

Engineering Geological Assessment of Recurrent Landslides at Chakki Moad Along NH-05, Solan District, Himachal Pradesh, India

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Systematic Review

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Abstract

The Chakki Moad section of National Highway-05 (NH-05) in Solan District, Himachal Pradesh, represents one of the most landslide-prone corridors within the Lesser Himalayan region. The area experiences recurrent slope failures that significantly disrupt transportation, damage infrastructure, and threaten public safety. The present study evaluates the geological, geomorphological, structural, hydrological, and anthropogenic factors controlling slope instability in the corridor. The regional geology comprises the Subathu, Dagshai, and Kasauli Formations, while local exposures include highly weathered sandstone, siltstone, mudstone, shale, and unconsolidated colluvial deposits. Structurally, the area is influenced by the Main Boundary Thrust (MBT), Surajpur Thrust, and associated fault systems, resulting in highly fractured and sheared rock masses. Unfavourable bedding orientation, intense monsoonal precipitation, river-induced toe erosion, inadequate drainage, and extensive slope cutting associated with highway widening have collectively increased landslide susceptibility. Historical landslide records demonstrate repeated failures between 2010 and 2026, highlighting the persistent instability of the corridor. GIS-based landslide susceptibility studies classify Chakki Moad among the highest hazard zones along NH-05. The study concludes that slope instability is controlled by the combined influence of weak lithology, active tectonics, adverse geomorphology, hydrological conditions, and anthropogenic disturbances. Comprehensive slope stabilization, improved drainage systems, and continuous monitoring are recommended for long-term risk reduction.

1. Introduction

The Himalayan Mountain chain is one of the youngest and most tectonically active mountain systems in the world. Ongoing convergence between the Indian and Eurasian plates continues to generate deformation, seismicity, uplift, and widespread slope instability throughout the region. Consequently, landslides represent one of the most significant geohazards affecting infrastructure development and transportation corridors in the Himalaya.

The Chakki Moad landslide zone along NH-05 in Solan District, Himachal Pradesh, has emerged as a critical geotechnical hazard zone due to repeated slope failures. The corridor serves as the primary transportation link between Chandigarh and Shimla and therefore carries immense strategic, economic, and tourism-related importance. Repeated disruption of traffic caused by landslides has highlighted the necessity for detailed investigations into the geological and geomorphological processes governing slope instability.

This study aims to evaluate the geological setting, historical landslide occurrences, structural controls, hydrogeological conditions, and geomorphic factors contributing to recurrent slope failures at Chakki Moad and to propose engineering measures for hazard mitigation.

2. Study Area

Chakki Moad is situated along NH-05 approximately 30 km north of Chandigarh within Solan District of Himachal Pradesh. The site lies between the towns of Kasauli, Dagshai, Solan, and Barog and forms part of the highly vulnerable Chandigarh-Shimla highway corridor.

The area is characterized by steep hill slopes, deep drainage incision, active tectonic structures, and fragile lithological units. The corridor falls within Seismic Zone IV, indicating high seismic hazard potential. Frequent slope failures during monsoon seasons have resulted in repeated road blockages and infrastructure damage.

3. Historical Record of Landslide Activity

3.1 Landslide of 2010

A major landslide event occurred during the monsoon season, causing complete blockage of NH-05 for several days. Intense rainfall combined with slope excavation during highway widening destabilized highly weathered Subathu shale and limestone units.

3.2 Landslide of 2013

A medium-scale slope failure occurred during heavy rainfall, resulting in traffic disruption and partial road closure. Water infiltration into weathered shale and inadequate drainage systems were identified as major contributing factors.

3.3 Landslides During 2022–2023

Significant slope failures occurred near the Shamlech bypass area adjacent to Chakki Moad, damaging infrastructure and nearby properties. Geotechnical observations indicated elevated moisture content, reduced shear strength, and extensive weathering of exposed rock masses.

3.4 Landslide Events During 2025–2026

Recurrent landslides and debris flow events were reported during successive monsoon seasons. Recent GIS-based susceptibility assessments classified Chakki Moad as a very high hazard zone due to persistent slope failures, active tectonic influence, and unfavourable slope geometry.

4. Regional Geological Setting

The study area falls within the Lesser Himalayan tectonic domain, which has evolved through intense compressional deformation associated with Himalayan orogeny.

4.1 Subathu Formation

The Subathu Formation of Palaeocene-Eocene age comprises splintery shale, carbonaceous shale, and fossiliferous limestone. These lithologies exhibit low shear strength and high susceptibility to

weathering, making them particularly vulnerable to landslide initiation.

4.2 Dagshai Formation

The Oligocene-aged Dagshai Formation consists predominantly of friable red sandstone and siltstone. Weathering and disintegration of these units contribute significantly to debris generation.

4.3 Kasauli Formation

The Miocene-aged Kasauli Formation is composed of coarse sandstone and conglomerate units. Although relatively stronger than the underlying formations, extensive jointing and fracturing reduce rock-mass stability.

5. Local Geology of Chakki Moad

The immediate landslide zone is characterized by highly weathered and jointed sandstone, siltstone, mudstone, shale, and thick colluvial deposits. The lithological succession exhibits significant heterogeneity, resulting in variable engineering behavior.

The most critical units include:

Shale

Splintery and carbonaceous shale exhibits low cohesion, rapid deterioration upon wetting, and extensive fissility. These characteristics promote formation of failure surfaces and debris-producing slopes.

Sandstone

Weathered sandstones display reduced compressive strength and disintegration upon prolonged exposure to moisture and atmospheric weathering.

Mudstone

Mudstone units rapidly lose strength upon saturation and frequently act as failure planes during slope movements.

Colluvium

Unconsolidated colluvial deposits consisting of soil, debris, shale fragments, and sandstone blocks represent one of the principal causes of debris slides and flow-type failures during monsoon periods.

6. Structural Geological Controls

6.1 Main Boundary Thrust

The Main Boundary Thrust (MBT) forms the dominant tectonic structure influencing the area. The thrust has generated intense deformation, faulting, shearing, and fracturing within the surrounding rock mass.

6.2 Surajpur Thrust

The Surajpur Thrust represents a subsidiary thrust associated with the MBT system and is of particular engineering significance near Chakki Moad.

The thrust juxtaposes weak Subathu lithologies against Kasauli rocks and is characterized by:

- Sheared and crushed rock masses
- Extensive jointing
- Clay-rich gouge zones
- Enhanced groundwater infiltration
- Reduced rock mass strength

These conditions create ideal settings for repeated slope failures.

6.3 Bedding Orientation

Bedding planes generally strike NW-SE and dip toward the valley at angles between 35° and 45°. This orientation is unfavourable because bedding surfaces daylight within slope faces, facilitating planar and translational failures.

6.4 Jointing and Folding

Multiple intersecting joint sets fragment the rock mass into discrete blocks. Tight folding associated with Himalayan compression further weakens rock strength and generates additional discontinuities that promote instability.

7. Geomorphological Characteristics

The Chakki Moad landslide zone is characterized by:

- Steep slopes exceeding 35°
- Deeply dissected terrain
- Active valley erosion
- Unstable colluvial deposits
- Sparse vegetation cover

Road widening operations have significantly modified natural slope geometry and increased overall instability.

8. Hydrological Controls on Slope Instability

Hydrology plays a fundamental role in controlling slope failures at Chakki Moad.

Monsoon Rainfall

Annual rainfall ranges between approximately 850 and 900 mm, with peak precipitation occurring during July and August. Heavy rainfall saturates colluvial deposits and fractured rock masses.

Surface Water

Concentrated runoff and inadequate drainage systems promote gully erosion, infiltration, and saturation of unstable slopes.

Groundwater

Although shale and mudstone units possess low primary permeability, fracture networks and thrust zones serve as efficient groundwater conduits. Seasonal springs commonly emerge along bedding and fault planes, reducing effective stress and shear strength.

River Incision

The Kaushalya River and associated drainage channels actively erode slope toes, thereby reducing support and increasing the likelihood of slope failure.

9. Cause-Effect Relationship of Landslides

The interaction of geological, structural, hydrological, and human-induced factors creates a highly unstable environment.

Causative Factor	Effect on Slope	Resulting Instability
Weak lithology	Reduced shear strength	Shallow landslides
Colluvial deposits	Easy mobilization	Debris flows
Valley-dipping beds	Reduced stability	Planar failures
MBT and Surajpur Thrust	Sheared rock zones	Structural failures
Jointing and folding	Increased fragmentation	Rock falls
Monsoon rainfall	Elevated pore pressure	Slope collapse
River incision	Toe erosion	Slope steepening
Sparse vegetation	Lack of reinforcement	Surface erosion
Highway excavation	Over-steepened slopes	Artificial instability
Poor drainage	Water concentration	Gully erosion

10. Discussion

The recurrent landslides at Chakki Moad result from the combined influence of fragile lithological units, active tectonic structures, adverse structural orientations, intense rainfall, and human interventions. The dominant failure mechanisms include planar sliding along bedding planes, debris flows in colluvial material, rotational failures within heavily weathered zones, and block failures associated with joints and fault zones.

The engineering geological evidence indicates that no single factor is responsible for instability. Rather, landslide occurrence results from a cumulative interaction between weak rock mass properties, groundwater infiltration, tectonic deformation, and anthropogenic excavation.

11. Recommendations for Stabilization

To reduce landslide risk, the following engineering measures are recommended:

1. Construction of comprehensive surface and subsurface drainage systems.
2. Installation of retaining structures, reinforced earth walls, and rockfall barriers.
3. Rock bolting and shotcrete treatment in fractured rock slopes.
4. Bioengineering measures including deep-rooted vegetation.
5. Real-time slope monitoring using geotechnical instrumentation.
6. GIS-based early warning systems.
7. Controlled excavation and optimized slope geometry during highway widening.
8. Regular maintenance of drainage channels and culverts.

12. Conclusions

Chakki Moad represents one of the most critical landslide-prone sectors along NH-05 in Himachal Pradesh. The instability is primarily governed by weak shale, mudstone, sandstone, and colluvial deposits combined with unfavourable structural conditions created by the Main Boundary Thrust and Surajpur Thrust systems.

Valley-dipping bedding planes, extensive jointing, fault-controlled groundwater movement, intensive monsoon rainfall, river-induced toe erosion, sparse vegetation, and highway excavation collectively generate a highly vulnerable slope environment. Historical records demonstrate persistent landslide activity over the past decade, confirming the chronic nature of the hazard.

The study establishes that effective risk reduction requires an integrated engineering geological approach involving drainage control, slope reinforcement, bioengineering, monitoring, and scientifically designed stabilization measures. Failure to implement such interventions will likely result in continued disruption of highway connectivity, economic losses, infrastructure damage, and increased risk to human life.

Chakki Mod landslide zone along the **Kalka-Shimla National Highway (NH-05)** in Solan District, Himachal Pradesh. A hydraulic excavator is engaged in removing freshly failed slope material and loading it into a dump truck for disposal. The landslide debris consists predominantly of highly weathered soil, rock fragments, and colluvial material derived from the cut slope.

Declarations

Author Contribution

Conceptualization, methodology, field investigation, geological mapping, data collection, data interpretation, formal analysis, visualization, manuscript writing (original draft preparation), manuscript review and editing, and supervision. The author has read and approved the final manuscript.

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Figures



Figure 1

Legend not included with this version.