Coalition for Disaster Resilient Infrastructure

Landslide Risk Assessment of Strategic Roads in Shimla, 2024

Contents

Background and Rationale

In 2023, the Indian state of Himachal Pradesh (HP) faced intense monsoon rains that triggered 163 landslides and 83 flash floods. During the monsoon period of 2023, HP experienced three distinct spells of exceptionally heavy rainfall between 7-11 July, 11-14 August, and 21-23 August. These conditions caused extensive damage across the state, severely impacting critical infrastructure. Roads suffered losses amounting to ₹1,632.80 crore with a recovery requirement of ₹2,458.30 crore. The drinking water and sanitation sectors were also heavily impacted, with losses totalling ₹2,668.31 crore and a recovery estimate of ₹2,228.48 crore. Additionally, the power sector incurred ₹279.56 crore in total damage and loss, with a recovery estimate of ₹213.94 crore. Overall, the total recovery estimate for the critical infrastructure sector alone stood at ₹4,900.72 crore.

By mid-August 2023, the state had reported over 330 fatalities due to rain-related incidents, with 38 individuals missing and more than 100 injured. The relentless rains caused severe disruptions: at one point, over 1000 roads were blocked due to landslides and damage to infrastructure. Key highways, including parts of the Kalka—Shimla route, suffered significant damage, leading to prolonged closures. Total losses were estimated at approximately ₹10,000 crore, with floods and landslides resulting in the destruction of 774 houses and leaving an additional 7317 houses partially damaged. The disasters also disrupted 274 electricity supply schemes and 42 water supply schemes, leading to widespread outages that affected daily life. In mid-August, Shimla experienced devastating landslides that destroyed a temple, houses, and other structures, resulting in at least 57 deaths. Sections of the Himalayan Expressway, part of the Chandigarh Shimla route, were severely damaged due to landslides and floods. Experts suggested that construction activities might have destabilized the slopes, exacerbating the impact. , The Himachal Pradesh State Disaster Management Authority (HP SDMA), the state's nodal agency for disaster management, recognized the vulnerability of roads and initiated efforts to enhance their resilience, seeking technical support from the Coalition for Disaster Resilient Infrastructure (CDRI).

CDRI is a global multi-stakeholder partnership comprising national governments, UN agencies, multilateral development banks, the private sector, and academic institutions. CDRI aims to advocate for building resilience into infrastructure systems to ensure sustainable development. To achieve this, a DRI Task Force mechanism has been designed to assist member countries in enhancing the resilience of their infrastructure systems against climate and disaster risks. This mechanism serves as a collaborative platform where member nations can share expertise, develop best practices, and pilot strategies tailored to their unique risk contexts and economic needs. Key benefits to Coalition members include access to expertise on infrastructure resilience, opportunities to engage in collaborative research initiatives, enhanced resilience of infrastructure, and resource mobilization for implementation of resilience projects.

In response to the request from the Government of Himachal Pradesh (GoHP), an initial mission was launched to assess slope stability and propose sustainable interventions to strengthen highway resilience. The study focused on two key road sections: Panthaghati to National Highway (NH) Crossing and Kennedy Chowk to Annadale Helipad. The mission aimed to identify structural and non-structural interventions to mitigate landslide risks and develop short-term, medium-term, and long-term strategies integrating engineering solutions (grey infrastructure) with Nature-based Solutions (NbS) to ensure sustainability and slope stability.

As part of CDRI's technical assistance (TA) programme, an initial on-ground assessment was conducted in February 2024 by CDRI, accompanied by representatives from the stakeholders of the identified roads. The findings from this initial assessment laid the foundation for further detailed analysis (see Figure 1). At the request of HP SDMA, a detailed mission was subsequently planned for June 2024. This mission involved experts in landslide assessment, geology, geotechnical engineering, and bioengineering. Their focus was on identifying measures to incorporate into future detailed project reports (DPRs) for developing resilient roads.

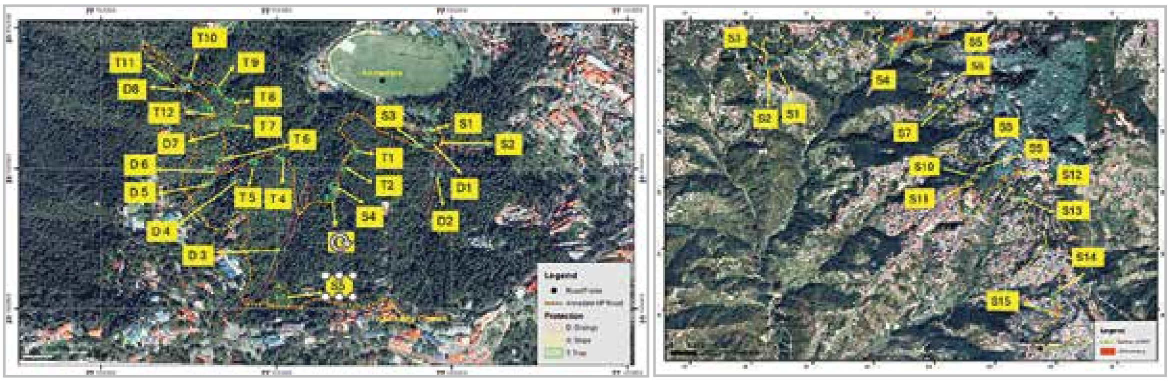

Figure 1: Considered landslides for assessment along the identified road sections

The **scope of work** included: (i) Data collection and field surveys to understand geological and geomorphological features causing landslide through visual inspection; (ii) Slope stability and risk assessment, which included failure mechanism and contributing factors, risk prioritization, and landslide susceptibility modelling; (iii) Suggested measures that included assessment of structural and non-structural measures, NbS, and capacity development via training programmes on slope maintenance and disaster preparedness; and (iv) A categorization of suggested measures divided into short-, medium-, and long-term strategies, including immediate stabilization measures (short-term), hybrid solutions (engineering combined with NbS) for slope reinforcement (medium-term), and resilient road infrastructure planning for the long term.

Key stakeholders involved in the initiative included the HP SDMA, which served as the anchor agency overseeing disaster resilience initiatives and coordinating technical assistance in the state. The district administration of Shimla was responsible for facilitating local implementation and ensuring coordination among government agencies, contractors, and communities. The Municipal Corporation and the Public Works Department (PWD), Himachal Pradesh, are responsible for road construction, maintenance, and integration of mitigation strategies into existing road infrastructure. Local communities and residents were engaged in community-based monitoring, awareness campaigns, and reporting landslide risks. In addition, technical experts and research institutions such as CSIR-Central Road Research Institute (CRRI), Forum for Energy and Environment Development (FEED) Nepal, and Tribhuvan University, Nepal, contributed to geotechnical and landslide risk assessments.

Figure 2

Challenges at Identified Landslide Sites along the Roads Assessed

The assessment identified multiple challenges affecting landslide-prone sections along the two road corridors (see Figure 2). On the **Panthaghati-NH road crossing**, there were frequent landslides and debris flows. Heavy rainfall increased soil moisture, weakening the slopes and leading to recurrent landslides. Poor drainage management caused blockages and waterlogging, causing water accumulation and further destabilizing slopes. Additionally, 'human-induced' slope instability, such as construction activities, deforestation, and unplanned urban expansion, exacerbated slope failure. On the **Kennedy Chowk-Annadale Helipad Road**, steep slopes and soil erosion were observed as the road passes through forested terrain, where tree removal and steep gradients contribute to erosion and instability in this area. Drainage channels were encroached upon due to the dumping of construction debris and household waste in natural streams, which alters water flow and triggers landslides. Further, weak soil conditions and intense rainfall have led to road subsidence, cracking, and uprooting of trees, creating further risks.

Figure 3: Culvert blockage

Figure 4: Household waste dumping

Figure 5: Construction waste dumping

Site-Specific Observation and Mapping: Case Example of One Site

Multiple landslides were identified along the two road sections surveyed. For instance, on the 11-km-long Panthaghati-NH road crossing section, around 25 landslides of different types and sizes were mapped. Below is a case study of one particular site, with 'debris flow' as the type of failure.

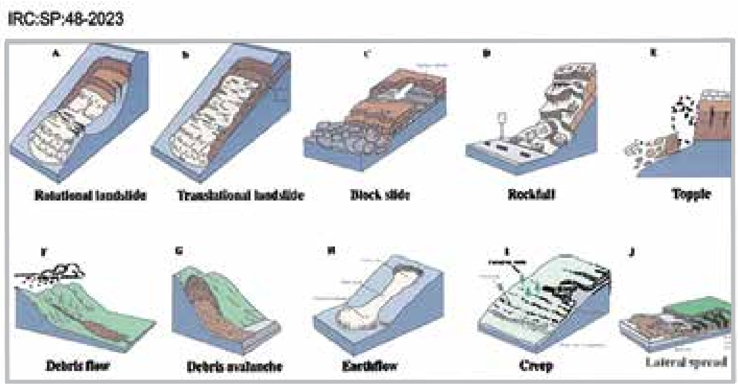

Figure 6: Type of debris flow

Case Study of Site 'S': Presenting 'Debris Flow' as Failure on Panthaghati-NH Crossing Road Section

Site Information

The area of this site can be characterized as a stream-guided debris flow zone (refer to Figure 3). Rainwater accumulates along the roadside and water from the upstream channel flows through the culvert. However, the area downstream of the culvert and the stream channel lacks protection. As a result, frequent runoff widens the channel and creates a gully. The slope on the right side has failed due to the undercutting process caused by the stream. During field observations, freehand sketches of each landslide were developed, and a field checklist was prepared.

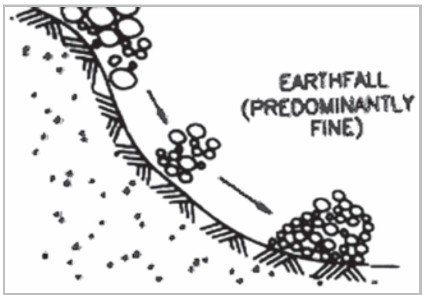

Figure 7: Typical debris flow

Attributes / Site Details:

- **Stratigraphic horizon:** Jutogh Group-Bhotli Formation
- **Lithology:** Thick overburden (predominantly phyllite/shale)
- **Type of landslide:** Debris flow
- **Slope angle and direction:** 40-50° and N 75°
- **Affected area along the slope:** ~50 m long and ~20 m wide at start

Failure mechanisms/phenomena and contributing factors

1) This is a culvert-guided debris flow. The mouth of the culvert discharges a large volume of water during the rainy season and opens onto a downhill slope (see Figure 5). The stream from this culvert converges with another stream at the adjoining site.

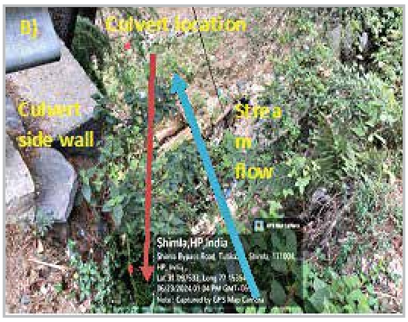

Figure 5: Culvert location

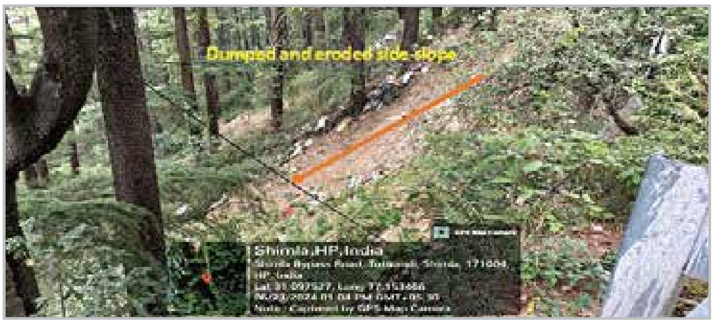

Figure 6: General view of slope failure

2) The downhill slope is unprotected, leading to the formation of a gully or streamlet due to the continuous flow of water along the entire length of the slope down to the toe, which results in repeated erosion. Furthermore, it has been observed that both sides of the culvert were littered with various types of waste, including plastic. This dumping of waste is damaging the slope and accelerating the erosion process.

3) During the rainy season, the waste that is dumped on both sides of the slope flows down and obstructs the water flow from the culvert. This blockage further damages/erodes the slope. As a result, what started as a minor issue has gradually worsened and now requires immediate attention to ensure the safety of the residents living downhill (see Figure 6).

4) Therefore, the assessment concluded that the debris flow problem is caused by uncontrolled culvert water, heavy rainfall, and waste disposed of on the slope.

Suggested measures

The slope failure resulted from stream undercutting during periods of excess rainfall. To address this issue, it was proposed that a gabion check dam immediately downstream of the culvert be constructed. Additionally, a vegetative stone-paved surface channel should be built leading up to the toe of the slope, followed by planting local grass on the exposed surface. The vegetative channel will extend to the nearest natural drain (nala). It was emphasized that managing waste disposal on the slope effectively is crucial.

Immediate: A vegetative abion check dam (~4 m long and ~1.5 m high, excluding the foundation) should be placed immediately downstream of the culvert (refer to Figure 7). The spillway of the check dams must not exceed the outlet height of the culvert

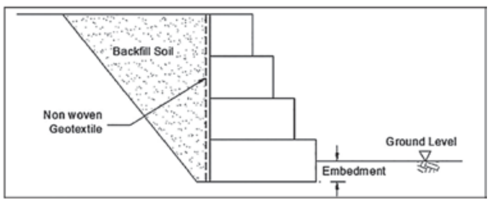

Figure 7

Medium term:

- The vegetative stone-paved surface channel (~1.5 to 2 m wide) should extend to the natural drainage along the footill.
- A local grass plantation on the exposed surface should be established, covered by a jute net (~500 m2).

Long term: Upstream surface water management.

Engineering and Non-engineering Measures Suggested as Part of the TA

The TA recommends both engineering and non-engineering measures to enhance resilience and slope stability while reducing the risks associated with landslides. The **engineering measures (structural interventions)** include:

(i) Slope stabilization techniques such as the use of retaining walls made of reinforced concrete and gabion retaining walls to provide lateral support and prevent soil movement, soil nailing, and anchoring, which involves installing steel rods and anchors into slopes to increase shear strength and prevent landslides, and using terracing and bench cutting to create step-like formations, which will reduce slope steepness and minimize erosion;

(ii) Damage and erosion control via improvement of surface and subsurface drainage systems through the construction of stepped trench drains, culverts, and chute drains to manage surface runoff and reduce pore water pressure, installation of small check dams and silt/sedimentation traps to slow down water flow and prevent debris flow, and ensuring that roads are paved and properly sloped to divert water away from slopes; and

(iii) Road protection and monitoring through construction of concrete breast walls and toe walls to strengthen the base of slopes to prevent road subsidence and implementation of a highway slope monitoring and maintenance system for continuous geotechnical monitoring and risk assessment using inclinometers, piezometers, and remote sensing to detect early signs of slope movement.

Advisory on Highway Slope Stability Management (HSSM)

Based on insights from the technical assistance mission, there is a clear need for structured guidelines to identify **challenges** and provide relevant solutions for highway slope stability management. In response, CDRI is currently developing a comprehensive Guidance on Highway Slope Stability Management aimed at enhancing the disaster resilience and sustainability of highways, particularly in mountainous regions.

This technical note aims to outline a set of preparedness measures to reduce landslide risks along highways. It is intended to be shared with Coalition member countries, with a special focus on mountain regions and to validate its applicability during technical missions in South Asia. The Advisory on HSSM aims to institutionalize slope risk management, promote climate-resilient infrastructure, and serve as a replicable model for other mountainous regions.

The proposed HSSM includes the following core components:

- **Slope Inventory Framework**
  A standardized template to identify and document unstable slopes along highways.
- **Assessment Methodology**
  Use of technology and data to prioritize location and resource allocation on slope stabilization efforts.
- **Best Practices Repository**
  A curated collection of learning and proven adaptation and preparedness.

The **non-engineering measures (nature-based and policy interventions)** involve NbS. This includes bioengineering techniques such as live staking and brush layering, which use layers of vegetation to stabilize slopes. Additionally, live check dams and vegetative gabions can be employed to slow down water flow and further stabilize slopes. Vegetative cover is also essential for protecting soil from erosion. It is recommended that a hybrid approach be adopted to drainage management and the stabilization of channels and banks. This approach combines engineering with NbS. For high-risk slopes, structural solutions (like toe walls and soil nailing) can be utilized. For low-to-moderate risk areas, NbS techniques (such as bioengineering and reforestation) should be applied. Furthermore, implementing monitoring and early warning systems is crucial to ensure timely interventions when needed.

The TA recommends a **phased implementation plan** focusing on high-risk areas and implements solutions in phases (immediate, medium term, and long term). This approach is part of a comprehensive scheme to achieve the desired outcomes. In the short term (0–6 months), the immediate actions include debris removal, the installation of temporary geotextile covers, and emergency drainage repairs. For the medium term (6–18 months), the focus will be on structural reinforcements, advanced drainage systems, and vegetation-based stabilization efforts. In the long term (18 months to 3 years), the plan calls for full-scale slope stabilization, comprehensive vegetation coverage, and the establishment of highway slope monitoring systems.

Policy Messages

The key policy messages from this TA for mountain and hill roads include:

1. The TA recommends **comprehensive monitoring and management, and risk assessment** of landslide-prone areas, especially along critical road infrastructure, to identify vulnerabilities and prioritize mitigation measures, and adaptive management for long-term slope stability. Proactive risk assessments, including geological and hydrological studies, can help identify unstable slopes and prevent future disasters.

2. It highlights the importance of **developing a highway slope stability management system** to support disaster resilient and sustainable highway development in hilly areas. This system can help identify risks and prevent disasters by proactively maintaining highway slopes, and it is currently in development (Box 1). The methodology involves several steps: first, preparing an inventory of existing highway slopes, including landslides, to prioritize which slopes require appropriate action. Next, developing landslide susceptibility models to classify slopes based on their risk levels. Finally, implementing the highway slope monitoring system for continuous monitoring, allowing for proactive interventions for hazardous slopes, and providing early warnings.

3. **Integration of NbS**, with the key policy message being to promote using NbS for slope stabilization and erosion control, as they are sustainable, cost-effective, and environmentally friendly. Techniques such as vegetation planting, brush layering, and vegetative gabion check dams effectively stabilize slopes and reduce landslide risks while improving ecological health. The TA suggests incorporating NbS into road construction and maintenance plans, and combining NbS with traditional engineering measures (hybrid solutions) for high-risk areas.

4. A core policy recommendation is to **enhance drainage systems and debris management** to effectively manage surface runoff and prevent water accumulation, which is a major trigger for landslides. Well-designed drainage systems can significantly reduce landslide risks. To achieve this, actionable steps include constructing and maintaining vegetative stone-paved surface channels to guide runoff safely, regularly cleaning and maintaining drainage systems to prevent blockages, especially before the monsoon season, and identifying **specific sites for debris disposal,** as debris is highly susceptible to further sliding into the valley. When selecting debris disposal sites, it is advisable to follow the relevant Indian Roads Congress (IRC) Guidelines for detailed technical guidance.



5. **Developing a monitoring and evaluation (M&E) plan** will includes a comprehensive monitoring strategy that leverages technology to include early warning capabilities. The TA recommends a structured maintenance approach that addresses both structural and non-structural components. This should involve clear documentation and reporting, as well as flexibility and adaptability, ensuring that the slopes along the identified road sections are stabilized in a sustainable and resilient manner.

Next Steps

The GoHP intends to take the following steps based on the above messages: (i) Develop detailed project reports (DPR), which will incorporate suggested measures to transform certain roads into model resilient roads and (ii) Provide capacity building and training for staff of nodal bodies such as HP SDMA and HP PWD in collaboration with CDRI and AFD India. These initiatives are crucial for stabilizing the slopes along identified road sections in a sustainable and resilient manner, as well as other vulnerable road sections in the state. This will help reduce the risk of landslides, thereby protecting both the infrastructure and the surrounding communities

Key Lessons and Conclusions

This TA report indicates that both natural factors (such as intense rainfall and fragile geology) and human activities (including poor drainage management, improper disposal of construction wastes, and inadequate waste management) contribute to triggering landslides. These incidents are becoming more frequent due to the increasing threat of extreme weather events, exemplified by the unprecedented rainfall events in July 2023. The report emphasizes the need for proactive risk assessments and systematic classification of slope risks, as well as effective road maintenance and management. The existing road and highway sinfrastructure are constructred rior to understanding of extreme weather events and increasing impacts of climate change. This existing asset base require review of design and detailed risk and resilience assessments, to identify the resilience measures. Equally, the report highlights the importance of well-designed and maintained drainage systems to prevent water accumulation and slope destabilization. Engaging local communities in maintenance and raising awareness about risks (e.g., waste disposal) can reduce human-induced triggers of landslides.

It suggests that NbS, while sustainable and cost-effective, are unlikely to be able to mitigate all landslides on their own. Moving forward, **hybrid approaches** that combine NbS with vital structural solutions for stabilizing high-risk slopes are expected to be more effective. To accurately evaluate landslide risks and design effective mitigation strategies, geological and geometeorological assessments (such as soil testing, geological, geomorphological and geophysical investigations) are necessary.

The TA highlights the importance of embedding resilience throughout the infrastructure project lifecycle, forming the foundation of decision-making. Effective landslide risk management can be achieved by integrating mitigation strategies into sustainable development plans and continuously updating them based on new data. This calls for an integrated and well-planned approach that combines natural, structural, and community-based solutions, supported by ongoing collaboration among key stakeholders to build resilient transport systems.

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