core operational departments activated in parallel once an incident occurs, reflecting a shared understanding of multi-sector coordination during mountain road emergencies. At the local level, all groups highlighted the essential contribution of village leaders, community organisations, and volunteers for evacuation, first response, and information relay. Despite variations in presentation, the overall structure followed the same logic: state guidance, district-level decision and coordination, sectoral implementation, and community-level execution and feedback.

d) Main differences between groups

Differences across groups were mainly related to the level of detail and institutional emphasis. Some groups presented highly granular chains, adding elements such as traffic checkpoints, emergency operation centers, or specialised engineering teams, while others used broad institutional categories without subdivision. The placement and role of the Emergency Operations Center varied, with some placing it close to the DDMA and others situating it downstream with line departments. The community's role also differed: certain groups portrayed communities as first responders responsible for initial verification and mobilisation, while others positioned them as recipients of instructions. A few groups incorporated hazard detection and early warning steps, whereas most concentrated strictly on response actions, revealing different levels of familiarity with preparedness-oriented practices.

e) Identification of Weak Points in Coordination

Across the groups, participants consistently identified delays in detection, decision making, and information flow as the most significant weak points in the coordination chain. Several groups noted that responsibilities were well defined on paper but often blurred in practice, resulting in slow activation of SOPs and confusion regarding who should issue instructions at critical moments. Communication breakdowns between district authorities and field-level responders appeared as a recurrent concern, especially in scenarios requiring rapid clearance of debris or rerouting of traffic. Participants also highlighted the potential for misinformation to circulate among the public when official channels are delayed, as well as the limited integration of local communities into formal coordination structures. These recurring issues suggest that even where institutional responsibilities are clear, operational readiness and communication protocols remain vulnerable points in real emergency response.

4.5 Session 6: INSTITUTION & Financial Capacity - PILLAR 5

4.5.1 Strengthening Governance for Building Infrastructure resilience and Climate Financing Resilient Road Infrastructure

PRESENTER: Mr. Jagan Shah, CEO, The Infravision Foundation

Mr. Jagan Shah provided a comprehensive overview of Pillar 5: Governance and Finance, characterizing it as the structural foundation for climate-resilient infrastructure. He highlighted that resilient systems are not built by engineers alone but rely heavily on how institutions absorb risk into decision-making.

Mr. Shah underscored that good governance for resilient infrastructure relies on the alignment of three core elements listed below:

a) **Policy & Regulatory Frameworks**: He emphasized the need to integrate adaptation directly into sectoral plans rather than treating it as an add-on. He further stressed the importance of aligning national policies with global frameworks to ensure eligibility for international funding.

b) **Institutional Mandates**: Mr shah also highlighted a necessary shift from rigid, rule-based compliance to risk-informed accountability. He underscored that the transition would require clear protocols, Standard Operating Procedures (SOPs) to ensure swift and effective disaster response.

c) **Risk-Informed Decision Making**: He stressed that data transparency and sharing are vital to building trust and facilitating coordination across different government departments. He highlighted that adaptation must be absorbed into all planning stages to achieve "resilience by design." He also underscored the critical role of incentivizing "climate-smart procurement." This involves not just purchasing materials, but procuring the right human resources and specialized equipment, such as multi-functional disaster response vehicles. And finally, he stressed that effective governance requires multi-stakeholder collaboration sharing Indian model where disaster management falls under the Home Ministry rather than a specific sectoral ministry as a strong example of centralized authority facilitating a swift, unified federal response.

In the second segment of his presentation, Mr. Shah focused on the critical role of financial mechanisms in transforming resilience from intention to implementation. He emphasized that climate finance is not merely a cost but an investment that pays for itself by mitigating future losses. He underscored the necessity of funding across three levels: hard infrastructure (roads, bridges), large-scale corridor-level programs, and emergency preparedness infrastructure. Mr. Shah presented a innovative finance models of financial instruments designed to mobilize capital effectively. He highlighted the following key models:

- **Resilience & Catastrophe Bonds:** He stressed the value of these instruments, noting how they link funding to predictable, measurable outcomes through parametric insurance.
- **Blended Finance:** The speaker underscored the utility of mixing public, concessional, and private capital to de-risk projects and attract broader investment.

- **Debt-for-Nature Swaps:** He **highlighted** this mechanism as a vital tool for exchanging debt for environmental protection commitments.
- **Value Capture:** Mr. Shah **emphasized** the concept of Payment for Ecosystem Services (PES) to compensate upstream landowners for land management practices that build resilience.
- **Ring-Fencing:** He **stressed** the critical importance of ensuring funds meant for resilience are strictly ring-fenced to prevent misappropriation.

Addressing the "how" of mobilization, Mr. Shah underscored several strategic imperatives for governments:

- **Bundling Interventions:** He emphasized creating portfolios of projects rather than seeking funding for single assets to increase attractiveness and impact.
- **Leveraging Technical Assistance (TA):** He highlighted that TA grants are crucial for ensuring rigorous project due diligence and design.
- **Designing for Speed:** Mr Shah stressed the need to create "fast-dispersing layers" of finance to ensure immediate cash availability in the aftermath of a disaster.
- **Fiscal Engineering:** He underscored the need to educate finance departments to design frameworks capable of supporting these sophisticated instruments.

Mr. Shah noted that the market is evolving, with Multilateral Development Banks (MDBs) demanding higher complexity in Detailed Project Reports (DPRs). While engineering practices are advancing, he highlighted that the supply ecosystem of specialized contractors in South Asia still requires significant development. In his concluding remarks, Mr. Shah stressed that building resilience is fundamentally about learning from the past. He emphasized that governance must shift towards risk-informed budgeting and that finance must be intricately linked to measurable economic outcomes. Finally, he underscored that the way forward involves leveraging regional networks like CDRI and investing heavily in local capacity building.

4.5.2 Resilient Cost Benefits Analysis Tool

PRESENTER: Mr. Raj Vikram Singh, Senior Specialist, Disaster Risk Financing

Mr. Raj Vikram Singh introduced CDRI's finance program, which rests on two pillars: promoting resilience in new infrastructure investments and ensuring resilient recovery post-disaster. He shared that the economic case for this is urgent as global infrastructure investment requirements are estimated at $94 trillion by 2040, disaster-induced damages currently amount to approximately $0.25 trillion annually.
Mr. Singh presentation highlighted that transport infrastructure faces significant exposure. Data from the Global Infrastructure Risk Model indicates that 48% of infrastructure damages in the roads and bridges sector are caused by flooding, followed closely by rain-induced landslides. To address gaps in contracting and standard bidding processes, CDRI, in collaboration with India's Department of Economic Affairs, developed the RCBA tool. This open-source framework allows decision-makers to conduct a deterministic disaster risk assessment and evaluate the economic viability of investing in resilience.

He shared the features of the RCBA tools listed below.

1. **Exposure Dashboard:** utilizing district-level hazard catalogs (based on IMD and BMTPC data) to map asset exposure to specific hazards (flood, wind, earthquake, landslide).
2. **Scenario Comparison:** Simulates lifecycle costs (O&M, recovery) for "Business as Usual" versus "Resilient" scenarios over the project's lifespan (e.g., 30 years).
3. **Financial Indicators:** Outputs key metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost Ratio (BCR) to justify the "resilience dividend."

Mr. Raj Vikram Singh highlighted the tool's practical efficiency through pilot tests on road projects, presenting promising results from Assam and Uttarakhand. He underscored the substantial financial returns, noting that in Assam (Silchar-Jiribam), an additional resilience investment of ₹27 Crore for slope protection and drainage projected an absolute saving of ₹218 Crore over the asset lifecycle representing an 8x return with an Internal Rate of Return (IRR) of approximately 15%. Similarly, for Uttarakhand, he pointed out that a resilience investment of ₹31 Crore projected savings of ₹226 Crore, yielding a 7x return and an IRR of roughly 14.8%. Addressing the current scope, Mr. Singh acknowledged specific limitations that the tool currently utilizes deterministic risk assessment based on the past 10-15 years of data rather than probabilistic modeling. He emphasized that the current version does not yet account for future climate change volatility and quantifies only direct economic benefits, such as avoided losses, rather than broader socio-economic co-benefits. Concluding the session, he announced that a comprehensive toolkit, including a resilience checklist and user guide, is scheduled for launch in the next quarter. He stressed that the aim is to scale this framework beyond India to other CDRI member countries facing similar risk landscapes.

Key Take Aways:

- **Policy and regulatory frameworks that embed climate and disaster risk considerations across the project lifecycle**
- **Institutional mandates and coordination mechanisms that clarify roles and ensure vertical and horizontal cooperation**
- **Risk-informed decision-making systems that enable the use of data, climate models, hazard mapping, and asset information to guide investments.**

4.5.3 Reflections from Nepal

PRESENTER: Mr. Niranjan Thapa, Senior divisional engineer, Department of Roads Government of Nepal (GoN)

Mr. Niranjan Thapa highlighted the influence of Nepal's geography on its infrastructure challenges, noting that with 83% of the terrain being mountainous, engineering and maintenance are exceptionally difficult. He underscored the vulnerability of the 14,700 km Strategic Road Network, particularly pointing out that North-South roads aligned along riverbanks are highly prone to flood risks. Mr. Thapa stressed the economic severity of these threats, estimating that climate-induced risks cost Nepal between 1.5% and 2.5% of its annual GDP. He specifically emphasized the danger of Glacial Lake Outburst Floods (GLOFs), citing the July 2025 Lhende River event which severed the China-Nepal connection, as a critical example. Mr. Thapa outlined the role of the NDRRMA as the apex body for disaster risk management and MoPIT's responsibility for National Highways. On the financial front, he emphasized the looming challenge of

Nepal's graduation from Least Developed Country (LDC) status in 2026, which he warned would likely reduce grant availability and necessitate a shift toward loans.
He stressed a critical gap in current practices: "Climate Blind" maintenance funding, which has contributed to an estimated $100 million maintenance backlog. However, he highlighted emerging opportunities, including the Green Climate Fund (GCF) and the exploration of Public-Private Partnership (PPP) models like the Hybrid Annuity Model (HAM) for roads.
Best Practices and Technologies Mr. Thapa showcased Nepal's extensive experience with bioengineering, a practice standardized since 1999 to stabilize slopes using vegetation and civil engineering.
He also underscored the adoption of digital tools such as the World Bank-supported Navigate System for real-time road closure data and the Bridge Site Monitoring System. Furthermore, he celebrated the success of the rural connectivity program, noting the construction of over 11,000 suspension bridges which have been vital for tourism and last-mile access.
Lastly, Mr. Thapa emphasized the urgent need for regulatory reforms to integrate climate resilience into planning. He stressed that the sector must move away from "climate-blind" financing to ensure maintenance budgets accurately reflect climate realities and highlighted the need for harmonizing data standards across agencies.

4.5.4 Reflections from Vietnam

PRESENTER: Ms. Thai Minh Huong, Vietnam Disaster and Dyke Management Authority, Government of Vietnam

Ms. Thai Minh Huong highlighted Vietnam's position as a new member of the coalition and underscored the unique dual-ministry responsibility for resilient infrastructure shared between the Ministry of Agriculture and Rural Development (MARD) and the Ministry of Construction. She emphasized the severe climate risks facing the country's mountainous regions, specifically stressing the increasing frequency of flash floods and landslides, as evidenced by recent isolation events in South Central Vietnam caused by heavy rainfall.
Reflecting past World Bank-funded projects, Ms. Kung pointed out critical gaps, particularly insufficient hydrological surveys and the lack of comprehensive landslide inventory maps. She stressed that current Vietnamese Standards are often outdated regarding rainfall and flood parameters, which has historically led to inadequate drainage designs.
Consequently, she underscored Vietnam's adaptation priorities: investing in risk-informed planning through hazard mapping, implementing engineering solutions like larger bridges and sediment checks, and highlighting the urgent institutional need to update national standards with future climate parameters to ensure long-term resilience.

4.5.5 Group exercise/ Case Study

Group exercise n°5: Institutional & financial capacity

The objective of Pillar 5 was to introduce participants to the institutional and financing dimensions of climate-resilient road development. Due to limited time, the exercise focused exclusively on identifying two feasible financial mechanisms that could support resilient road and bridge projects in mountainous regions. Participants were divided into small groups and asked to propose financing options applicable to the three road segments used throughout the workshop. This rapid exercise aimed to highlight how practitioners perceive the financing landscape and the mechanisms they consider most realistic or immediately deployable.

a) Summary of Financial Mechanisms Proposed by the Groups

<u>Most Common Mechanisms</u>

1. Public–Private Partnerships (PPP)

Groups frequently cited PPPs to leverage private investment where government budgets fall short. PPPs were perceived as instruments to bridge viability gaps, accelerate reconstruction, and mobilize long-term financing.

2. Climate or Catastrophe Bonds

Several groups proposed issuing climate bonds or catastrophe bonds to generate capital specifically for resilience investments or post-disaster recovery in high-risk regions.

<u>Additional Mechanisms Mentioned</u>

3. Climate Surcharges or User Fees

These were suggested as sustainable, predictable revenue streams. The idea is to collect small surcharges from users, earmarked for slope stabilization, drainage upgrades, and other recurrent resilience needs.

4. Crowdfunding and Local Area Development Funds (e.g., MPLADS Fund)

Some groups proposed local-level financing, either through community-based contributions or district-level development funds for emergency rehabilitation.

5. Multilateral or Multi-actor Funding

A few notes referenced multilateral agencies or multi-actor pooled financing as a means of covering the increasing cost of resilient construction in fragile locations.

Even within a 10-minute exercise, participants demonstrated an understanding that resilient road development requires diversified and innovative financing sources, beyond annual public budgets. Public-private partnerships and climate-related bonds emerged as the dominant proposals, showing that resilience financing is increasingly recognized as needing both public leadership and market-based solutions. Importantly, the range of answers points to a gradual shift from purely engineering responses toward integrated financial thinking in road sector planning.

4.6 Closing Remarks

SPEAKER: Mr. Ramraj Narasimhan, Deputy Director General, CDRI

In his concluding address, Mr. Ramraj Narasimhan highlighted the enthralling nature of the workshop, with the high level of participant engagement as a testament to the complex and relevant problems posed by the organizing team. He underscored the immense value of the collective expertise present in the room, which he estimated amounts to "thousands of years" of professional experience. Mr. Narasimhan provided a synthesis of the day's discussions, which focused on three of the five resilient infrastructure pillars:

- Operations & Maintenance (O&M): He emphasized the critical shift from standard maintenance to climate-informed preventive maintenance. He stressed that resilience is defined by the ability to absorb shocks and recover quickly, advocating for the strategic allocation of scarce resources to high-risk areas. He further highlighted the potential of digital tools like iRoads, describing current capabilities as just the "tip of the iceberg."
- Contingency Planning: Reflecting on the session led by Mr. Binu, he stressed that roads function as vital connectors for healthcare and economic stability, not just transport assets. Consequently, he advocated for emergency management plans that actively involve every stakeholder residing or operating in the affected area.
- Governance & Finance: He underscored the foundational role of strong institutional frameworks and financing, as presented by Mr. Jagan Shah, noting that these elements are essential for the other technical pillars to function effectively.

Mr. Narasimhan acknowledged the diverse regional perspectives brought forward during the sessions:

- **Bhutan:** For significant strides in O&M within challenging mountainous terrains.
- **Papua New Guinea:** For the ambitious scale of the "Connect PNG" investment plan.
- **Nepal:** He singled out Nepal's innovation born of necessity, specifically highlighting the integration of bioengineering as a standard departmental practice for over 25 years as a key lesson for the region.

Concluding his remarks, Mr. Narasimhan highlighted that the workshop was a beginning rather than an end. He stressed for the creation of a Community of Practice through the DRI Connect platform to leverage collective learning for other countries. He urged participants to actively share case studies and engage in the upcoming DRI Dialogues webinar series. He closed by extending gratitude to the Ministry of Road Transport and Highways (MoRTH), HPRIDCL, the World Bank, and the CDRI team. Lastly, he described the day's sessions as a "trailer," with the upcoming field visit serving as the reality where participants can see these concepts in action. He ended with the philosophy that "learning is a two-way process; until you teach, you don't learn."

5. Field Visit- Day 3

The site visit to the HPRIDCL road in India illustrated how nature-based solutions (NBS) can substantially reduce geotechnical risks while enhancing the long-term performance of mountain roads. Bamboo plantations, native species, and a set of bio-engineering measures were strategically deployed to stabilise slopes, limit erosion, and reduce the likelihood of shallow landslides. These interventions were complemented by gabions used in critical sections to reinforce the toe of the slope and provide an additional mechanical barrier where vegetation alone would not be sufficient. Together, the vegetative systems and structural elements improved water absorption, reduced runoff, and strengthened overall climate-resilience, demonstrating how hybrid solutions can outperform purely engineered designs by creating long-term, self-reinforcing protection.

Beyond their technical function, the interventions demonstrated how road resilience can be approached through social and economic co-benefits. Local communities were directly involved in planting and maintaining bamboo and other species, as well as in the upkeep of bio-engineering installations, generating employment while fostering ownership of the asset. The development of ponds used for leisure, small recreational spaces, and improved drainage infrastructure created additional public value around the corridor. These measures not only supported local livelihoods but also enhanced biodiversity—bamboo, for instance, provides habitat and food for monkeys and other wildlife. The site visits therefore highlighted an integrated resilience model in which ecological, social, and technical measures reinforce each other to make road corridors safer, more sustainable, and more beneficial for surrounding communities.

6. Recommendations and Next Steps

The three-day workshop brought together experts, government delegates, policymakers, and practitioners from seven countries to promote collaboration and exchange knowledge on building resilient roads in mountainous regions. Presentations on resilient characteristics, pillar of resilient transport, good practices in mountain road development were shared by the World Bank, HPRIDCL, and partner organizations, highlighting key experiences and lessons learned.

The workshop, followed by a field visit and reflections from participating countries, contributed to identifying key recommendations and next steps for strengthening resilience in mountain road and transport systems.

Way Forward

- Co-develop a training curriculum focused on resilient road and transport systems for mountain regions engaging world bank transport team and CDRI experts along with participants
- Identification of champions on mountain transport to support facilitation of CoP
- Establish a Community of Practice (CoP) or Road Clinic with regular engagement for knowledge sharing and collaboration.
- Promote the DRI Lexicon and e-learning courses on resilient infrastructure among participants.
- Conduct specialized training on slope management for geotechnical department units.
- Share the Slope Management Guidelines among coalition members.
- Mobilize the DRI task force to provide ongoing support for countries with technical support.
- Capacity building for engineers on network-wide vulnerability assessments
- Establishing a dedicated Climate Resilience Fund.

Annexes

Annex 1: Agenda of the workshop

From (IST)	To (IST)	Presentations	Presenters
9:00	9:45	Registrations	-
9:45	9:55	Welcome All and Overview of the Agenda	-
9:55	10:15	Inaugural Session - Lamp Lighting	-
10:15	10:20	Event Introduction Video	-
10:20	10:30	Welcome and Opening Remarks	Ramraj Narasimhan Deputy Director General, CDRI
10:30	10:45	Keynote Address by Chief Guest	Anil Kapil Advisor (infra) to CM, Govt. of HP
10:45	11:00	Special Remarks by The World Bank	Paul Procee Acting Country Director India, The World Bank
11:00	11:15	Group Photo	-
11:15	**11:35**	**Networking Tea/Coffee Break**	
SESSION-1: Introduction Session			
11:35	11:45	Five I's of Resilience - Characteristics	Arnab Bandyopadhyay Lead Transport Specialist The World Bank
11:45	12:05	Introduction to Climate & Disaster Resilient Transport: WB's Five Pillars of Resilience	Vijetha Bezzam Senior Transport Specialist The World Bank
12:05	12:30	a. Overview of the Mountainous Hazards b. Challenges faced by Mountainous Road Network	Kishore Kumar Ex-Chief Scientist CSIR - Central Road Research Institution, New Delhi
12:30	12:45	Reflections from Participating Countries	
12:45	13:00	Q&A Session	
13:00	14:00	**LUNCH**	
SESSION-2: Resilience Concepts & Case Studies			
Pillar-1: Network Planning			

14:00	14:20	Risk-Informed Planning and Mountain Road Networks: Assessing Hazards, Vulnerabilities, and Exposure Q&A	Anup Karanth Senior Disaster Risk Management Specialist The World Bank
14:20	14:40	National Adaptation Plan (NAP): Prioritizing Climate Resilience in the Transport Sector - Reflection from Nepal's NAP Q&A	Yeshika Malik Climate Change Specialist The World Bank
14:40	15:25	Group Exercise/Case Study	
15:25	**15:40**	**Networking Tea/Coffee Break**	
Pillar-2: Design and Engineering			
15:40	16:00	Embedding Climate Resilience in Transport Design and Implementation Q&A	Goverdhan Lal Verma Senior Road & Bridge Engineer EPC Consulting Firm
16:00	16:35	Sharing of Slope Stabilization guidelines and experiences from various countries Q&A	Dr. Kishor Kumar Ex-Chief Scientist CSIR - Central Road Research Institution, New Delhi
16:35	16:55	Reflections from GNHCP Project by MoRTH Q&A	Nikhil Narang, IES Executive Engineer MoRTH
16:55	17:15	Reflection from HPSRTP Project by HPRIDCL Q&A	Pawan Kumar Sharma Director (Projects) HPRIDCL
17:15	18:00	Group Exercise/Case Study	
18:00	18:10	Closing Remarks	Jen Jung Eun Oh Practice Manager SAR Transport The World Bank

Day-2 November 27, 2025

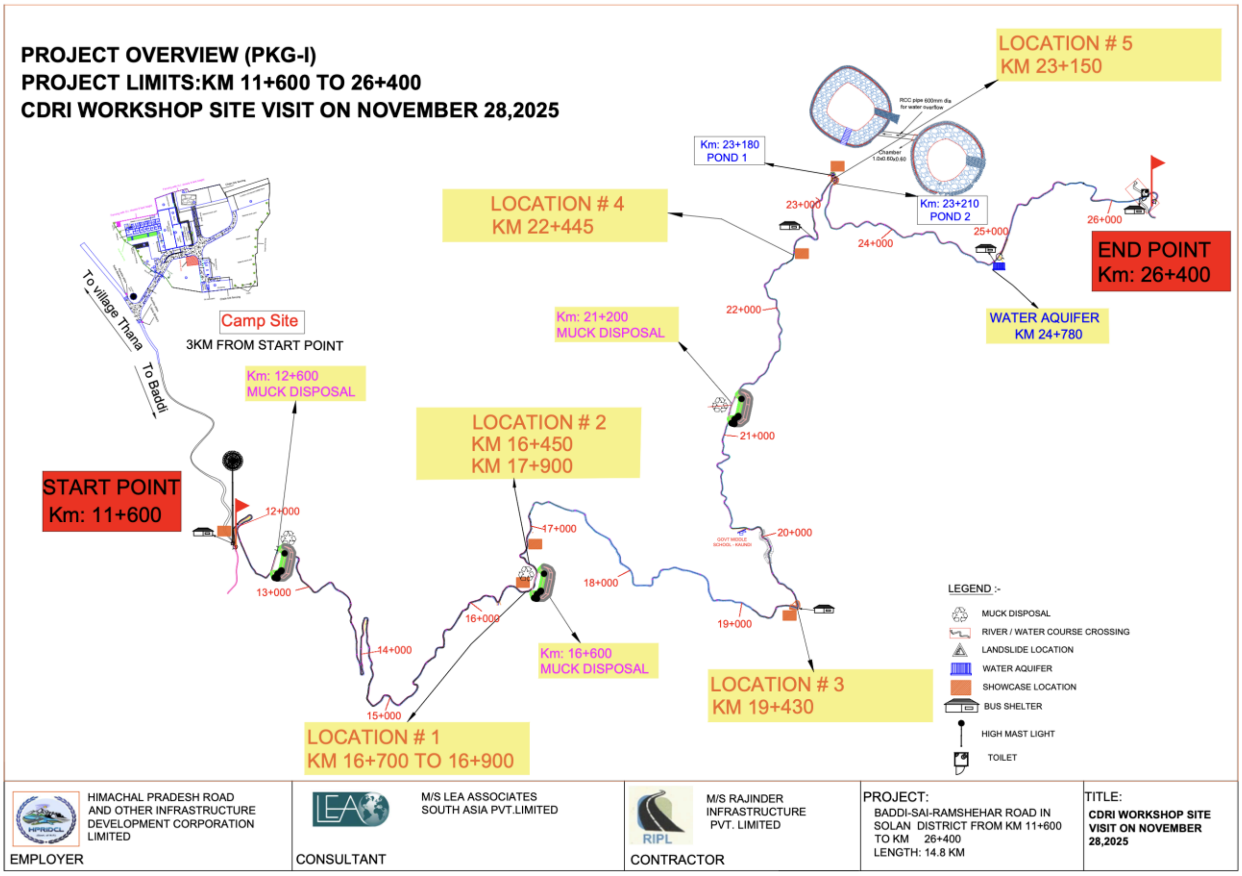
From (IST)	To (IST)	Presentations	Presenters
10:00	10:10	Recap of Day-01	
		Pillar-3: Operations and Maintenance	
10:10	10:35	(a) Introducing RAMS and in-built Climate Module: A tool for climate-informed planning (b) Maintenance and Inspection Regimes Q&A	Bhavesh Jain Principal Transport Specialist, TRL, India
10:35	10:55	Reflections from Bhutan Q&A	Ms. Yeshey Choden Deputy Executive Engineer Design & Geotech Division, Govt. of Bhutan
10:55	11:40	Group Exercise/Case Study	
11:40	**11:55**	**Networking Tea/Coffee Break**	
		Pillar-4: Contingency/Emergency Planning	
11:55	12:15	Transport Emergency Management Plan & Traffic Evacuation Plan Q&A	Binu Mathew COO and Partner Tarutium Global Consulting
12:15	12:35	Integrating Disaster Risk Management into the transport sector Q&A	Empati Uday Kumar Specialist, Technical Studies, CDRI
12:35	13:00	Reflections from PNG	Govt. of PNG
13:00	**14:00**	**LUNCH**	
14:00	15:00	Group Exercise/Case Study	
Pillar-5: Institution & Financial Capacity			
15:00	15:30	(a) Strengthening Governance for Building Infrastructure resilience (b) Climate Financing Resilient Road Infrastructure Q&A	Jagan Shah CEO The Infravision Foundation
15:30	**15:45**	**Networking Tea/Coffee Break**	
15:45	16:15	Resilient Cost Benefits Analysis Tool Q&A	Raj Vikram Singh Senior Specialist Disaster Risk Financing CDRI
16:15	16:30	Reflections from Nepal	Govt. of Nepal
16:30	17:15	Group Exercise/Case Study	
17:15	17:20	Closing Remarks	Ramraj Narasimhan DDG, CDRI

17:20	17:30	Final Closing Day -03 Overview of the Site Visit Plan	Nicolas Ziv CDRI

Day-3 November 28, 2025

From (IST)	To (IST)	Site Visit
8:15	Participants to be assembled in Lobby, Buses will leave at 8:30 AM for the Site Visit	
10:00	13:00	Site Visit of Baddi–Sai–Ramshahar Road (Package -1) of Himachal Pradesh State Road Transformation Project
13:00	**14:30**	**LUNCH**
14:30	15:00	Closing Remarks
15:00	17:00	Return to the Hotel (End of workshop)

Annex 2: Site visit map



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