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हिमाचल प्रदेश के सोलन, शिमला और किन्नौर जिलों में कालका-खाब राष्ट्रीय राजमार्ग-05 के हिस्सों एवं शिमला शहरी क्षेत्र में भूस्खलन के प्रारम्भिक आंकलन पर प्रतिवेदन

(भा. स. वि. टोपोशीट संख्या: 53बी/13, 53एफ/01, 53इ/04, 53इ/08, 53इ/11,
53इ/14, 53आइ/02 एवं 53आइ/09)
(मद संख्या: M4EGG/C/NR/SU-PHP/2023/45656)
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**A NOTE ON THE PRELIMINARY ASSESSMENT OF LANDSLIDES ALONG THE
KALKA-KHAB NATIONAL HIGHWAY-05, COVERING PARTS OF SOLAN, SHIMLA &
KINNAUR DISTRICTS AND AROUND SHIMLA URBAN AREA HIMACHAL PRADESH**

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श्रेयसी महापात्रा, वरिष्ठ भूवैज्ञानिक

भारतीय भूवैज्ञानिक सर्वेक्षण, उत्तरी क्षेत्र

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Abstract

Consequent upon broad terms of reference framed for carrying out the preliminary assessment of landslide along Shimla town and the Solan – Shimla- Kinnaur National Highway road corridor, Himachal Pradesh, a team of geoscientists from Engineering Geology Division, GSI, Chandigarh undertook a geological traverse along with the authorities from District Disaster Management (DDMA) and National Highway Authorities of India (NHAI) to study the landslide vulnerable sites and to suggest the short term remedial measures. During the course of the field work landslide vulnerable sites were taken up on priority as identified by State Disaster Management Authorities (HP SDMA) along the Kalka- Solan National Highway-05 Road Corridor, along Shimla Urban, Solan-Rampur National Highway-05 Road Corridor and along the Rampur-Khab NH-05 Road Corridor.

The various locations of the slide were visited to ascertain the geoscientific cause of the landslide and provide the suitable remedial measures.

A number of landslides have occurred along the Kalka- Solan affecting the National Highway-05 obstructing the vehicular movement. The National Highway has been shown signs of subsidence at many locations as well as has completely caved in at numerous sites. The observations of the slides along Solan- Shimla section revealed that most of the slides were debris slides, occurring due to deep to shallow rotational failure. The landslides are mostly active and have primarily occurred due to the oversaturation of the loose overburden during the incessant rains during the monsoon of 2023. The sites of landslide incidences were checked for presence of ground signatures of slope instability such as development of tension cracks, land sinking, tilting of trees etc. The structural data and other rock properties of the bedrock exposed along the slide zone were collected for understanding the failure mechanism.

Geologically, the study area is structurally disturbed by large scale faulting and thrusting during the Himalayan Orogeny and comprises of rocks varying from Proterozoic to Holocene. The problem of slope instability is vulnerable mainly in the proximity of major tectonic features like MBT, MBF and HFT. The Tertiary rocks are the worst affected and recorded most of the landslides between Kalka and Solan along (NH-05) owing to major road widening activities in the area. The study area exposes Proterozoic rocks of Jutogh, Jaunsar, Shimla and Baliana groups successively tectonically underlain by Sirmur and Siwalik Group of rocks. The structural elements have regional trend along NW-SE. The most significant causative factor for the triggering and development of landslide is the continuous heavy rainfall leading to saturation of thick slope wash debris material/highly weathered rock and poor drainage system. It has also been observed that increased anthropogenic activities, such as ill planned construction of buildings, civil structures, and other infrastructure projects, have contributed to hill slope cutting and modification in recent years. This raises concerns about potential slope instability incidents or failures in the future, particularly if these activities are taken up without thorough geoscientific studies. The absence of proper drainage network has also played a crucial role in inducing the slope failure.

The suitable remedial measures were suggested. The primary suggestions were provision of lined drainage to divert the water away from the slide area, provision of suitable retaining structures as per design engineer and sealing of all the ground cracks with impervious material to arrest further ingress of the water.

The landslide zones in and around Shimla town were also visited. The landslides at Shimla town were identified as debris slide which are active and widening in nature attributed due to shallow rotational failure which was caused by the oversaturation of water within the fragile and loose material of slope forming material during heavy precipitation. Absence of adequate drainage network have also drastically worsened the situation deteriorating the slope stability and ultimately causing the slope failure. The remedial measures suggested were provision of proper drainage system away from vulnerable areas to efficiently manage surface water runoff, mitigating the risk of slope destabilization, provision of sturdy retaining structures with staggered drains and weep holes at the hillside road level to prevent soil erosion and sealing of ground cracks with impervious material to minimize water infiltration and further damage.

The landslide incidences along the Shimla to Khab section also visited for assessing the affected sites. The landslides along the section are primarily identified as rock failure. The structural data of the beds were collected for kinematic analysis. The jointed nature of the rock mass has led to

wedge and planar failures Field observations and empirical equations were used to characterize the rock mass, revealing varying degrees of weathering and strength. Rock Quality Designate (RQD) ranged from 'poor' to 'fair' rock mass condition. The Rock Mass Rating (RMR) values in the study area falls in poor to fair category (Class IV to III). The kinematic analysis carried out with the help of joint sets leading to wedge and planar modes of failure. Remedial measures suggested included proper drainage management, stabilizing the crown with cable anchors, grouting and stitching of open joints with the help of rock bolts, and steel fiber reinforced shotcrete at the rock face, flexible wire mesh for rock interception etc.

1. INTRODUCTION

Unprecedented rains during the monsoon of 2023 has wreaked havoc across the state of Himachal Pradesh. Extreme events such as flash floods, cloudbursts and associated landslides, subsidence and sinking of land and complete failure of the heavily populated hill slopes has brought wide spread devastation across the State, causing severe causality and injury to the local inhabitants. The damages to buildings and infrastructure forcing the large population including local dwelling inhabitants to seek alternate places to live. Huge losses have occurred for agricultural and horticultural lands due to various hazardous landslides and flooding. The National highway, particularly the Kalka-Khab four lane from Parwanoo to Khab and the Kiratpur-Manali four lane from Mandi to Manali were also washed away at many places. During the monsoon season of 2023, three extreme spells from 8th to 11th July, 14th to 15th August, and 22nd to 23rd August 2023 caused around 72 flash floods in the state of Himachal Pradesh and have been responsible for most of the landslide hazards. Kullu, Mandi, Shimla, Sirmaur, Solan and Chamba districts were some of the worst affected.

In response to the natural calamity, the Geological Survey of India (GSI), being the nodal agency for carrying out landslide related studies in India on the request of the Principal Secretary (Rev-DM) to the Government of Himachal Pradesh, Shimla Vide letter No. Rev (DMC) (F) 11-09/2021-LM dated 15.09.23, deputed a team of geoscientist from Engineering Geology Division of GSI Chandigarh, to carry out the preliminary geological assessment to evaluate the landslide potential hazard and other vulnerable areas along the Kalka – Khab section of NH-05 from 23rd November 2023 to 1st October 2023, in coordination with the Himachal Pradesh State Disaster Management Authority (SDMA), District Disaster Management Authority (DDMA) and other concerned district authorities. During the course of preliminary field work, necessary geological/geotechnical study in and around the affected area were studied to know probable causes, assess damages and to suggest suitable remedial measures.

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time-to-time suggestions, constant guidance, support, keen interest and critical review during the course of investigation and report writing. The authors also express their sincere thanks to Sh. DC Rana, IAS, Director cum Special Secretary, SDMA, Himachal Pradesh for providing necessary logistic support during the course of investigation. Thanks, are also to Dr. SS Randhawa, Principal Scientific Officer, Himachal Pradesh for his time-to-time coordination during the field visits. Support extended by the DDMA officials of District Solan, Shimla and Kinnaur are highly acknowledged which had helped the authors in managing field visits along the stretch of National Highway-05.

3. INTRODUCTION

During the course of the field work many sites were taken up on priority as identified by State Disaster Management Authorities (HP SDMA). These landslides sites visited by the authors were categorized into two parts, viz.; 1) along the Kalka- Rampur National Highway-05 Road Corridor and 2) along the Rampur- Khab National Highway-05 Road Corridor.

The landslides site details in both categories are listed below as:

A) Along Kalka- Rampur National Highway-05 Road Corridor

a) Along Kalka- Solan National Highway-05 Road Corridor

1. Datyar slide, Solan District, Himachal Pradesh
2. The Dimple Dhaba Slide, Solan District, Himachal Pradesh
3. The AAA Hotel slide, Solan District, Himachal Pradesh
4. The Haveli subsidence, Solan District, Himachal Pradesh

b) Shimla Urban

1. Tutikandi Slide, Shimla Town, Himachal Pradesh
2. Rajvir Motor Slide, Shimla District, Himachal Pradesh
3. Victoria Tunnel road, Komli bank land subsidence, Shimla District, Himachal Pradesh
4. Centre of Advanced study, Shimla
5. Vidhan Sabha to Annadele Helipad Road subsidence

c) Along Solan-Rampur National Highway-05 Road Corridor

1. Mohan Meakin Slide, Summer Hall, Chambaghat, Solan District, Himachal Pradesh
2. Mansar subsidence, Solan District, Himachal Pradesh
3. Karibangla Slide, Kandaghat, Solan District, Himachal Pradesh
4. Nangal Devi Mandir Rock slide, Theog, Shimla District, Himachal Pradesh
5. Rahighat-Kiartoo Slide, Theog, Shimla District, Himachal Pradesh

6. Hyundai Showroom slide, Rampur, Shimla District, Himachal Pradesh
7. Khaneri Hospital Slide, Rampur, Shimla District, Himachal Pradesh

B) Along Rampur-Khab National Highway-05 Road Corridor

1. Baruni Khad, Rampur, Shimla District, Himachal Pradesh
2. Jeori Rock Fall, Sarahan, Shimla District, Himachal Pradesh
3. Chaura Rock Fall and Chaura Tunnel, Sarahan, Shimla District, Himachal Pradesh
4. Panvi Bridge Rock Fall, Kinnaur District, Himachal Pradesh
5. Nathpa Jhula Rock Fall, Nichar, Kinnaur District, Himachal Pradesh
6. Khab Slide, Pooh, Kinnaur District, Himachal Pradesh.

The authors of the note held discussions with concerned DC's of the district along with other associated officials from DDMA. The authors also held discussion and collected information regarding the affected area from the officials of concerned DDMA and local peoples to get a proper perspective view of sites. Suggestions were given to the officials to take care of precautionary measures to arrest the slope failure. A note on the meeting held with district authorities of Kinnaur is annexed in Annexure 1.

After the completion of field investigation along the Kalka -Khab National Highway-05, a meeting was held with Sh. DC Rana, IAS, Director cum Special Secretary, SDMA Himachal Pradesh and Dr. SS Randhawa, Principal Scientific Officer, Himachal Pradesh on 1st December 2023 at the Secretariat, Shimla. GSI field officers appraised the Secretary about the highlights of work and their salient observations along the NH-05.

4. Kalka- Rampur National Highway-05 Road Corridor

4.1 Location and Accessibility

These vulnerable landslides' location was mainly restricted to the NH-05, Solan- Shimla Highway in Solan and Shimla district, Himachal Pradesh falling in longitude range of $76^{\circ} 55' E$ to $77^{\circ} 45'05'' E$ and the latitude range of $30^{\circ} 50' N$ to $31^{\circ} 30' N$. The area of investigation falls in the Survey of India Toposheet No 53 B/13, 53 F/01, 53 E/04, 53 E/08 and 53 E/11. The area is well connected by rail and road network and can be accessed by Chandigarh- Kalka- Simla road by National Highway – 05 or the Kalka Shimla toy train. The study area is bounded by Mandi district in north, Kullu district in north-west, Kinnaur in the north-east, Sirmaur districts in the south. The study area has inter-state boundary in the south - east with State of Uttarakhand. The nearest airports are at Simla (Jubbal Hatti) and Chandigarh.

The study area includes major township such as Dharampur, Kandaghat, Subathu, Dagshai, Theog, etc. and major industrial hubs such as Solan, Simla Urban, Rampur etc. The area has high density of road network which includes important National Highway like NH-05, NH-72 & State highways like SH-06 (Solan-Rajgarh), SH-02 (Kumarhatti-Nahan) and Kandaghat-Chail etc. The National Highway 05, is connected by Dharampur-Kasauli road, Parwanoo-Taksal road, Kumarhatti-Nahan road, Chail-Kandaghat road, Solan-Rajgarh road. Over the recent years, the study area has experienced various infrastructure advancements, particularly in the expansion of roads and the construction of buildings. The location map is give in figure 1 below.



Fig 1-Location Map of Landslides along Kalka – Rampur section of National Highway-05 in Solan and Shimla, Districts, Himachal Pradesh

4.2 Climate and Rainfall

Overall, the climate of the districts of Solan and Shimla is sub-tropical in the valley and tends to be temperate on the hilltops. It is quite pleasant throughout the year with the summers being hot and wet and the winters being cold and dry. The average annual temperature ranges from 17 -30°C.5 °F with June being the hottest and January the coldest month. In the winter season, precipitation as snowfall also occurs in the higher reaches. The Figure 2 shows the increase of rainfall in the last four years during the monsoon season (July- Aug) in the district of Shimla and Solan.

According to Köppen and Geiger, this climate is classified as Cwa i.e Monsoon-influenced humid subtropical climate. The annual rainfall is 1262 mm | 49.7 inch. When compared with winter, the summers have much more rainfall. The driest month is November, with 13 mm/0.5 inch of rain. During Monsoons, in the month of July, the precipitation reaches its peak, with an average of 325 mm /12.8 inch. The rainfall in the last five years' have increased significantly. The Figure shows the increase of rainfall in the last four years during the monsoon season (July- Aug) specially in year 2023 in the districts of Shimla and Solan.

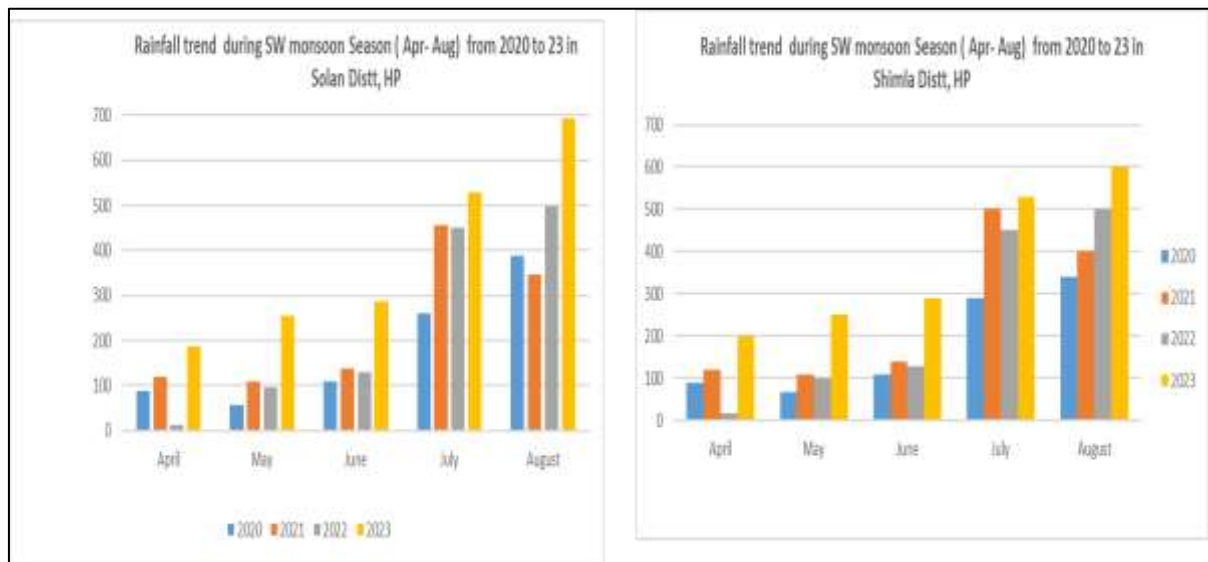


Figure 2. General trend of rainfall in Solan and Shimla District of Himachal showing significant increase in rate of precipitation during last four years. (Source IMD)

4.3 Geomorphology, Drainage and Soil type of the study area

The study area presents an intricate mosaic of high mountain ranges, hills and valleys with altitude ranging from 300 to 3000 m above msl. The altitude of the hill ranges is higher in

northern parts, whereas south-western part of the district is represented by low denuded hill ranges of Siwalik. In the areas underlain by high hill ranges of Himalayas, the valleys are narrow and deep with steep slopes trending in NW-SE direction. The terrain is moderate to highly dissect with steep slopes.

Shimla and Solan districts of Himachal Pradesh are drained by streams/rivers forming part of the drainage basins of the Sutlej, the Yamuna, the Pabbar and Tons rivers. The Sutlej River is the longest river traversing the study area and major part of the district is drained by tributaries of Sutlej River viz., Ghaggar River and Sirsa Nadi. Ghambhar. The Ghaggar River flows towards south-west and marks the south-eastern boundary of the Solan district while the Sirsa *Nadi* flows towards north-west in the Nalagarh valley. The Giri River which is the tributary of the Yamuna River and its tributary named Assan, forms part of Yamuna river basin originates from the eastern part and runs in the SW direction. The tributaries of Tons river flow in the southern parts and the Pabbar River in the eastern parts of the district. Most of the rivers/streams/*khads* maintain base flow for major part of the year. In hilly terrain, the drainage density is high, but it become coarse in foothills, Kandi areas and valleys. In general, the density of drainage is moderate to high and is not uniform all over the study area.

Soil is generally sandy loam in valley areas of the study area and in rest of the hilly and mountainous areas soil is skeletal. The soil depth is generally shallow except in areas having good vegetative cover. It is generally dry, shallow, nutrient rich and deficient in organic matter. Landslides are the common features in the mountainous terrains having mountainous/ skeletal soil.

4.4 Geology of the area

The study area is occupied by the rocks of Proterozoic to Quaternary age represented by Jutogh, Shimla, Baliana, Krol, Sirmur, Siwalik, Older Alluvium and Newer Alluvium Groups. The rock succession from Proterozoic to Pleistocene have undergone polyphase deformation during Himalayan orogeny resulting in to development of several NW-SE trending regional thrusts (Jutogh Thrust, Krol Thrust, Chail Thrust and, Markanda or Poanta Thrust, Nahan Thrust, Himalayan Frontal Thrust, etc.) and fault (Kandaghat Fault, Surajpur Fault and Main Boundary Faults. Along these thrusts different rock successions override (Bhargava et al. 2020).

The Quaternary sediments have been classified into the Older Alluvium and Newer Alluvium groups represented by the Ludhiana Formation, Channel and Terrace Alluvium

respectively. Siwalik Group is divisible into Lower, Middle and Upper Siwalik Sub Groups. Upper Siwalik Group thrusts over Alluvium along Himalayan Frontal Thrust and also having faulted contact along Surajpur Fault. Lower Siwalik Group tectonically rests over the Upper Siwalik Group along the Markanda or Poanta Thrust. The Sirmur Group rests over the Siwalik along the Main Boundary Fault. Subathu and Dagshai Formation of Sirmur Group is thrust over Upper Siwalik along Nahan Thrust. Subathu Formation is overriding over Kasauli Formation along Ronan thrust. Chhaosa Formation of Shimla Group overrides over Subathu Formation along Krol Thrust and erosion of this thrust sheet has exposed Subathu Formation in the antiformal core as Solan window.

The Krol Group is divisible into the Chambaghat, Mahi, Jarasi and Kauriyala Formations in ascending stratigraphic order (Srikantia et al. 1998). The Chambaghat Formation is followed by the Mahi Formation (i.e., Krol 'A' lithounit (Auden, 1934) forming the lower Krol of the Krol carbonate suite which is gradationally overlain by the Jarasi Formation (Krol 'B') forming Middle Krol. The Kauriyala Formation represents undifferentiated Krol 'C', 'D' and 'E' lithounits (Auden 1934) and also forms upper Krol.

The Baliana Group in the area is represented by Blaini and Infrakrol formation and unconformably deposited over the Shimla Group. The Infrakrol Formation is conformably succeeded by the Chambaghat Formation of Krol Group. Infrakrol thrusts over by Shimla Group and rests over by the Eocene Subathu Formation along MBT

The Jutogh is represented in the area only by the Panjerli Formation thrust over the Chandpur Formation of Jaunsar Group. The Shimla Group in the area is represented by Chhaosa and Sanjauli Formation is thrust over by Jaunsar Group along the Chail thrust. The Jutogh Group rests over the Chandpur Formation of Jaunsar Group along Jutogh Thrust. Generalized stratigraphic succession of the study area has been given as per Table 1

Age	Group	Formation	Lithology
Holocene	Newer Alluvium	Channel Alluvium	Grey fine to coarse sand with pebble and clay
		Terrace Alluvium	Multiple fill cyclic sequence of medium to coarse grained grey sand and grit with pebbles of sandstone and lenses of clay
Middle to Late Pleistocene	Older Alluvium	Ludhiana	Brown to grey micaceous sand, silt and clay with Kankar.
Plio-Pleistocene	Upper Siwalik		Coarse sandstone, grit and conglomerate with local clay and sand lenses.
Mio-Pliocene	Middle Siwalik		Coarse micaceous sandstone with interbands of earthy clay
Miocene	Lower Siwalik		Fine to medium grained sandstone and sandy clay.
Early Miocene	Sirmur	Kasauli	Sandstone, clay, siltstone and shale
Late Eocene to Oligocene		Dagshai	Predominantly purplish sandstone, interbedded with clay
Palaeocene to Middle Eocene		Subathu	Olive green shale and Limestone
Neo-Proterozoic	Krol	Kauriyala /Krol C, D and E	Dolomite, cherty limestone, shale, sandstone, quartz-arenite, calcilutite
		Jarasi /Krol B	Shale, dolomite, limestone, calcilutite
		Mahi /Krol A	Dolomite, oolitic limestone, shale
		Chambaghat	Quartz-arenite and friable sandstone
	Baliana	Infra Krol	Black shale and slate, slaty quartzite
		Blaini	Diamictite shale and dolomitic limestone
	Simla	Sanjauli	Shale, Sandstone, greywacke conglomerate
		Chhaosa	Shale, siltstone, greywacke and orthoquartzite
	Jaunsar	Chandpur	Rhythmic Shale, Siltstone, Greywacke, Arenite, local metavolcanics
Proterozoic (Undifferentiated)	Jutogh	Panjerli	Carbonaceous schist, phyllite with limestone and quartzite.

Table. 1: Generalized stratigraphy succession of the Solan-Shima section after Bhargava et al. 2020.

The geological map of the area is given in Figure 3

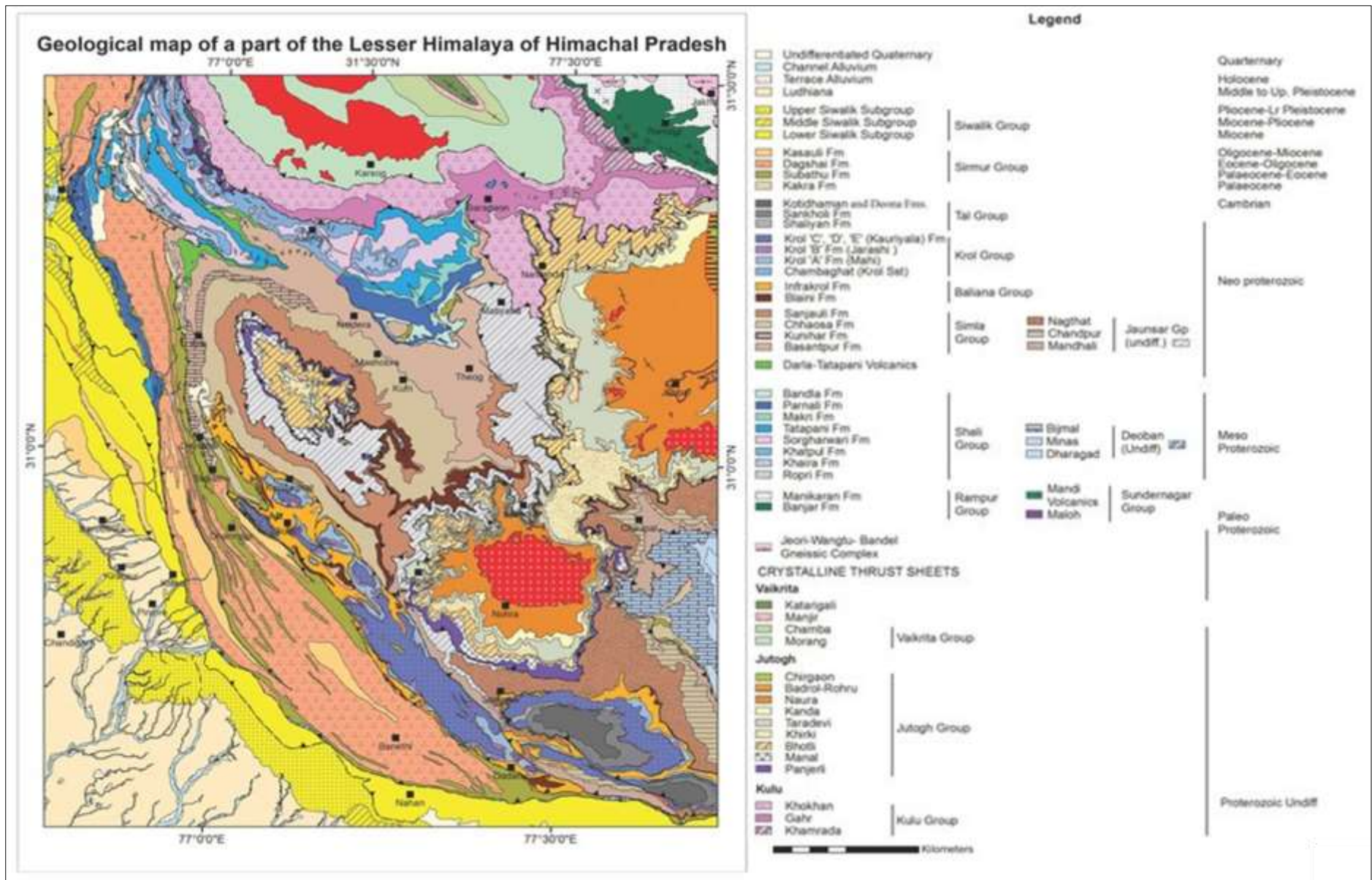


Figure 3. Geological map of a part of Himachal Pradesh (After Bhargava.. et al. 2020)

4.5 Seismicity of the study area

The state of Himachal Pradesh located in the western Himalaya has experienced major earthquakes because it is seismically a very active region and falls in the zone of continental collision of the Indian and Eurasian plates (*Chandra Citation1992*). The seismic activity of this area is closely associated with the active faults and the regional tectonic features (which include the north-west-south-east trending Main Boundary Thrust (MBT) and Main Central Thrust (MCT) running parallel to Himalayas (*Arya Citation1992*) and other local transverse faults across the area (*Mahajan and Kumar Citation1994*).

The north-west Himalaya has distinct crustal zones of homogenous seismic behaviour demarcated by major thrusts and faults. The Main Himalayan Seismic Zone is the most seismic prone belt (*Narula and Shome Citation1992*), and this zone forms a major portion of the study area.

The Shimla and Solan districts fall in seismic zone IV, which has been classified as high damage risk zone MSK VIII (Source: BMPTC Earthquake Hazard Map, HPSDMA website). The NW-SE trending Jutogh Thrust is the main tectonic feature lying at an aerial distance of approx. 1km from the study area and makes it seismically more sensitive.

As per the data of National Centre for Seismology (NCS), an earthquake of magnitude M 5.8 occurred on 5th August 2023, with its epicenter in Hindu Kush Region, Afghanistan. The earthquake is widely felt in Himachal Pradesh, Jammu and Delhi-NCR region. Aftershocks events also occurred on 05th August and 06th August 2023. (NCS, Report No.: NCS-NSN-EPG-05).

The seismic amp of Himachal Pradesh is given in figure 4. (Source Vulnerability Atlas of India, Third Edition 2019, <https://vai.bmtpc.org/eq-hp.html>)

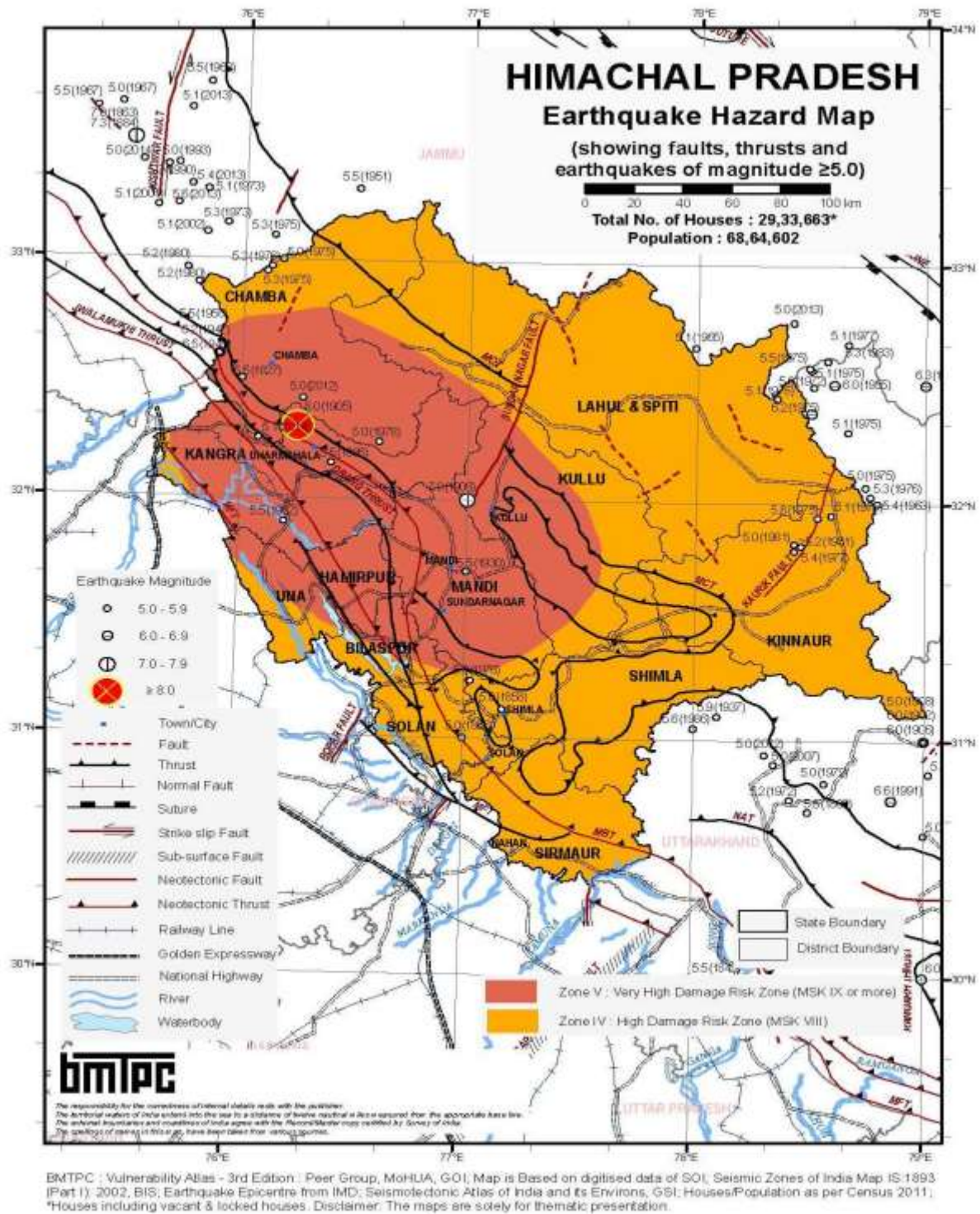


Figure 4. The seismic Map of Himachal Pradesh indicating the study area falls in seismic zone IV, which has been classified as high damage risk zone MSK VIII

5. The landslide incidences along Kalka-Solan National Highway-05 Road Corridor

The details of the landslide studies carried out at various locations along the Kalka- Solan National Highway-05 Road Corridor are as below.

5.1 Datyar landslide, Solan District, Himachal Pradesh

The landslide zone is situated at coordinates $30^{\circ}50'48.92''\text{N}$ and $76^{\circ}59'41.22''\text{E}$, along the National Highway-05 the right bank of Ghaggar River. It is approximately 2.5 Km southeast from Chakki Modh, Solan and falls in Survey of India Toposheet no. 53B/13. The slide lies at an elevation of 1020 m MSL. The location map of the slide on the google/satellite imagery is shown in fig 5 (b). The slide dimensions are 260m in height and 170m in width, resulting in a 30m stretch of NH-05 completely collapsing/caving in. This landslide incident has also affected ~450m stretch of the National Highway, leading to significant disruptions in vehicular traffic. The slope of the slide is steep at the crown approx. 75° , moderate at the belly with an angle of 50° and gentle at the toe with an approx. angle of 30° . This landslide has occurred in direction $\text{N}84^{\circ}$. The slope morphometry is given in Figure 5 (a).



Figure 5(a) Morphometry of the Datyar Landslide, 5(b) Satellite imagery of Datyar landslide along NH-05 , 5(c) 3 set of prominent joint and one set of random joints along the sandstone of Kasauli Formation, 5(d) Seasonal Nala cutting across road causing major damage.

The landslide first showed signs of failure on 8th of July, 2023 and finally caved in on 11th of July, 2023. The observations revealed the landslide to be a debris slide, which is a rotational failure presently triggered due to slope saturation. The landslide is active with its toe terminating in mid hill part. The area exhibits generally moderate to steep slope. The debris slide is attributed to weakened slope debris due to water ingress and subsequent slope saturation by heavy rain. Even though no casualties took place, damage to the retaining walls along with the drainage pipes/ culvert has been reported.

During course of the investigation, the Google earth satellite imagery was also referred, to understand the development of the landside during the last few years. It was observed that the location of the landslide (fig 5 (b)) incidence during the construction of the four lane was used as a dumping site, wherein the loose unconsolidated material was dumped. This loose material during the unprecedented rainfall during the month of August, 2023 failed and led to complete collapse of a stretch of the National Highway. The figure 5 (e) shows the google satellite imagery taken from Google Earth exhibiting the phase of initiation of the slide zone due to dumping of road building material.



Figure 5 (e) Satellite imagery showing development of the slide by creation of dumping zone along road during construction of the four lane National Highway from 2015 to 2021

The landslide is retrogressive and widening in nature due to presence of loose unconsolidated debris material. The landslide is active, single with its toe terminating in mid hill part at the NH-05. The area exhibits generally moderate to steep slope. The debris

slide is attributed to weakened slope debris due to water ingress and subsequent slope saturation by heavy rain. The landslide area mostly comprises of alternate bands of sandstone and siltstone of Kasauli Formation.

The area has already been identified as Moderate landslide susceptibility zone by Geological Survey of India (GSI, 2018-2019). The Weathering index of the slope forming material ranges from W4- W5 (ISRM, 1981a). However, it was observed, that sandstone was exposed on the slide zone just below the road at the crown of the slide. The sandstone exhibited three main set of joints and one random set of joints. The jointed sandstone is shown in figure 5(c). The details of the joints as observed at the site are tabulated in Table 1.

Table 1. Details of joints at Datyar Landslide area, Solan District, Himachal Pradesh.

Joint Sets	Dip Amount and direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J1	30° →N330°	80-100	0.1	1.0	Nil	Dry
J2	80° →N250	60-70	1.0	<1	Clay & loose soil	Dry
J3	75° →N180°	40-50	0.2	<1	Clay	Dry
J4 (Random)	50° →N85°	50-60	0.2	<1	Nil	Dry

The presence of outcrop has provided adequate support to remaining section of the National Highway and seems safe for the vehicular traffic. The road section did not exhibit any ground crack.

Around 200m NW from the slide zone, a seasonal nala was observed. The Nalah was charged with heavy boulders and the culvert was also damaged due to the heavy slush of water during monsoon season heavily charged with boulders. The transmission line and the road section near the nala was also broken. The site of the broken culvert due to the seasonal nala is shown in Fig 5 (d).

The salient features of the landslide have been enumerated below-

1. An overburden cover having thickness of more than 5 m was observed around the slide area which was possibly accumulated and deposited during the construction of four lane road. This overburden material comprises of unconsolidated soil and debris.
2. Prima facie, a rotational failure along this overburden covered slope has been suspected which was triggered by the extensive rainfall for a prolonged duration.

3. The main two spell of continuous rainfall in the month of July and August 2023 lead to increase in pore pressure within the soil reducing friction along the potential failure surfaces. A culvert constructed to regulate the flow of water from the nala, did not prove effective to manage the slush and failed.
4. The slide is enlarging in nature due to presence of large amounts of dumping material on both ends of the slide. The nala on the northern end of the slide is also adding to the damage by cutting the dump material.
5. Gully erosion were observed on the loose overburden material.
6. The southwardly flowing Ghaggar River caused some toe cutting further activating the slide.
7. The weep holes provided on the retaining walls along the road were obstructed shown on figure 5 (g).
8. Interbedded sequence of sandstone-mudstone of Kausali Formation is exposed along the road cut section. The rock mass is jointed and exhibits poor to fair RMR. The rocks exhibited moderate weathering.
9. The upslope of the slide also exhibited loose overhanging blocks posing severe threat to the vehicles plying on the National Highway as shown in figure 5 (f).
10. It was observed that the railway track was only 50 m away from the slide zone on the upslope hill and zone susceptible to rock fall required immediate attention.
11. Macroscale National Landslide Susceptibility Mapping (NLSM) studies carried out during the FS: 2017-18, the presently affected area lies in high landslide susceptibility zone.



Figure 5 (f) Loose overhanging blocks on the upslope of Datyar slide

Figure 5(g) Obstructed weep holes on the retaining walls along the National Highway-05

Future Menace

The terrain generally exhibits moderate to steep valley slope. In view of presence of loose debris, the stretch is seemed to remain unstable and required to be dealt carefully and scientifically. Interbedded sequence of sandstone-mudstone of Kausali Formation is exposed along the road cut section exhibits poor to fair RMR. In view of the steep gradient of the upstream part, the rock fall incidence cannot be ruled out. The blocks need to be dealt carefully for safety of the commuters.

Geoscientific Causes

The geoscientific factors attributed to the cave-in of the road are as follows:

- 1) Over Saturation of the loose slope forming material during heavy precipitation and subsequent development of pore water pressure.
- 2) The absence of proper drainage network has played a crucial role in inducing the slope failure.
- 3) The steep slope having an inclination of approx. 45°-50° further facilitated the rapid movement of debris material and erosion of surrounding hill slope.
- 4) Toe cutting action by Ghaggar river further added to the damage.

Recommendations

The following remedial measures have been suggested to contain the road to cave in further:

- 1) Identifying the sound rock for foundation of erecting adequate retaining wall.
- 2) Provision of suitable retaining structure at the toe portion of the slope should be constructed in consultation with design engineers.
- 3) Proper drainage management system should be implemented. Catch water drains or chute drains may be provided above the crown of the landslide to divert or channelize the water away from the slide area.
- 4) Geojute/Geotextile may be used to protect the overburden face from further weathering and erosion on the slope affected by the incidence.
- 5) The surrounding area susceptible to further slope failure along with the buffer zone may be identified for monitoring developments of new ground cracks or subsidence of land. The cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure

surface water does not pond in the area.

- 6) The valley slopes along the four lane Kalka-Shimla Highway NH-05 have been subjected to dumping of excavated muck during the back cutting which has been confirmed by timeline google earth imageries. Gradually with time, these dumped materials give rise to loosely compacted overburden cover which are highly prone to slope failure incidences during the extreme rainfall events. Therefore, such locations which have been designated as dumping zones during the construction of four lane road must be identified and investigated for any susceptible zone for slope failure.

5.2 The Dimple Dhaba, AAA Hotel and Haveli Slide, Solan District, Himachal Pradesh

The Officials from NHAI have identified certain locations exhibiting subsidence/sinking incidences along the National Highway. It was observed that there is creep movement for most parts along the hill slopes along which the road twirls. The evidences of creep movement such as tilted trees, bulging in retention structures/walls, differential settlements etc. were observed during the uphill and downhill trekking. It was found that the buildings were constructed over the unconsolidated debris material comprising silty sand matrix.

A rotational failure has been suspected along the slided slope. The manifestation of the same on ground was in the form of arcuate subsidence zones prevailing at least at two levels as observed during field study. Several wide cracks were observed at the Dimple dhaba. The cracks were trending $N25^{\circ} E$ and upto 6 -10 m long and 1m wide (Figure 6a and 6e). The subsidence in the land was upto 3m. The Dimple Dhaba had completely collapsed due to the slide (Figure 6b and 6d).



Figure 6 (a) Ground cracks along NH-05 near collapsed Dimple Dhaba.



Figure 6 (b) subsidence upto 2 m near Dimple Dhaba.



Figure 6 (c) Highly Jointed sandstone on upslope of NH-05



Figure 6 (d) Collapsed building due to subsidence



Figure 6 (e) Ground cracks trending N25° E at Dimple Dhaba



Figure 6 (f) Ground cracks trending N230° at AAA hotel



Figure 6 (g) Damaged AAA hotel due to subsidence



Figure 6 (h) Ground cracks trending N20°E at Haveli

The AAA Hotel (up to 2 to 3 stories) was observed to have tilted drastically and needs immediate action. It was intimated that the instability in the area was initiated on 7th July, 2023 following incessant rains. After initiation and further development of instability signatures and resultant instability, the pockets of the area were abandoned.

The slope is oriented in a valley ward direction, and prima facie, it appears that a combination of poor natural and man-made drainage, the nature and characteristics of the slope-forming material, and the loading of the slope has played a critical role in inducing the slope failure. The site appears to be still active. Wide cracks were found on the ground (Fig. 6(f)) and subsidence was also observed in the form of displacement between the beam and the wall of the building figure 6(g).

The Haveli site was also located 300 m ahead on the road to Shimla also had shown some subsidence and ground cracks. The cracks were trending N40°E (Figure 6h). Maximum subsidence of upto 1.5 m was observed. The Haveli hotel had also developed some cracks and requires immediate attention.

Future Menace

It was also observed that due to various anthropogenic activities like construction of buildings (hotels, guest houses, Shops and dhabas etc) and other infra-structure developmental activities in unplanned/less-planned manner, cutting/modification of hill slopes have increased in past few years leading to possibilities of slope instability incidences/failures in times ahead, if the same are done without proper geoscientific studies.

Geoscientific Causes

The Geoscientific factors attributed to the slide are as follows:

1. Over saturation of the loose unconsolidated material of slope forming material during heavy precipitation.
2. Lack of adequate drainage system/network.

Recommendations

1. Clearing out of the collapsed Dimple Dhabha building material from the slope. The AAA hotel building located adjacent to incidence zone should be demolished. The retrofitting of the affected Haveli building can be considered in due consultation with the design engineers.
2. Protection of surrounding slope from further ground water saturation is of the utmost requirement at this particular stage. Catch water drains or chute drains may be provided above the crown of the landslide to divert or channelize the water away from the slide area. Proper Drainage management system should be implemented

around the settlements.

3. Provision of suitable retaining structure at the toe portion of the slope in consultation with design engineers.
4. Geojute/Geotextile may be used to protect the overburden face from further weathering and erosion on the slope affected by the incidence.
5. Area above the crown of landslide needs to be monitored for development of any new ground cracks. Under such conditions, the ground cracks need to be covered up effectively in order to avoid any further rain water percolation. The cracks must be sealed either by filling them with puddle clay or other impervious fill. Bentonite or other natural material to reduce further permeability can be used so that surface water does not pond in the area.
6. Since the entire area is covered with very thick debris/overburden, it should be ensured during any new construction, that foundation in the soft ground does not undergo shear failure during or under the loading of the structure especially in the saturated wet conditions.
7. People should be educated about the ill-effects of unscientific slope modifications to avoid slope failures in future.
8. The Tell-tales crack monitoring gauge is also suggested to be installed between the cracks to observe the vertical and horizontal movement across a crack.

6. Landslide Incidences in Shimla Urban, Shimla District, Himachal Pradesh

6.1 Tutikandi, Bangali Bagicha Landslide in Shimla Urban

The landslide zone is located on the Shimla Bypass road at N 31°5'50" and E 77°9'13" and falls in Survey of India Toposheet no. 53E/04. The slide lies at an elevation of ±1941m MSL. On the night of 14th August 2023, at around 8:30 pm, approximately a 05-m stretch of the NH caved in following a major slide. The slide was primarily caused by oversaturation of the loose overburden material owing to the incessant rains on preceding days of 12th and 13th of August, 2023. On inspection of the crown portion of the slide, a blocked drainage pipe of approx. dia. 25 cm and a leaking agricultural pipe was observed as shown in fig 7 (b). The blocked drain has led to a creation of a new nallah having dimensions roughly 1.5 m wide and 1 m deep as depicted in fig 7(a).

The findings indicated that the landslide/slope failure was identified as a debris slide with dimensions of 70m in height and 50m in width. The slide can be described as a shallow

rotational failure presently triggered due to slope saturation. The area exhibits generally moderate to steep slope. The debris slide is attributed to weakened slope debris due to water ingress and subsequent slope saturation by heavy rain. The landslide incidence caused deaths of 6 livestock (cows) and injury to several people. The cow shed located just below the slide zone was completely damaged as shown in figure 7(c). Many trees (Forest Numbered) were also uprooted as shown in figure 7(d).



Figure 7 (a) New nalah created at site of slide



Figure 7 (b) Crown of slide at the road level



Figure 7 (c) Damaged houses and cowsheds located on 1st order stream highly susceptible to future slide



Figure 7 (d) Debris and uprooted trees accumulated at toe of slide

The landslide area mostly comprises of phyllites of Botli Formation of Jutogh Group. The area has already been identified as Moderate landslide susceptibility zone by Geological Survey of India (GSI, 2018-2019).

Table 2. Details of joints at Tutikandi area, Shimla District, Himachal Pradesh.

Joint Sets	Dip Amount and Direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J1	12°→N170°	40-50	2.0-5.0	1.0	Clay & loose soil	Damp
J2	40°→N40°	30-40	1.0	2.0	Clay	Dry
J3	45°→N200°	40-50	1.0	2.0-3.0	Nil	Dry
J4	75°→N90°	30-40	5.0	3.0	Clay	Dry

The area is in close proximity to the MCT, Shimla thrust and Jutogh Thrust and hence the rocks are highly jointed and fractured. The Weathering index of the Slope forming Material at the toe of the slide ranges from W4- W5 (ISRM, 1981a). No out crop was observed on the slide area, however, outcrop was observed on the upslope of the slide area. Four set of joints were observed. The details of the joints as observed at the site is tabulated in Table 2.

Salient Features

The salient features of the landslide have been enumerated below-

1. Landslide is a result of rotational failure.
2. The slide can be described as transgressive, advancing and widening due to the creation of a new nalah. The nalah is trending N71°.
3. The geomorphic causes worked out be over saturation of the fragile and loose material of slope forming material during heavy precipitation enhancing rate of denudation process.

Future Menace

The terrain generally exhibits moderate to steep valley slope. The creation of the new nalah along the steep slope will further widen during the successive monsoon season. The houses located on the stream are highly vulnerable and vigilance must be ensured.

Recommendations

The following remedial measures have been suggested to contain the road to cave in further:

- i. The newly created nalah must be channelized away from the slide zone. The water may be diverted to the already existing lined drainage along the right bank
- ii. Construction of proper lined drainage along hill side to arrest maximum infiltration of water surface water into distressed zone. It is also suggested that the trained drainage should be connected with the main Khad to avoid surface water discharge on the distressed slope
- iii. The broken drain/sewerage line along with the agricultural pipe must be shifted to a suitable site.
- iv. Reconstruction of breast and retaining structures along the road with adequate filter and drainage, in particular, when constructed in debris filled mass.

- v. Vigilance must be maintained during monsoons regarding the safety of the dwellers of the habitants of the houses constructed along the 1st order streams
- vi. No further construction may be allowed within the first order stream.

6.2 Rajvir Motor Slide, Shimla District, Himachal Pradesh.

A major slide took place on 23th of August 2023, following the incessant rains where debris material charged with large boulders brought down by a flood like situation washing away a major portion of the CPWD road, retaining structures and vehicles on the downslope as shown in Figure 8 (b) and (d). The retaining structures suffered a major displacement by >1.5 m along the CPWD road on the upslope (Fig 8(e)). The heavily charged debris flow from the upslope area was triggered by head ward landslide due to incessant heavy rainfall during previous nights of 22th and 23th August, 2023. It was also informed by the officials of DDMA that the drainage was completely blocked during the construction of the retaining structures and caused the slope to ultimately fail. The incidence at the site can precisely be describe as a debris flow hit. The runout distance extends around 200 metres with a maximum spread of approximately 100 metres. The general slope of the debris flow in the down slope varies from 30° to 40°. The morphometry of the slide is given in figure 8(a)

The adjoining landmasses on right flank have also been disturbed due the incidence. It has been observed that the adjoining hill masses also suffered moderate landslides of smaller magnitude. It was observed that the area was still damp with several prominent seepage zones as shown in figure 8 (c) and the ground water was very shallow at the site.

The observations revealed the landslide to be a debris slide presently triggered due to slope saturation. Landslide is a result of rotational mass failure occurred due to slope failure of unconsolidated slope material and saturation due to rainwater ingress and excessive erosion by the nalas. A retrogressive rotational failure is confirmed by presence of tension cracks, subsidence and titling of trees (Fig8 (f) and (g)) at the crown of the slide as confirmed by the locals.

The landslide is 200m in length, 90m in width and nearly 50m in height. The landslide is active and single.

The slide is retrogressive and enlarging in nature and confirmed by the development of tension cracks on the upslope.



Figure 8 (a) Morphometry of Rajvir Motor slide in Shimla Urban

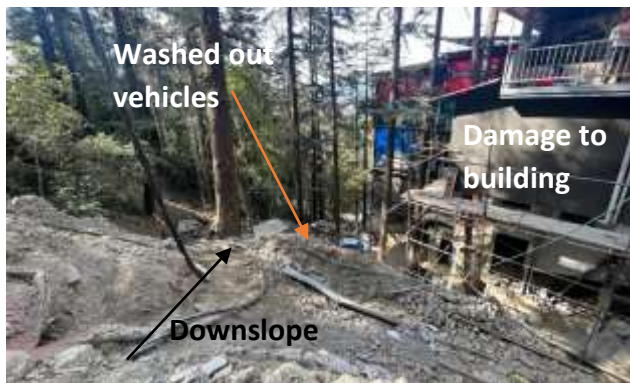


Figure 8 (b) Downslope of slide showing washed away vehicles



Figure 8 (c) Seepage zones created at sites where culverts have been blocked



Figure 8 (d) Damaged CPWD road and retaining structures



Figure 8 (e) Displacement of the retaining wall by 2 m along CPWD road



Figure 8 (f) Subsidence at crown by 1.5 m



Figure 8 (g) Titling of trees and ground cracks observed at crown

The Future Menace

It has been observed that increased anthropogenic activities, such as ill planned construction of civil structures, and other infrastructure projects, have contributed to hill slope cutting and modification in recent years. This raises concerns about potential slope instability incidents or failures in the future, particularly if these activities are taken up without thorough geoscientific studies.

Remedial Measures

- i. Proper channelization for water to avoid its further ingress at the earliest away from the sliding zone.
- ii. The benching in uphill debris mass as well as in rock mass, may be carried out very carefully, scientifically along with their simultaneous effective stabilization.
- iii. The up-slope hill mass and village establishments must be put to frequent observations with regards to any ground signature of instability such as developments of tension crack, joint openings/ widening, land sinking, development of crack in building, collapse of soil along slope or nala, tilting of trees, sudden appearance or disappearance of surface stream or reduction in water volume etc.
- iv. Immediate filling of transverse and contour parallel tension cracks with appropriate impervious material.
- v. Altering the geometry of the steep slope by flattening and benching along with draining out any ingressing nala or rain water.
- vi. Use of wire mesh draping, biotechnical slope stabilization measures (plantation of suitable trees with deep rooted species, application of geo-jute/geo-mats etc) in the slope debris mass of the uphill and downhill (road/ dump filling).

- vii. The suitable retaining structures must be provided with adequate filter and drainage, in particular, when constructed in debris filled mass.

6.3 Comely Bank Road, land subsidence, Shimla District, Himachal Pradesh

The Comely Bank area is situated in Shimla City and falls in Survey of India T.S. 53E/04. It is located at the coordinates of 31°06'27"N latitude and 77°09'47"E longitude. The north portal of Victory Tunnel, Shimla and Lakkar Bazar Road is situated in the upslope side at an aerial distance of approx. 250m. Consequent upon the heavy precipitation on 14th August 2023, major ground subsidence was reported from this locality. Though no loss to the live had taken place, the Comely Bank Road has suffered slope failures at multiple locations. One school building suffered major damage while one under construction building suffered partial damage (Fig.9(b)). As per the Macroscale National Landslide Susceptibility Mapping (NLSM) studies carried out by GSI during the FS: 2017-18, the presently affected area lies in high landslide susceptible zone.

Geologically the surrounding area exposes schist, quartzite and dolomite of Manal Formation belonging to Jutog Group of Undifferentiated Proterozoic age. Though, no insitu rock was observed around the landslide affect area, a thick overburden cover comprising of moderately compacted soil and palaeo-debris material having an approx. thickness of 3-5m has dominantly been observed around the affected area.

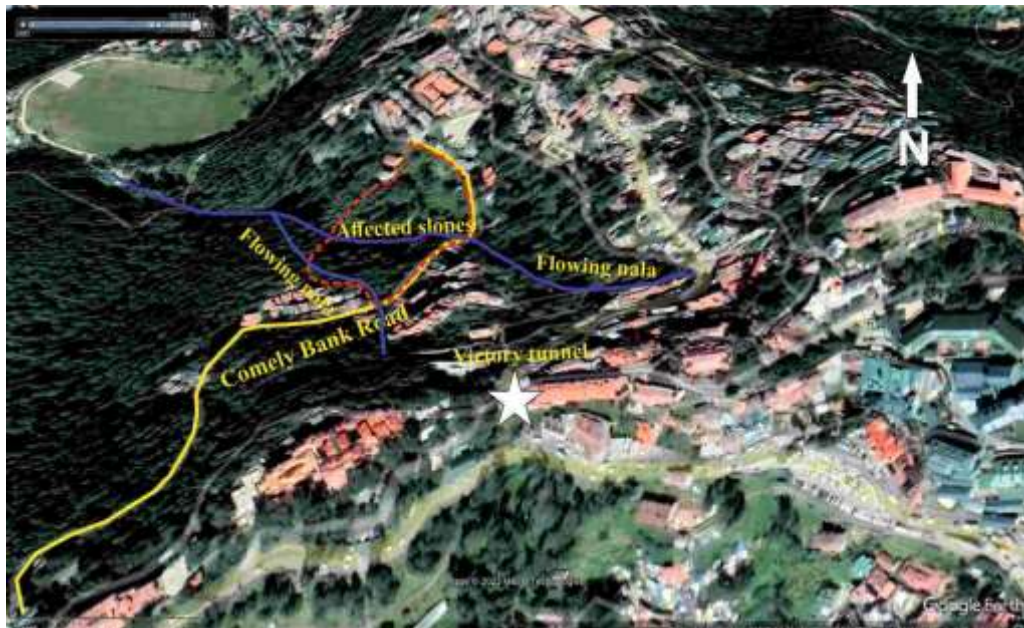


Fig. 9 (a) Google Earth imagery showing the location of affected slopes along the Comely Bank Road.

The salient features of the affected slopes around Comely Bank Road

Field traverse was taken along the Comely Bank Road and various ground features related to slope failure were recorded (Fig. 9 (a)). As per the local authority and residents, small scale creep/ground subsidence has been observed during the previous year monsoons also but the extreme rainfall during 14th-15th August 2023 had led to large scale subsidence and ground cracks had appeared subsequently.

During the course of present investigation, it was observed that the Comely Bank Road and the downslope area have suffered ground instability. The road had subsided by 1m-1.5m which was later on refilled and levelled by the public works department (Fig. 9c). As per the discussions with residents, except for two to three houses along the road, no house in the upslope area have been reported for any damage. 2.5 cm wide Longitudinal cracks with a continuity of 10-15m can be observed along the road stretch (Fig. 9d). A parking area had suffered ground subsidence and the retaining wall has been damaged partially and tilted (Fig. 9e). Three actively flowing nala have been observed along the affected road and according to the residents a huge flow of water is seen during every monsoon. (Fig. 9f&g). The residential buildings including Police Department quarters have suffered damages and cracks have been observed in these buildings both at foundation level as well as along the walls (Fig. 9 h & i). Ground signatures of road subsidence can be very well observed along the road in form of cracks in both retaining walls and road (Fig. 9 j & k)



a) Damaged school building along the Comely Bank Road. b) Stretch of damaged Comely Bank Road.



c) Longitudinal cracks on Comely Bank Road.



d) Ground subsidence and failed wall at parking area.



e) Flowing nala along the left flank of affected area.



f) Flowing nala along the right flank of affected area.



g) Damaged buildings along the Comely Bank Road.



h) Cracks at the foundation level in residential building along the road.



i) Subsidence observed along the Comely Bank Road.

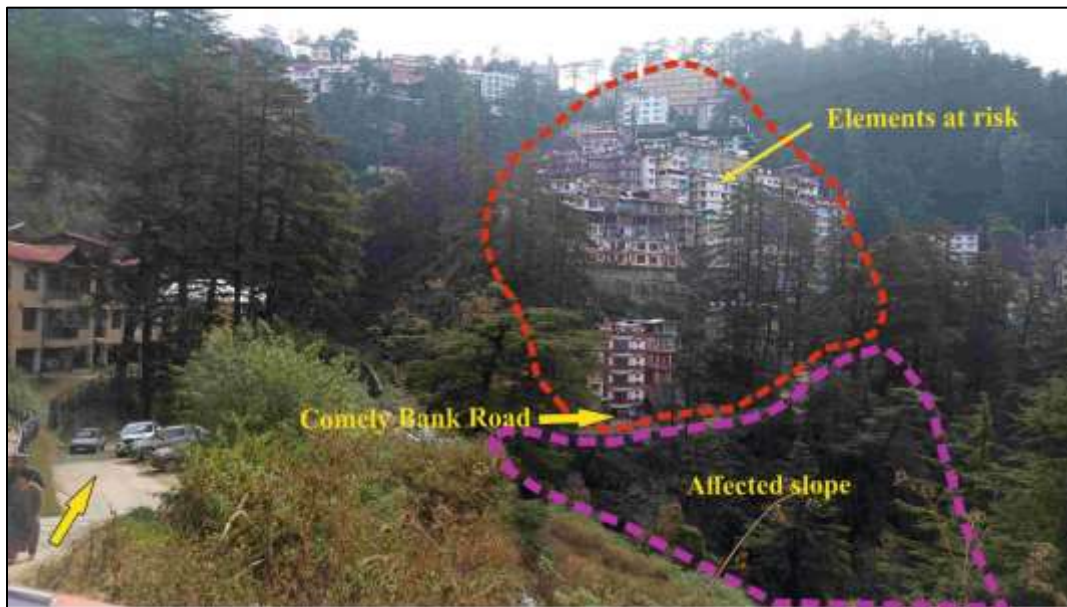


j) Cracks observed in the retaining wall along the road.

Fig. 9 Field photographs from the affected area.

Future Menace

Prima facie, the distressed slopes have been observed along the road stretch extending for an approx. length of 400m-500m, which starts at Police Line Road bend and ends at damaged parking area. The hydrological conditions around the area and thick overburden cover are favourable enough for triggering slope failure incidences in such a scenario. The actively flowing three drainages flowing across the Comely Bank Road and the slopes along these drainages need to be carefully dealt with. During the interaction with local residents, it was informed to the authors of this note that the muck generated during the construction of Victory Tunnel in the upslope area was dumped along the slopes of Comely Bank Road, and during the later periods huge construction activity had taken place in this area, though no official record regarding this is known. A dense settlement including multi-storeyed buildings



Geoscientific Causes

1. Prima facie it appears that the extensive rainfall had led to the super saturation of thick overburden material exposed in the area and further development of the pore water pressure. A deep rotational failure has been apprehended which ultimately caused the ground to subside.
2. The area lies in the close vicinity of a tectonically active zone where the rocks of Jutog Group are having a thrust contact with the rocks of Baliana Group. Though no insitu rock exposures have been observed around the landslide affected area, the impact of this thrust zone located in the vicinity of landslide can't be ruled out.

Recommendations

1. The ground cracks need to be covered up effectively in order to avoid any further rain water percolation. The cracks must be sealed either by filling them with puddle clay or other impervious fill or some trenches can be excavated along the tension cracks and backfilled with the impervious material. Small quantities of bentonite or other natural material to reduce further permeability can be used so that surface water does not pond in the area. Impervious membrane may be used as an emergency or temporary measure.
2. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. can be installed below the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions.
3. Sufficient drainage arrangements must be provided along the affected slopes, especially along the Comely Bank Road. Catch water drains or chute drains may be provided above the crown of the landslide to divert runoff water.
4. The drain water (domestic discharge) from individual houses must be channelized effectively to avoid any ground water saturation.
5. Regular inspection and maintenance are required in case of continued movement, since it may cause previously sealed cracks to reopen. Therefore, in order to monitor small levels of ground creep, installation of a geodetic system may be considered at first in consultation with geotechnical engineers.
6. The surrounding area susceptible to further slope failure along with the buffer zone may be identified and no new construction activity or slope modification work should be carried out in this zone.
7. Provision of suitable retaining structure at the toe portion of the slope, i.e along the main drainage should be made in consultation with design engineers.
8. A detailed site-specific study should be carried out to formulate long term mitigation measures.

6.4 Indian Institute of Advanced Study, District Shimla, Himachal Pradesh

A landslide incident has impacted the Indian Institute of Advanced Study, Rashtrapati Niwas, Toposheet No. 53E/04 in Shimla City. The affected area is located at 31°06'12"N and 77°08'28"E. The Himachal Pradesh University Campus lies approx. 1km N of this location. Earlier, a debris slide was reported, just below the western flank of Indian

Institute of Advanced Study, on 14th August 2023 at around 7.30AM which led to the loss of around 20 human lives who had gathered for morning prayers in a Shiv Temple. Two link roads connecting Shimla City to Summer Hill area, one UNESCO World Heritage Shimla-Kalka Railway line (narrow-gauge) also suffered huge damages.

Subsequently after the incident, GSI had carried out preliminary study of this site in the month of August 2023, during which no damage to the IAS building was reported by local administration. But later on after a span of time, few ground cracks and subsidence were observed by the IAS authorities, which was communicated to the Shimla Administration and then this site was recommended by SDMA, HP for a preliminary study by GSI.

This monumental building is located at the hill top and the above-mentioned Shiv Mandir Landslide spot is located along the western flank of valley slope. During the study of Shiv Mandir Landslide, it was established that the initial slope failure had taken place just below the western flank of IAS building which had ultimately triggered a debris slide. As per the Macroscale National Landslide Susceptibility Mapping (NLSM) studies carried out by GSI during the FS: 2017-18, the presently affected area lies in high landslide susceptible zone.

Geologically the landslide affected slope exposes phyllite, schist and quartzite of Bhotli Formation belonging to Jutog Group of Undifferentiated Proterozoic age. Overall, the area is covered by a thick overburden comprising of moderately compacted to loose soil and palaeo-debris material having an approx. thickness of 3-5m. The Weathering index of the exposed rock mass at the road level ranges from W4- W5 (ISRM, 1981a). The exposed rock mass exhibited three main set of joints and one random set of joints. The details of the joints as observed at the site is tabulated in Table 3.

Table 3. Details of joints characteristics around the landslide affected area of IAS, Shimla, Himachal Pradesh.

Joint Sets	Dip Amount and Direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J1	10°→N295°	60-70	0.1	<1	Nil	Damp
J2	85°→N80	50-60	0.3	<1	Clay & loose soil	Damp
J3	80°→N170°	40-50	0.2	<1	Clay	Damp

The salient features of the affected slopes around the IIAS campus-

During the course of present investigation, it was observed that the southern and western flank of the valley slopes have suffered major damages and the ground signatures in form of ground cracks, subsidence and land sliding could be observed at multiple locations around the campus (Fig. 10 a). The SSE facing slope in a stretch of approx. 100m has suffered major damage where the ground cracks and subsidence have developed out of which the main entrance area of the premises was found to be highly affected. In order to restrict the infiltration of rainwater through ground cracks, the IIAS authorities had covered this area by tarpaulin sheets in the month of August just after the Shiv Mandir Landslide incidence. The sheets were removed for inspection during the present visit, during which it was conveyed by the IIAS staff that the cracks had widened up around three times since the initiation. Even the sealed cracks were found to be open (approx. 1-3cm). Moreover, the continuity of cracks had encroached the much larger area as compared to the initial phase of slope instability.



Fig. 10a Google Earth Imagery representing the affected slopes around the IIAS Campus.



b. Easterly facing affected zone.

c. Westerly facing affected zone.

Fig. 10 Gound cracks observed at the main entrance of IIAS.

The width of cracks ranges from a minimum of 5mm upto a maximum of 25cm and can be traced upto a length of 10-15m. These ground fissures have a general trend of N50°-70° and are mostly longitudinal in nature (Fig. 10b and c). An approximate ground subsidence of 1-1.5ft could be observed towards the boundary wall side, just at the entry point. The inner boundary wall itself has suffered damage and is tilted. The retaining wall has bulged and partially damaged at one location and its highly possible that it may fail in case of heavy rainfall (Fig. 10 c, d, e and f).



c. Displaced retaining wall along the failed slope.



d. Partially covered wall along the failed slope.



e. Bulged retaining walls along the pedestrian pathway



f. Cracks along the pedestrian pathway

Fig. 10 Photographs showing damage to the retaining walls.



Fig. 10 (g) Slope failure at the western flank of IIAS below which the Shiv Madir Slide had occurred in the month of August 2023.

The failed slope along the western flank of IIAS was hit by a debris slide during the month of August 2023 due to which the retaining wall has been damaged extensively and foundation land mass has been washed out. No insitu rock mass was observed during the field work and the slided portion is mostly covered by loosely compacted soil and debris material (Fig. 10 (g)). Though, a sound rock mass is exposed at the road level, just below this slide. The landslide is retrogressive and widening in nature due to presence of unconsolidated debris material and has resulted due its shallow rotational failure. The landslide is active and the area exhibits a steep slope.

Future Menace

Prima facie, the distressed slopes around IIAS are limited to the valley side mainly, but any delay in implementing mitigation measures especially before the onset of next monsoons could worsen the situation. The southern and western slopes around the IIAS have suffered major slope failure incidences out of which the southward facing slope (main entrance area) is found to be more critical, as the thickness of overburden is comparatively more and the bed rock is exposed at a much lower level. Moreover, the ground signatures such as ground cracks, bulged walls and subsidence are found to be active in this particular zone. The western portion of slope facing towards Shiv Mandir Landslide zone is comparatively stable and has support of good rock maas below it. Therefore, the southward facing slope at the main entrance area looks more vulnerable and needs to be dealt carefully for preventing further deterioration of slope stability conditions.

Geoscientific Causes

- 1) Super saturation of loosely compacted ground mass present along the valley facing slopes during heavy precipitation.
- 2) The steep slope towards the Shiv Mandir side having an inclination of approx. 50°-60° further facilitated the rapid movement of debris material and erosion of surrounding hill slope.

Recommendations

- 1) At the western flank, a sound rock mass needs to be intercepted/Identified for the foundation of retaining structures.
- 2) Sufficient drainage arrangements should be made to channelize the water away

from the slide area. Catch water drains or chute drains may be provided above the crown of the landslide to divert runoff water.

- 3) Provision of suitable retaining structure at the toe portion of the slope (road level) may be made in consultation with design engineers.
- 4) Geojute/Geotextile may be used to protect the overburden face from further weathering and erosion on the slope affected by the incidence.
- 5) At the southern flank towards the main entrance area, the surrounding area susceptible to further slope failure along with the buffer zone may be identified for monitoring developments of new ground cracks or subsidence of land. The cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area.
- 6) In order to monitor small levels of ground creep, installation of a geodetic system may be considered at first in consultation with site geologist and design engineers.
- 7) The further development of ground cracks need to be monitored frequently.
- 8) Tilt meters can be installed to monitor the retaining walls which are prone to any further tilting or failure.
- 9) **It is recommended to carry out detailed geotechnical studies around the premises of IAS for deciphering the sub surface geology and the depth of bedrock. Suitable geophysical studies can be carried out in accordance with the site conditions; however, it should determine the depth of bedrock and thickness of overburden material.**

6.5 Vidhan Sabha to Annadele Helipad Road subsidence

The study and assessment of affected sites on road section along Vidhan Sabha to Anadele were carried regarding sinking of the road section after a significant rift developed along road. The area is very strategically located.

Physiographically, the area falls within the Lesser Himalaya. Geologically the landslide affected slope exposes phyllite, schist and quartzite of Bhotli Formation belonging to Jutog Group of Undifferentiated Proterozoic age (Fig. 11 (f)). Overall, the area is covered by a thick overburden comprising of moderately compacted to loose soil and palaeo-debris

material having an approx. thickness of 5-7m. The Weathering index of the exposed rock mass at the road level ranges from W3- W5 (ISRM, 1981a). The exposed rock mass exhibited three main set of joints. The details of the joints as observed at the site is tabulated in Table 4

Table 4. Details of joints characteristics around the landslide affected area on Vidhan Sabha to Anadele Road, Himachal Pradesh.

Joint Sets	Dip Amount and Direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J1	20°→N310°	50-60	1.0	1.0 m	Nil	Damp
J2	85°→N80°	40-50	0.5	<1	Clay	Damp
J3	70°→N155°	40-50	0.7	<1	Clay & loose soil	Damp

The study revealed that steep slopes, high relief, and thick slope wash material/overburden complex structural fabrics and proximity to MCT, Shimla and Jutogh thrust has rendered the slopes highly vulnerable to mass movements. The surrounding bedrocks, as a consequence, are highly fractured and deeply weathered attesting the easy supply of boulder material for various kinds of valley fills.

The study and assessment of affected sites around revealed varied unfavourable geological (highly weathered rocks due to its proximity to three thrust zones) features. The most significant causative factor for the triggering and development of landslide is the continuous heavy rainfall leading to saturation of thick slope wash debris material/highly weathered rock and poor drainage system.

The crown could be located on the day of field studies but several signatures of land sinking in form off ground cracks, minor slides, slump zones and creeping in trees were observed (Fig. 11 b, c, d and e). Some damage to the foundation of houses and retaining structures were also observed (Fig. 11 (a)).



Figure 11(a) Damage to the foundation of the house and retaining wall



Figure 11(b) Minor slides and creeping in trees



Figure 11(c) Subsidence observed along road section



Figure 11(d) Subsidence and tilting of trees observed along road section



Figure 11(e) Minor slides observed along road section



Figure 11(f) Phyllite showing three set of joints

The Future Menace:

The observations along the road reveal the presence of highly weathered *in-situ* rock mass and a significant amount of precariously disposed boulders in the debris.

Considering the close proximity to major thrusts, any seismic activity or intense rainfall could potentially trigger a landslide. In this effect and in view of rainy season in the coming years, it is highly recommended to design an effective drainage system to aid in mitigating the risk associated with slope instability and prioritize the safety of the residents. This safety-oriented approach should also be extended to other villages/habitats, especially to those in proximity to thrust zones, to ensure comprehensive hazard mitigation and community well-being.

Remedial Measures:

- i. Provision of sturdy retaining structures with staggered drains and weep holes at the hillside road level to prevent soil erosion.
- ii. Sealing of ground cracks with impervious material to minimize water infiltration and further damage.
- iii. Retrofit and reinforce existing structures in the village, including roads and buildings to improve their resistance to seismic events or ground movements thereby enhancing their structural integrity.
- iv. Installation of monitoring devices to constantly track ground movements, slope stability and soil moisture levels for timely intervention and hazard mitigation.
- v. Improve drainage system to efficiently manage surface water runoff, mitigating the risk of slope destabilization. Design proper drainage channels to divert water away from vulnerable regions.

7. Solan-Rampur National Highway-05 Road Corridor

7.1 Mohan Meakin Slide, Summer Hall, Chambaghat, Solan District, Himachal Pradesh

The landslide zone is located at 30°55'24.00"N and 77° 6'40.00"E and falls in Toposheet no. 53F/01 on the Solan Shimla Highway, 3.5 Km North of Solan. The slide zone lies at an elevation of 1474 m MSL. A 150-m stretch of the NH-05 village, caved in as shown in figure 12(b) causing a major slide and disrupting vehicular traffic following incessant rains. Slush generated from seepage of water caused erosion of the road on the Solan-Shimla section of National Highway No. 05 and triggered the caving in of the road and damage to the road on the downslope leading to the PHC (Fig. 12 (c)). Several seepages point were also identified in this zone led to piping out of finer sand, silt and clay material of the slope and contributed to the subsidence and caving in. The morphometry of the slide

is given in Fig. 12 (a). A culvert had also been constructed to regulate the flow of water, however it did not prove effective to manage the slush. The retaining walls had also failed and the low breast walls of 1.5 m to 3 m failed to contain the landslides.

The field observations revealed the landslide to be a debris slide, which is a rotational failure triggered due to slope saturation and slush generated from seepage of water caused the land to cave in on 11.07.2023. The landslide is 60m in length, 150m in width and nearly 55m in height and retrogressive in nature. The landslide is active and single. Area exhibits generally moderate to steep slope of around 70°.

The site lies at the contact zone rocks of Balani Formation and Infra Krol Formation of Baliana Group (Fig. 12 (g)). The site are composed of rocks are splintery and very fragile shale overlain by quartz arenite and dolomites in patches (Fig. 12 (f)). The highly weathered folded shale form a very poor foundation for the road (Fig. 11(d), (f) and (g)). The area is in close proximity to the Krol thrust and Chail thrust in the north east and Jutogh thrust and MCT in the south west.

The evidences of creep movement such as tilted trees, bulging in retention structures/walls etc (Fig. 12 (e)). were observed during downhill trekking. It was found that the buildings were constructed over the weak foundation.



Figure 12 (a) Morphometry of Mohan Mekin Landslide, Solan Dist. Himachal Pradesh.



Figure 12 (b) Road cave in at Mohan Mekin Landslide, Solan Dist. Himachal Pradesh.



Figure 12 (c) Damaged retaining structure and road to PHC, Summer hall, Solan

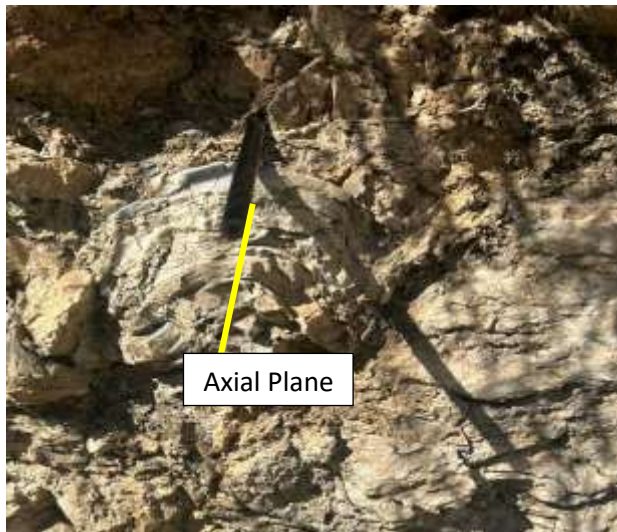


Figure 12 (d) Folded shale of Infra Krol Formation, Baliana Group.



Figure 12 (e) Creeping of trees and bulging of retaining structures



Figure 12 (f) Contact zone between Infra Krol Fm. And Blaini Fm.

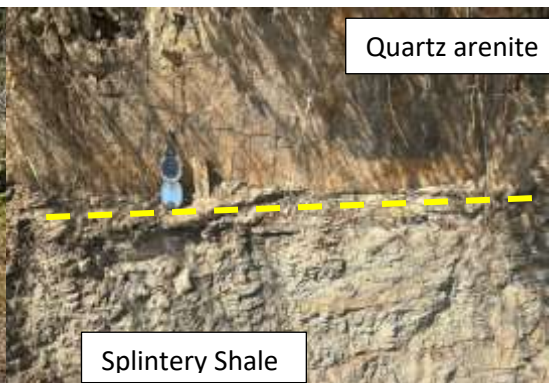


Figure 12 (g) Interbedded competent and incompetent layers of quartz arenite and shale.



Figure 12 (g) Damaged culverts and transmission lines at Mohan Mekin Landslide, Solan Dist. Himachal Pradesh.



Figure 12 (h) Downslope of Mohan Mekin Landslide, Showing large boulders within unconsolidated material of silt matrix

Three set of joints were observed in the area surrounding the slide area shown in Table 5. The details of joint are as follows:

Table 5. Details of joints characteristics around the landslide affected area at Mohan Mekin Slide, Solan Himachal Pradesh.

Joint Sets	Dip Amount and Direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
S0 J1	22° →N60°	60-70	0.4	4.0	Nil	Dry
J2	60° →N230°	50-60	1	1.0	Clay	Dry
J2	78° →N210°	50-60	2	2.5	Clay & loose soil	Dry

The area has already been identified as Moderate landslide susceptibility zone by Geological Survey of India (GSI, 2018-2019).

Future Menace:

The observations revealed the presence highly weathered strata in the bed rock foundation. Anthropogenic construction activities in unplanned/less-planned manner, cutting/modification of hill slopes have increased in past few years leading to possibilities of slope instability incidences/failures in times ahead, if the same are done without proper geoscientific studies.

Geo Scientific Causes:

1. Slope saturation and slush generated from seepage of water.
2. Construction of retaining wall without proper sound rock foundation.
3. Construction of road within highly weathered material without any sound foundation.

Remedial Measures:

1. The Nallah needs to be trained and channelized properly.
2. Identifying the sound rock for foundation of erecting adequate retaining wall.
3. Concrete retaining structure all along the debris cone material with adequate drainage holes.
4. Afforestation should be done to stabilize the debris cone.

7.2 Mansar subsidence, Solan District, Himachal Pradesh

Mansar subsidence is not a purely landslide rather a subsidence located at (30°56'33.00"N and 77° 7'45.00"E) and is a prominent and sinking/subsidence zone located along NH-05 as shown in Fig 13 (a). It falls in SoI Toposheet no. 53 F/1. It is located ~4.5 km south of Kandaghat, Himachal Pradesh. The slide lies at an elevation of 1452 m MSL.

At the failure affected site ~300 m length of the road bench has been perennially affected due to subsidence prior to monsoon 2023, which was restored by backfilling techniques but finally the road was closed for traffic since major subsidence and development of cracks during month of July, 2023 (as informed by DDMA, Shimla) causing severe difficulties for the vehicular traffic, local inhabitants and tourist. The subsidence zone lies on a slope having an angle of 45° -75° and Aspect is ENE

Several seepage spots were also observed below road level (Fig 13 (f)) and within the erected retaining wall towards valley side. The gabion walls constructed within the distressed zone have been tilted, partly damaged and needs to be repaired (Fig 13 (b) & (d)). Within the affected area loose boulder to pebble size with semi consolidated sand and silt and minor clay material formed the dominant slope forming material of the slide.

Overall the distressed area is damp and wet. Signs of severe gully and rill erosion were observed in the affected area on valley side, there was no channelized lined drainage in the distressed zone. Several seepages were identified at distressed zone. Major ground crack has been observed on the subsidence zone having dimensions varying from 1m to 8m long, up to 15 cm wide and 1.0 -3.0 m deep trending 122° (Fig 13 (c)).

Three sets of joints have been observed in the rock mass constituting of argillaceous shale interbedded with limestone of Mahi Formation of Krol Group (Fig 13 (e)). The prominent sets of joint observed in the rockmass are: J1 (Foliation Joint) dipping towards N210°, J2 dipping towards N80° and J3 dipping towards N20°. The foliation plane of shale is observed to be parallel to J1 which is a hill-ward dipping joints. On the other hand, J2 is oblique

dipping and J3 is valley dipping. J3 is a sub vertical steeply dipping joint which is sub parallel to the slope face (Valley dipping). It is undulating, rough and sometimes shows a moderately smooth surface. J2 is a steep to moderately dipping joint. Its surface is slightly rough in nature and dips oblique to the slope face with no filling within the aperture openings. J1 is a moderately dipping joint which dips against slope face (hill-ward dipping) has its dip amount varying from 15°-25°. J3 have potential for planar failure while J1 J2 and J3 intersect each other, thus giving rise to form wedges having potential for failure on the slope profile. All the joints observed have low persistence varying from 1m-3.5m.

The three set of joints observed in the area surrounding the slide area shown in Table 6. The details of joint are as follows:

Table 6. Details of joints characteristics around the landslide affected area at Mansar Road subsidence, Solan Himachal Pradesh.

Joint Sets	Dip Amount and Direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
S0 J1	15° →N210°	70-80	0.5	3.0	Nil	Dry
J2	70°→N80°	50-60	1	1.0	Clay	Dry
J3	65° →N25°	60-70	2	3.5	Clay & loose soil	Dry

Salient features of the subsidence zone

1. The general slope of subsidence valley side face is steep i.e. 35° to 80° towards N15°-N45° being relatively steeper in upper portion, slightly moderate slope in main body part and very gentle towards toe.
2. The Road NH-05 has been constructed across the semi to loose unconsolidated debris material. Slope forming material is dominated by loose boulder, cobble and pebble size embedded within semi to unconsolidated sand silt material.
3. Structural discontinuity in rock exposed show presence of at least 3 set of joints forming both minor planer and wedge failures.
4. Entire subsidence zone is dominantly covered with patches of grassy vegetation
5. Several active seepages at many points were observed from where the discharge water are actively flowing across and along the slope without any proper lined drainage.
6. Retaining walls/structures including concrete buttress and gabion walls have been constructed almost all along the toe of subsidence zone

7. The retaining walls/structures constructed within the slope has been either partially damaged at many levels and some were observed disturbed due to creeping effect
8. Major ground crack has been observed on the subsidence zone having dimensions varying from 1m to 8m long, upto 15 cm wide and 1.0 -3.0 m deep

Geo-genic Causes

1. Steep slope of the order of $\sim 45^\circ$ - $\sim 75^\circ$ below road level.
2. Construction of NH-05 within loose debris material and vertical pressure exerted to the slope from perennial heavy vehicular movement might be another factors leading to bulging and tilting of erected gabion walls below road level.
3. Extensive gully and rill erosion in a distressed slope indicate absence of proper channelized lined drainage above.
4. The Kuhl/artificial nala constructed parallel to the road (hill side) for draining of waters is clogged at certain portion of the subsidence zone which overflows along NH-05 and contribute towards sinking of the road.
5. Several seepages point are identified in this zone which could lead to piping out of finer sand, silt and clay material of the slope are also likely to contribute to subsidence.
6. Saturation of loosed debris slope material during incessant rainfall events can reduces the shear strength of above material.

Recommendations

1. The cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area.
2. Appropriately designed retention structures at suitably identified locations at lower level as support to failing mass with weep holes at different levels.
3. In crown portion, along the main sinking zone at road level, the constructed lined drainage is observed to be choked This need to be cleaned at regular intervals of time to collect maximum surface runoff water from upslope at the earliest to arrest any further infiltration of surface water into distressed zone.
4. On the upslope of the slide an orchard and nursery plantation practices is observed. Thus, proper channelized lined drainage must be assured to avoid excess infiltration

/percolation/saturation of surface water within debris material. Also the aligned drainage for discharge of surface water should be avoided into the distressed slope

5. Several seepages were present at different level on the distressed zone and it is observed that it could lead to piping out of finer slope material slowly leading to continue sinking/subsidence of the slope. Therefore, it is highly recommended to carry out Geophysical survey to determine the ground water condition in consultation with Hydrologist to what best it can be done to reduce the seepage effect on the distressed slope
6. The damp zones, which are the probable zones of seepage of water, should be properly treated and coated with an impervious layer of clay or cover with plastic sheet to avoid water ingress into the slide area.



Figure 13 (a) Subsiding National Highway at Mansar, Solan Dist. Himachal Pradesh showing wide open cracks



Figure 13 (b) damaged foundation of retaining wall at Mansar, Solan Dist. Himachal Pradesh showing wide open cracks



Figure 13 (c) wide open cracks trending 122° SE.



Figure 13 (d) damaged (bulging and cracks) retaining wall at Mansar, Solan Dist. Himachal Pradesh showing wide open cracks

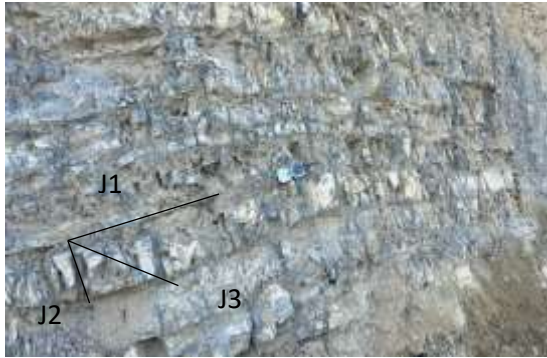


Figure 13 (e) Three sets of joints observed in the rock mass constituting of argillaceous shale interbedded with limestone of Mahi Formation of Krol Group.



Figure 13 (f) Damp zones and orchards on upslope of Mansar slide

7.3 Karibangla Slide, Kandaghat, Solan District, Himachal Pradesh

The Karibangla area falls in the Survey of India (SoI) Toposheet No. 53F/01 and is approx. 20 kms N of Solan City. The locality lies within the geo coordinates 30°59'28.35"N & 77°5'34.20"E on NH-05. According to the National Highway Authority of India officials, the slope failure incidence was initially triggered in the monsoon season of year 2020 by the back slope cutting of downslope area by a private land owner for building construction. Till then the slide has been active and is retrogressive in nature, affecting the stability of road stretch of approx. 100m (Fig. 14 (i)).



Fig. 14(i) Google Earth Imagery depicting the location of Karibangla Slide Zone

A major rock slump had triggered during the present monsoon season, especially during the month of August 2023, after which the shattered rock mass frequently gets deposited along the road causing inconvenience to the commuters and transport vehicles. As per the Macroscale National Landslide Susceptibility Mapping (NLSM) studies carried out by GSI during the FS: 2017-18, the presently affected area lies in high landslide susceptible zone.

Geologically the study area exposes shale and siltstone of Chhaosa Formation belonging to Shimla Group of Neo-Proterozoic age. The bedding plane of the exposed rock mass trend $270/35 \rightarrow N$ whereas three sets of dominant joint planes are exposed i.e

$S_0 \parallel J_1 \ 35^\circ \rightarrow N$

$J_2 \ 65^\circ \rightarrow 210^\circ$

$J_3 \ 60^\circ \rightarrow 160^\circ$

The slumped rock mass is highly disintegrated and splintery in nature while some massive competent siltstone beds can be observed along the road cut section (Fig. 2c). **The NW-SE trending Krol Thrust zone is the important tectonic feature passing approx. 1.5 km S of the affected area.**

The salient features of the affected slopes around Karibangla area

The road stretch along the NH-05 near Karibangla area has been affected by rock slump since 2020, but the slope stability of surrounding area got deteriorated during 2023 monsoon. The rock mass conditions along the slided slope are very poor as the splintery shales are dominantly exposed with alternate bands of siltstone (Fig. 14 a). Though a thin overburden cover of approx 30-50cm has been observed in the area, the fragile rock mass looks prone to failures in view of its poor engineering properties. Fresh ground subsidence has been reported at the upslope portion of the existing crown which can further reactivate in next spell of rainfall (Fig. 14 b).

Overall, the cut slope exposes rock mass of poor class with a weathering index ranging from W4- W5 (ISRM, 1981a). The details of the joints as observed at the site is tabulated in Table 7.

Table 7. Details of joints characteristics around the landslide affected Karibangla area.

Joint Sets	Dip Amount and Direction	Spacing (cm)	Aperture (cm)	Persistence (cm)	Filling	Hydrological Condition
S0 J1	35°→N0°	30-40	0.2	<5	Clay	Damp
J2	65°→N210°	20-30	0.3	<5	Clay & loose soil	Damp
J2	60°→N160°	20-30	0.3	<5	Clay & loose soil	Damp

A J2-J3 plane wedge failure has been interpreted after the kinematic analysis of the geometry of joint panes (Fig. 14 (iii)).

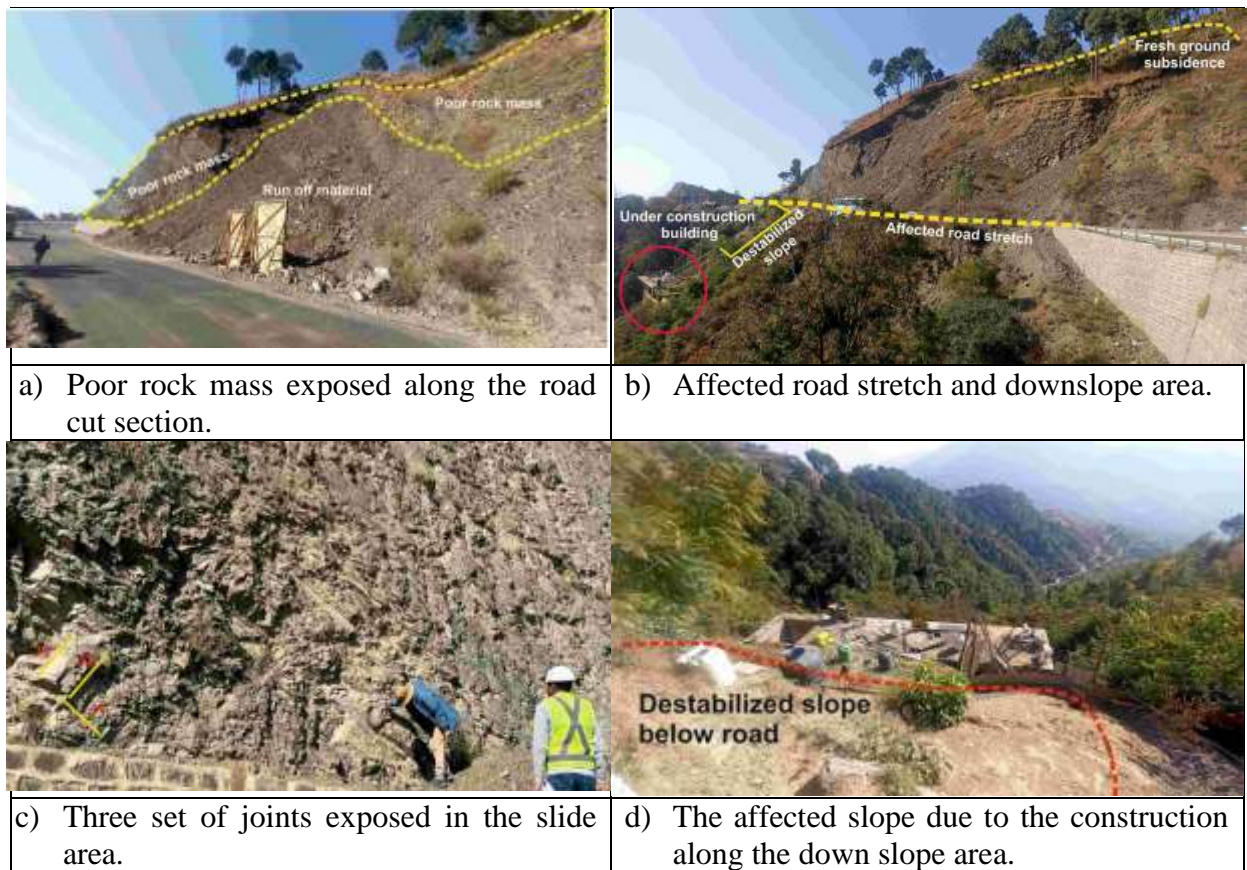


Fig. 14 Field photographs of Karibangla slide.

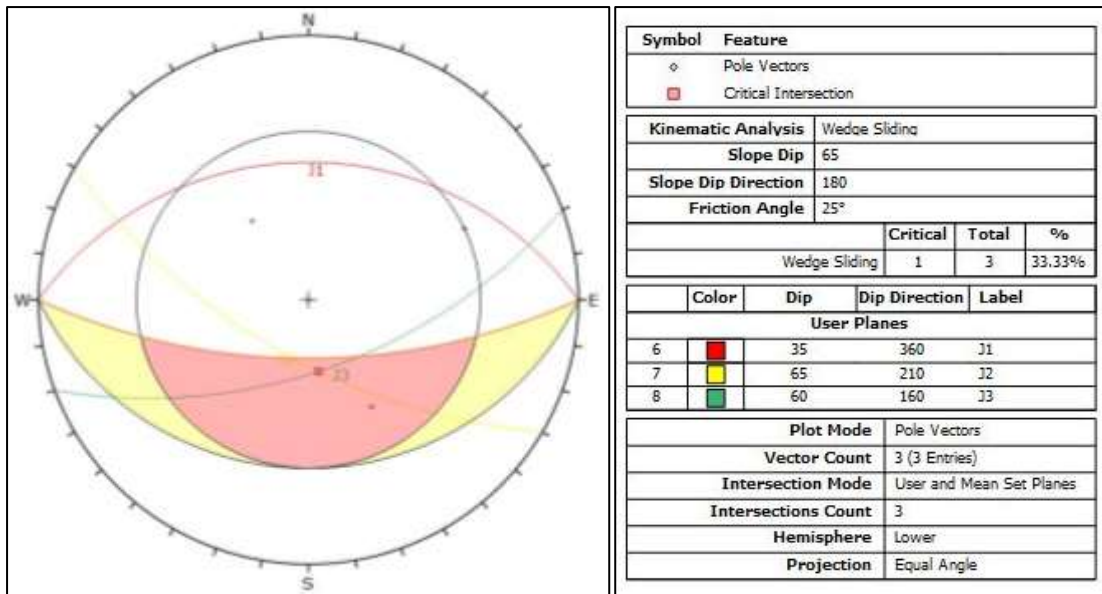


Fig. 14 (ii) J2 & J3 wedge failure interpreted by kinematic analysis.

Future Menace

The ground subsidence at the crown portion couldn't be examined due to accessibility issues in view of steep slope, but the distressed zone could be visualized from the road level. The poor rock mass conditions along the NH-05 under the influence of heavy precipitation can lead to retrogression of present slide in the upslope direction which could severely affect the stability conditions along the road.

Geoscientific Causes

1. Prima facie, it appears that the distressed slopes along the 150m road stretch of National Highway 05 exposing very poor rock mass have slid due to the super saturation by extreme rainfall.
2. The RMR analysis was carried out around the slide area, which suggests that the majority of rock mass fall under the poor category of good. (Class IV).
3. The anthropogenic activity in form of back cutting for construction has initiated the slope instability.
4. The landslide affected area lies in the close vicinity of NW-SE trending Krol Thrust zone which is an important tectonic feature passing approx. 1.5 kms. S of the affected area. The ground signatures of this thrust zone in the form of disturbed/ unstable terrain and a poor rock mass condition can be observed.

Recommendations

1. Provision of suitable light weight retaining structures at the road level along with proper drainage arrangements should be made in consultation with design engineers.
2. Suitable geotextiles/ geo-synthetic material such as geonet, geogrid, geo-composites etc. can be installed above the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions.
3. Catch water drains or chute drains must be provided above the crown of the landslide to divert runoff water.
4. Sufficient drainage arrangements must be provided along the affected slopes between the road and the under-construction house.
5. Above the crown portion, the cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area.

7.4 Nangal Devi Mandir Rock slide, Theog, Shimla District, Himachal Pradesh

Nangal Devi landslide ($31^{\circ} 7'11.00''\text{N}$ and $77^{\circ}20'5.00''\text{E}$) is located at a distance of 3 Km South of Thoeg on NH-05, Himachal Pradesh. It is a rock slide zone and is Retrogressive in nature and triangular/funnel shaped slide. It is a reactivation slide zone where the initial slide occurred during the monsoon of 2020. The general direction of the landslide is from $S80^{\circ}$ to 140°E , with an average slope angle of 60° . Figure 15(a) shows the morphometry of the slide.



Figure 15 (a) Morphometry of Nangal Devi Slide

The slide zone has dimensions of ~65 m (L) x ~100 m (W) x ~60 m (H). The crown of the slide is located at El±2287 m above msl (mean sea level) and is marked by prominent scarp and toe of the slide is located just above NH-05. The active slide zone is steep and the crown is overlain by ~3-5m thick overburden material. Cracks as informed by the authorities are present along the overburden material pose a serious threat to the settlement situated above the crown. Heavy rainfall has been reported in the affected area. This landslide poses a major threat to infrastructure above and below as it brings a major portion of the hill mass resulting in damage of ~200m road stretch along NH-05. The slide has been active since 2020.

Physiographically, the area falls within the Lesser Himalaya. Geologically the slide area area exposes quartzite and slate of Basantpur Formation belonging to Shimla Group of Neo-Proterozoic age. Highly fractured and jointed slates are exposed along this zone and it makes the vertical slip face at the top.

The overburden has preponderance of fines with some cobble grade coarse fraction. The rock exposed in this shows W2-W3 grades of weathering. There are clear signs of failure of the overburden and rock mass from this zone.

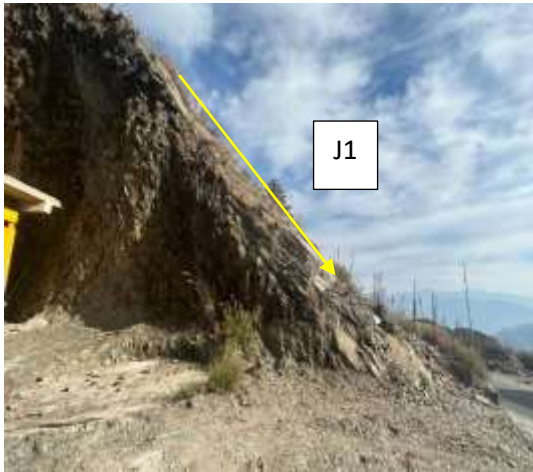


Figure 15 (b) J1 is the foliation joint having moderate to steep dip which dips towards slope face (valley dipping)



Figure 15 (c) Highly jointed slates of Basantpur Formation showing three set of prominent joints

Three sets of joints have been observed in the rock mass and their details are given in the Table 8 (Fig 15(c)).

Table 8. Details of joints characteristics around the landslide affected area at Nangal Devi Mandir, Theog, Shimla, Himachal Pradesh.

Joint Sets	Dip Amount and Direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J1 (Foliation parallel)	30° →N220°	80-90	0.5	20.0	Clay	Dry
J2	70°→N330°	60-70	5	10.0	Clay & loose soil	Dry
J3	85° →N75°	50-60	2	3.5	Clay & loose soil	Dry

Out of these, J1 is the foliation joint having moderate to steep dip which dips towards slope face (valley dipping). J1 is the prominent master joint controlling the slope profile (Fig 15 (b)). J1 dips moderately. It is wavy/ undulatory in nature and shows moderately smooth surface. J2 is an oblique joint and dip varies between 70°-85°. Its surface is slightly rough in nature and dips oblique to the slope face with no filling within the aperture openings. Opening upto 15 cm has been noticed along J2. J3 is a sub-vertical joint. J4 is a sub-vertical joint which dips oblique to the slope face.

J1 have potential for planar failure while J1, J2, J3 and J4 intersect each other, thus giving rise to form big wedges having potential for failure on the slope profile. All the joints observed have High persistence varying from ~10 to >20m.

Future Menace

The active slide zone is steep and the crown is overlain by ~3-5m thick overburden material. Cracks present along the overburden material pose a serious threat to the settlement situated above the crown. The open joints along the foliation plane of the slates pose a serious threat to the houses and road below

Remedial Measures:

1. The crown of landslide exhibits retrogressive in nature and further retrogressive upward may adversely affect the settlements. To contain further adverse effect, the exposed bare rock face can be shotcreted using steel reinforced shotcreting (SFRS) with provision of drainage holes
2. Several critical loose boulders present on the slope area between crown and toe can be removed manually followed by wire netting and rockfall/debris fall barriers
3. Rock mesh net with proper support can be suggested to stable the rock mass of the slide area.
4. Several vertical cracks/opening was present along the steep slope, this need to be sealed with impervious material at the earliest and arrest any further surface water percolation to those cracks by constructing lined drainage (contour parallel) above cut slope.

7.4 Himfed Petrol pump subsidence, Theog, Shimla District, Himachal Pradesh

The Himfed petrol pump subsidence is not a purely landslide rather a subsidence located at Latitude 31° 7'37.00"N and longitude 77°20'22.00"E and falls in Toposheet no 53E/8. The site lies at an elevation of 2284m MSL. At the failure affected site, ~800 m length of the road due to subsidence during monsoon since 2020. The subsidence along road is shown in figure 16(a). Within the affected area loose boulder to pebble size with semi consolidated sand and silt and minor clay material formed the dominant slope forming material of the slide.

Overall the distressed area is damp. In the affected area on valley side, there was no channelized lined drainage in the distressed zone. Several seepages were identified at

distressed zone. Major ground crack has been observed on the subsidence zone having dimensions varying from 5 to 10m long as shown in Fig 16(b). Physiographically, the area falls within the Lesser Himalaya. Geologically the slide area exposes quartzite and slate of Basantpur Formation belonging to Shimla Group of Neo-Proterozoic age. (Fig. 16(d)).

The study revealed that steep slopes, high relief, and thick slope wash material/overburden complex structural fabrics and proximity to MCT and Jutogh Thrust rendered the slopes highly vulnerable to mass movements. The surrounding bedrocks, as a consequence, are highly fractured and deeply weathered attesting the easy supply of boulder material for various kinds of valley fills. The village is situated in between two major hill spurs. The hill mass is moderately dissected and forested with scattered settlements.

The study and assessment of affected sites around, revealed varied unfavourable geological (highly weathered rocks due to its proximity to two thrust zones) and hydrogeological conditions. The most significant causative factor for the triggering and development of landslide is the continuous heavy rainfall leading to saturation of thick slope wash debris material/highly weathered rock and poor drainage system. No crown could be located on the day of field studies but several ground cracks along road corridor was observed. Along the downslope of slide area having some seepage zones were also observed.



Figure 16 (a) Road subsidence at Himfed Petrol Pump



Figure 16 (b) Ground cracks along Road at Himfed Petrol Pump



Figure 16 (c) Alternate bands of quartzite and slate of Basantpur Formation



Figure 16 (d) gentle downslope of slide area having seepage zones.

The Future Menace:

The observations along the NH-05 reveal the presence of highly weathered *in-situ* rock mass and a significant amount of precariously disposed schist boulders in the debris. Considering the sites close proximity to MCT and Jutogh thrusts, any seismic activity or intense rainfall could potentially trigger a landslide. In this effect and in view of rainy season in the coming years, it is highly recommended to design an effective drainage system. This will aid in mitigating the risk associated with slope instability and prioritize the safety of the village residents. This safety-oriented approach should also be extended to other villages/ habitats, especially to those in proximity to thrust zones, to ensure comprehensive hazard mitigation and community well-being.

Remedial Measures:

1. Removal of loose and precarious boulders along the road bench to enhance safety.
2. Provision of sturdy retaining structures with staggered drains and weep holes at the hillside road level to prevent soil erosion.
3. Sealing of ground cracks with impervious material to minimize water infiltration and further damage.

7.5 Rahighat-Kiartoo Slide, Theog, Shimla District, Himachal Pradesh

The Rahighat Kiartoo Road Zero Point area falls in the Survey of India (SoI) Toposheet No. 53E/08 and lies within the Theog Town. The locality lies within the geo coordinates $31^{\circ} 7'42.00''N$ & $77^{\circ}20'56.00''E$ and is situated adjacent to the old NH-05 stretch which presently connects Theog town to the new NH-05 bye pass road (Fig. 17(I)).

On the morning of 13th August 2023, a debris slide had triggered at this place after a continuous spell of extensive rainfall, as a result of which approx. 50m road stretch of Kiartoo link road was washed away. Though, no major damage to the old NH-05 road has been observed, the downslope area can be highly vulnerable to slope failure incidences in any case of extensive precipitation.



Fig. 17(I) Google Earth Imagery representing the location of Rahighat Kiartoo Road Zero Point slide.

As per the Macroscale National Landslide Susceptibility Mapping (NLSM) studies carried out by GSI during the FS: 2017-18, the presently affected area lies in high landslide susceptible zone. Geologically the slide area area exposes quartzite and slate of Basantpur Formation belonging to Shimla Group of Neo-Proterozoic age. No insitu rock is found to be exposed in the vicinity of landslide and the area is dominantly covered by thick overburden cover comprising of moderately compacted soil and palaeo-debris material. Though some probable rock exposures could be visualised at one location along the slided slope, but it couldn't be examined due to accessibility issue.

The salient features of the affected slopes around Rahighat Kiartoo Road Zero Point

The land sliding has washed out approx. 25-30m of retaining walls and subsequently the down slope area has also washed away. The 50m road stretch of Kiartoo link road has also been washed away, due to which the road connectivity to downslope areas has been affected (Fig. 17a). Flowing hydrological conditions have been observed along the slided area, where a major culvert has been damaged (Fig. 17b). As per the authorities, this culvert had been extensively flooded during rainfall which eventually led to the super saturation of overburden material exposed along the slope and thus casing the slope failure.

The debris slide has occurred along the steep (55° - 60°) north westerly dipping valley slope which dominantly comprise of overburden cover (Fig. 17c). The public amenities and retaining structures have suffered major damage and any further retrogression of this slide

may lead to the back cutting of main old NH-05. A partially choked, major lined drainage has been observed passing through the slide zone which was flooded during the rainfall and had facilitated the water saturation of ground mass (Fig. 17d).

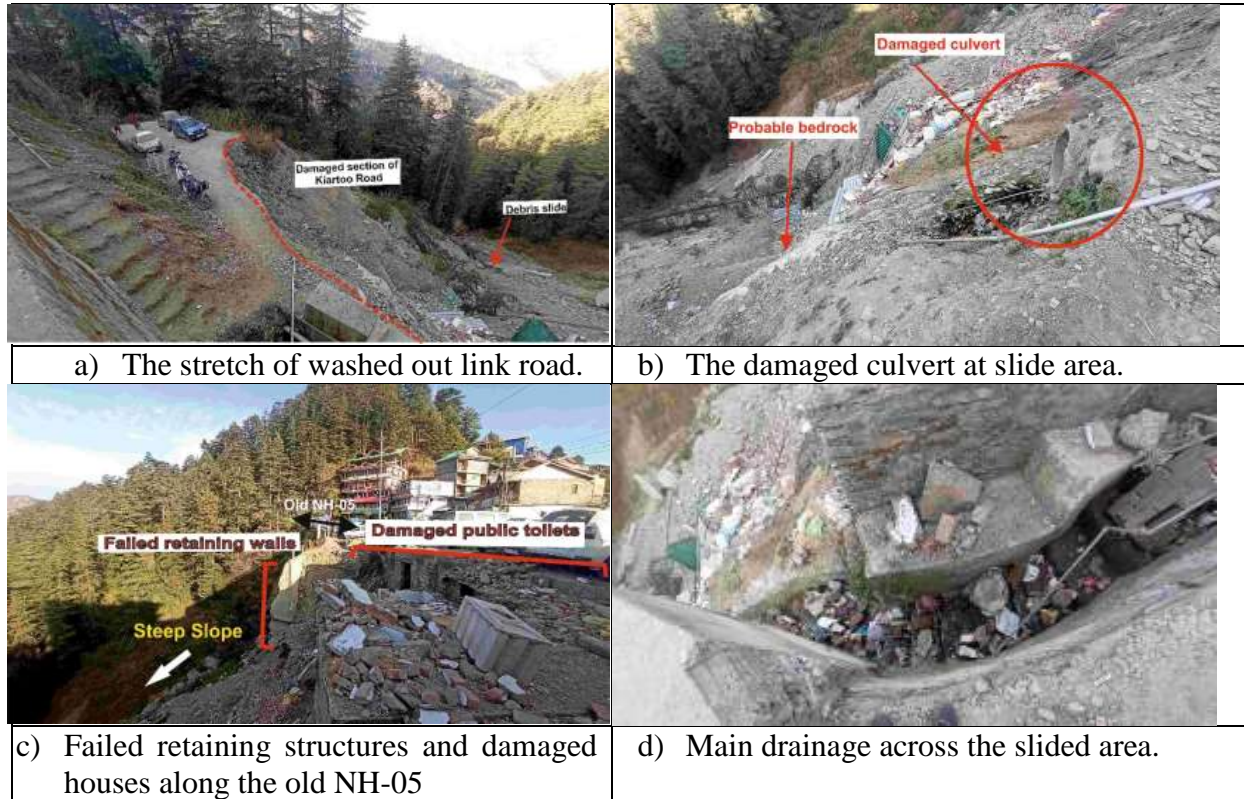


Fig. 17 Field photographs of Rahighat Kiartoo Road Zero Point Slide

Future Menace

The terrain generally exhibits valley slopes and in view of presence of thick debris cover, the slide is found to be both retrogressive and widening in nature. The main road at the ridge portion is at risk in view of any further heavy spell of rainfall.

Geoscientific Causes

1. Prima facie, it appears that the slide had triggered due to the supersaturation of thick overburden cover material exposed along the steep valley facing slope.
2. The high discharge along one of the major drainage situated at the site had facilitated the favourable hydrological conditions during the heavy rainfall.

Recommendations

1. The damaged portion of drainage needs to be channelized effectively to avoid any ground water saturation.
2. The concrete retaining walls should be constructed only after affirming the suitable bed rock at foundation level. In present scenario, deep foundations are strongly recommended as a thick overburden cover is dominant in the area.
3. The toe portion of slide needs to be effectively dealt with, as further deterioration of downslope areas can affect the stability of retaining structures to be reconstructed. For this check dams should be constructed in the downslope areas.
4. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. can be installed below the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions.
5. Sufficient drainage arrangements must be provided along the affected slopes, especially along old NH-05. Catch water drains or chute drains must be provided above the crown of the landslide to divert runoff water.
6. The drain water from nearby houses must be channelized effectively to avoid any ground water saturation.

7.6 Hyundai Showroom and Khaneri Hospital road cave in, Rampur, Shimla District, Himachal Pradesh

A major road cave in occurred near the Hyundai Showroom in Rampur District on the 11th of July which claimed the lives of 5 passengers plying on the road. The slide falls in Toposheet no. 53 E/08. The road cave effected nearly 80 m stretch of the Highway, with its toe terminating at the Sutlej River flowing around 100 m down slope.

The dimensions of the Hyundai Showroom slide are 80m width, 100m in length, and 90m in height. The observations revealed the landslide to be a debris slide, which is a rotational failure triggered due to slope saturation. The landslide is active, retrogressive, widening and single in nature. The area exhibits generally moderate to steep slope.

The debris slide is attributed to weakened slope debris due to water ingress and subsequent slope saturation by heavy rain. The slide zone is characterized by presence of loose boulder-pebble-sized materials embedded in unconsolidated debris, severe gully and rill erosion, abundance of seepage zones and the absence of channelized lined drainage within the distressed zone is a major triggering factor for initial subsidence and ultimately the caving in of the road section. The road section has developed numerous

wide cracks indicating that there is continuous sinking of the site as on date of study. The maximum subsidence has been measured to be >1m.

The area mostly comprises of highly weathered slates of Khamrada Formation of Kullu Group. The close proximity to the MCT has made the site geologically unstable.

Future Menace:

The observations along the downslope revealed the presence of lot of loose material and gully erosion. The presence of cracks varying in thickness from 1cm to 15 cm, length from 10 cm to 3m and 1cm to 20 cm deep, indicate the widening and retrogressive nature of the slide area. The presence of Sutlej river constantly leads to toe erosion and further worsening the slide. In view of the above mentioned, the area is highly susceptible to further caving in during heavy rains and needs regular monitoring.

Geo Scientific Causes:

1. Saturation of water within the fragile and loose material of slope forming material during heavy precipitation.
2. Construction of NH-05 within loose debris material and vertical pressure exerted to the slope from frequent heavy vehicular
3. Several seepages are identified in the distressed zone which could lead to piping out of finer sand, silt and clay material of the slope may be contributing subsidence.

Remedial Measures:

1. Identifying the sound rock for foundation of erecting adequate retaining wall.
2. At the damaged road section, a concrete retaining wall needs to be founded on a stable bed rock and a suitable culvert should be constructed to facilitate the smooth passage to rain water in near future. The back filling of the swept away slope needs to be done
3. Provision of suitable retaining structure at the toe portion of the slope should be constructed in consultation with design engineers.
4. Proper Drainage management system should be implemented. Catch water drains or chute drains may be provided above the crown of the landslide to divert or channelize the water away from the slide area.
5. Removal of the loose material and scoop out hanging over rock mass/material on failure slope.

- The ground cracks need to be covered up effectively in order to avoid any further rain water percolation. The cracks must be sealed either by filling them with puddle clay or other impervious fill. Bentonite or other natural material to reduce further permeability can be used so that surface water does not pond in the area.



Figure 18 (a) Road cave in near Hyundai Showroom, Nogli, Rampur



Figure 18 (b) Gully erosion and toe cutting action of Sutlej River



Figure 18 (c) Highly weathered slates of Khamrada Formation of Kullu Group.



Figure 18 (d) Minor slide in upslope of slide zone showing creeping movement of trees.

Around 10 KM from the Hyundai Showroom road cave in site, another road caved in near the Khaneri Hospital, Rampur district. The slide in has effected around 50 m stretch of the road section, wherein a part of the road has completely failed on 14th of August, 2023 (fig 19 (a)). The Slide is terminating at the Satluj river on the downslope at 100 m. The heavily flooded Satluj River had triggered toe erosion in the downslope area of NH-05.

The slide dimensions are 60 m wide, 90 m long and 70 m in height. The observations revealed the landslide to be a rock slide, which is a translational failure triggered due to slope saturation of the already weakened rock mass. The landslide is active, retrogressive, widening and single in nature. The area exhibits generally moderate to steep slope.

The road section has developed numerous wide cracks indicating that there is continuous sinking of the site as on date of study. The maximum subsidence has been measured to be approx. 10 cm.

Geologically, the site exposes the contact of the quartzites of Manikaran Formation and Phyllites of Banjar Formation of Rampur Group of Palaeo-Proterozoic age (Fig. 19 (b)). The MCT and the Jhakri thrust are in close proximity to the landslide site approx. 2 km East. and hence the rocks are highly jointed and fractured. The weathering index at the site of Slope forming material is W3-W4 as per the ISRM, 1981a. The rocks of the area have poor to Moderate RMR and hence very susceptible to landslide.



Figure 19 (a) Road cave in near Khaneri Hospital, Nogli, Rampur



Figure 19 (b) Lithological Contact between the quartzites of Manikaran Formation and Phyllites of Banjar Formation of Rampur Group



Figure 19 (c) Jointed Phyllites of Banjar Formation of Rampur Group



Figure 19 (d) Highly weathered and Jointed quartzites of Manikaran Formation

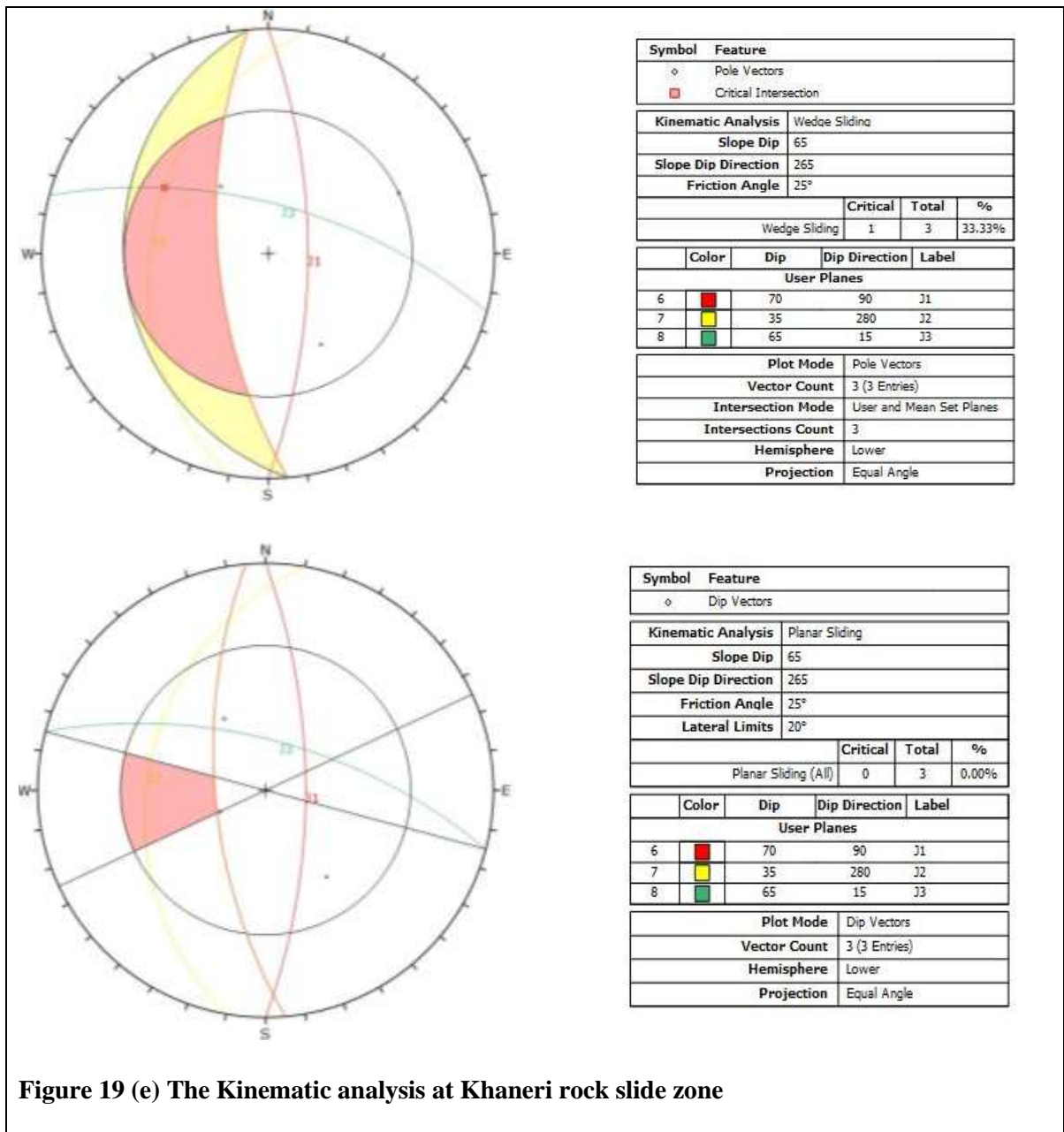
The area has already been identified as Moderate landslide susceptibility zone by Geological Survey of India (GSI, 2018-2019). The quartzite and phyllite are highly jointed (Fig. 19 (c) & (d)). Three set of joints were observed. The details of the joints as observed at the site is tabulated in Table 9.

Table 9. Details of joints characteristics around the landslide affected area at Khaneri Hospital Road Cave, Rampur, Shimla, Himachal Pradesh.

Joint Sets	Dip Amount and	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
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	Direction					
J1 (Foliation parallel)	70°→N90°	70-80	0.1	<1	Nil	Dry
J2	30°→N280	50-60	0.3	2.0	Clay	Dry
J3	75°→N90°	50-60	0.2	1.0	Clay	Dry

Kinematic Analysis



The Kinematic analysis (Fig. 19 (e)) has been attempted at Khaneri rock slide zone for graphically analysing the orientations of structural elements by using stereographic projection techniques.

As per the Markland's failure criteria, the J2-J3 planes satisfy wedge failure conditions while the valley dipping J2 plane satisfy planar failure condition.

Geo Scientific Causes:

1. The most important causative factor for the triggering and development of landslide is the continuous heavy rainfall. Highly weathered rock got saturated, causing slope failure.
2. The factors being, bank erosion and toe cutting of Sutlej river during high flood, causing slope failure
3. **Close proximity of MCT and the Jharki Thrust making the site highly vulnerable to slide**
4. Wedge failure along the J2-J3 joint plane and planar failure along the J2 joint plane.
5. Poor rock mass exposed along the slide area, as the rock slide affected area lies in the close vicinity of a thrust zone where the rocks belonging to Manikaran Formation of Rampur Group are thrust over the high-grade rocks of Jeori-Wangtu Gneissic Complex.

Recommendations

1. The quartzite band exposed below the road level is highly disintegrated and has a sharp contact with biotite schist which bears poor engineering properties. Therefore, a double layer shotcrete along with wire mesh should be used to support the poor rock mass.
2. Contour parallel drains along the affected slope at identified levels should be constructed to diver the surface water away from the slide.
3. A line drainage with sufficient discharge needs to be constructed along the road to diver run off water at the road level.
4. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. to provide enhanced drainage, protection, reinforcement, filtration and barrier functions can be installed at both the flanks of slide to protect any further widening of slide.
5. The toe cutting by Satluj River needs to be taken care off for which suitable retaining structures at the toe portion of the slided slope, should be installed in consultation with the design engineers.

6. Check dams can be constructed along the run off portion of slide so that the unconsolidated material can be protected from washing out during rainy season.

8. Rampur-Khab National Highway-05 Road Corridor

1. Baruni Khad, Rampur, Shimla District, Himachal Pradesh
2. Jeori Rock Fall, Sarahan, Shimla District, Himachal Pradesh
3. Chaura Rock Fall, Sarahan, Shimla District, Himachal Pradesh
4. Chaura Tunnel Rock Fall, Nichar, Kinnaur District, Himachal Pradesh
5. Panvi Bridge Rock Fall, Kinnaur District, Himachal Pradesh
6. Nathpa Jhula Rock Fall, Nichar, Kinnaur District, Himachal Pradesh
7. Khab Slide, Pooh, Kinnaur District, Himachal Pradesh.

(a) Location and Accessibility

The location of landslide areas was mainly restricted to the National Highway-05 (Old Hindustan Tibet Road) falling between Longitude $77^{\circ} 45' E$ and $79^{\circ} 00' 35'' E$ and Latitude between $31^{\circ} 05' 50'' N$ and $32^{\circ} 05' 15'' N$. Kinnaur is the south-eastern district of Himachal Pradesh and shares its boundary with Tibet, having its district Headquarter at Reckong-Peo. It lies 250 km away from Shimla, the capital of Himachal Pradesh and is situated on 5km off from the NH-05. These vulnerable sites can be accessed by Chandigarh – Simla – Rampur - Kaza road (NH – 05). The area of investigation falls in the Survey of India Toposheet No. 53E/14 and 53I/09. The location map of the Landslides along the NH-05 along Rampur to Khab section is given in Fig 1.

(b) Climate and Rainfall

Overall, the climate of Kinnaur is quite pleasant throughout the year, although the winters tend to be a bit harsh (sometimes dropping down to $-10^{\circ}C$ in the night). Summers are hot but the heat is not really scorching. The temperature during summers ranges from 8 to $30^{\circ}C$. The temperatures during monsoon range from $12^{\circ}C$ - $20^{\circ}C$ and sometimes get even colder due to continuous rainfall. The district is one of the driest parts of Himachal Pradesh recording less than 50mm of rainfall. Monsoon season in the valley brings a lesser amount of rainfall. However, during the month of September 2021, the amount of rainfall received was 83.3mm compared to normal rainfall received 67.9mm. It means 23% departure from normal rainfall. (<https://weathershimla.nic.in/en-IN/rainfallmonthly.html>). The district receives 30-40% of annual rainfall during SW

monsoon season (Fig.20). The average annual rainfall in the district is 816mm (CGWB information booklet Kinnaur District, Himachal Pradesh, 2013).

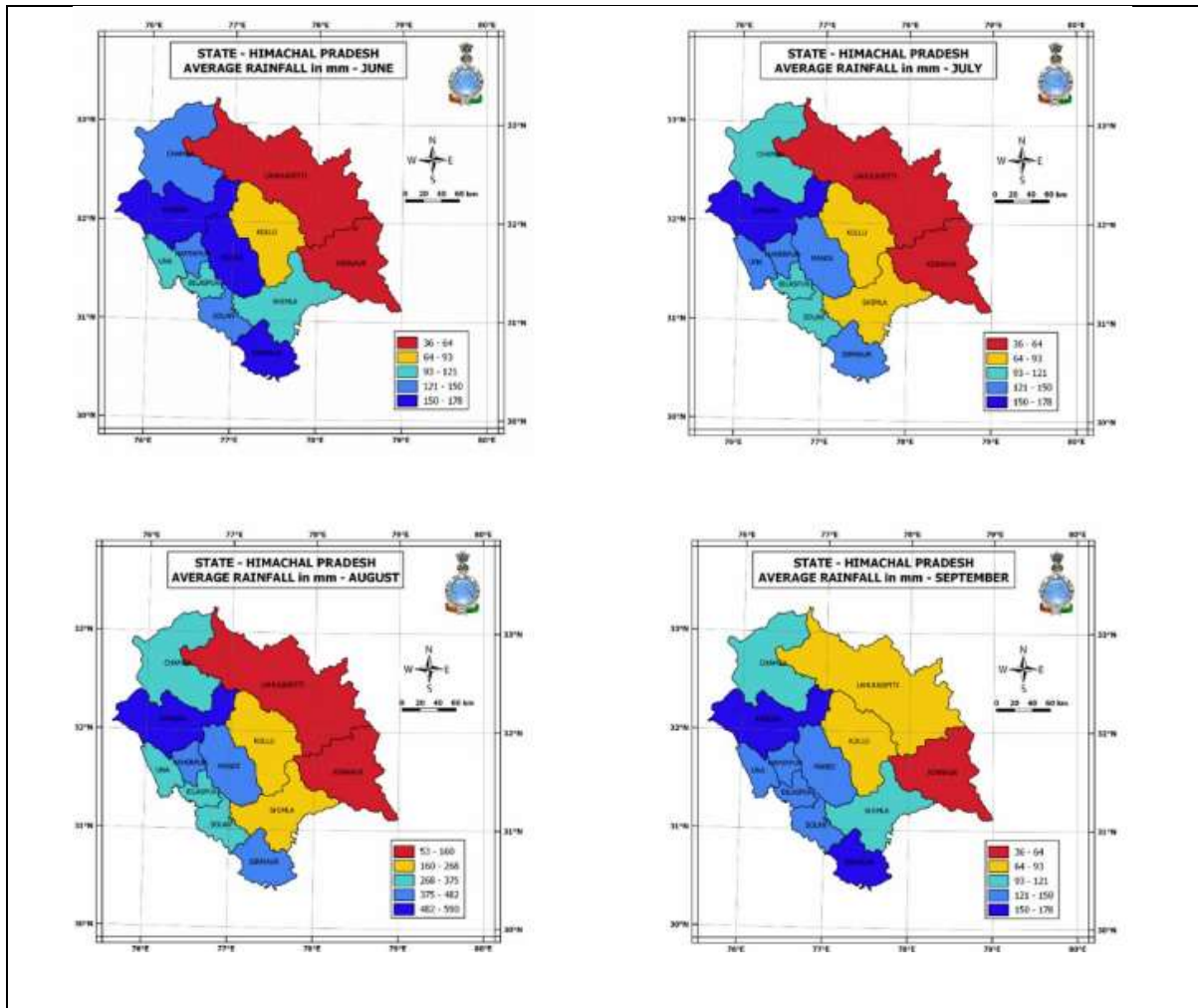


Fig.20: Mean rainfall pattern over districts of Himachal Pradesh shows Kinnaur to be the driest district (Met Monograph No.: ESSO/IMD/HS/Rainfall Variability/10(2020)/34 IMD)

(c) Geomorphology, Drainage and Soil type of the study area

Kinnaur Himalaya is part of the northwestern Himalayas, where its many subsidiary valleys lie between the Zanskar mountain range, the great Himalayan Mountain range, and the Dhauladhar mountain range. Due to the general conformation of the Kinnaur valley along the WNW-ESE direction, the slopes of the right valley are steeper with frequent rocky areas composed of loose to semi-loose slopes debris masses, while the slopes of the left valley they are sweeter and manifest as a flatter debris cone or colluvium. The settlement, agricultural fields and forests are mainly found along the left side of the valley. The straight slopes of the valley are heavily dissected land masses with

sparse vegetation.

Kinnaur district presents an intricate mosaic of mountain ranges, hills and deep valleys. It is primarily a hilly district, with altitudes ranging from 1,500 m to more than 6,500 m msl. There is a general increase in elevation, from west to east and from south to north. The master slope is south-westerly.

The drainage system of the district forms a part of the Indus River basin, except a small part in the northeastern area, which is a part of the Ganga River system. Geomorphologically, the district has been subdivided into the fluvial terrain, fluvio-glacial terrain, Alpines/meadows and Rocky terrain. The overall drainage patterns in the district are dendritic in nature suggesting predominant control of lithology and the prevalent structural fabrics such as master joints, faults and shears etc. in carving the topography and drainage pattern of the area. All rivers/streams flowing in the Kinnaur district are tributaries of the Satluj River catchment, the major river of the area flowing in south-easterly direction. The Baspa River is the major tributary of Satluj River which drains the southern part of the study area. Numerous small nalas and Gads feed the tributaries representing a dendritic drainage pattern. The main gads area is Ropa, Taiti, Wenger and Tidong. The rivers have carved deep V-shaped valleys in their upper reaches and widened valley in downslope. Fresh water springs are also quite common. The drainage map in Fig 4 shows the drainage network in Kinnaur dist. of Himachal Pradesh.

The study area lies in the greater Himalayas with the general slope in the terrain varying from 60 degrees to 75 degrees towards the WNW-ESE direction. The topography of the area is controlled by structure and lithology. The morphological and physio-chemical characteristics of the soils and general similarity in them, the various types of soils observed in the district can be grouped into three major types viz Type-I, Type-II & Type-III. Type-I soil is coarse loamy, mixed in nature. The soil is developed from the Rackham granites, highly metamorphosed gneisses, schists and occurs on moderately sloping to steep lands. These soils are well-drained, with moderately rapid permeability. Natural vegetation exists in these soils and various crops are cultivated according to their suitability. Type-II soil is fine, loamy, mixed and frigid in nature. They have developed on parent material consisting of granite-gneiss and mica schists, on steep to very steep slopes. These are grazing lands supporting alpine grasses. Type- III soil includes various series like Sangla, Spello, Kalpa, Rocky I, Rocky II and Scree series.

(d) Regional Geology of the area

Geologically, the study area is mainly comprised of the rock sequence ranging from Proterozoic to Cambrian age overlain by quaternary deposits belonging to the Middle Pleistocene to Holocene. age. The area exposes high-grade rocks of Higher Himalayan Crystalline (HHC) and Tethyan sedimentary rock sequence. HHC comprises Jeori-Wangtu-Bandal Gneissic Complex (JWBGC), Jutogh, Vaikrita, Kullu, Rampur groups whereas Tethyan rock sequence exhibits Haimanta, group. JWBGC is considered as the basement complex, which provided a basin for the deposition of rocks of Lesser Himalaya. Rocks of Rampur Group are tectonically overlain by rocks of Kullu Group along Kullu Thrust. Kullu Group has succeeded by rocks of Jutogh Group, which have moved along Jutogh Thrust to rest over the rocks of Kullu Group. Vaikrita Group rests over Jutogh Group along the Vaikrita Thrust, which in this area is considered equivalent of Main Central Thrust (MCT) (Bhargava and Bassi, 1994). Vaikrita Group constitutes the basement for the Tethyan basin. The Late Precambrian-Cretaceous sequence resting unconformably over the Vaikrita Crystalline; it has translated along the Vaikrita Thrust (Bhargava and Bassi, 1998). Haimanta Group is thrust over Jaunsar Group. Vaikrita Group has unconformably overlain Haimanta Group [Batal (Neoproterozoic) and Kunzam La (Early Cambrian) formations]. The study area has also exhibited widespread semi to unconsolidated deposits. These deposits are mainly of glacial, rock glacier, fluvio-glacial, fluvial, lacustrine, talus and locally aeolian sediments constitute the Quaternary deposits (Ameta, 1979, Bagati and Suresh, 1991; Bagati and Thakur, 1993; Bagati and Mohindra, 1997; Bhargava and Bassi, 1998).

Glacial deposits have mainly confined to upper reaches of Satluj, Spiti and Pin valleys and fluvio-glacial deposits present in lower reaches of Satluj valley. In lower reaches, these deposits have reworked by the fluvial agencies. The Undifferentiated Quaternary deposits range in age from Middle Pleistocene to Holocene. It consists of erratic boulders, cobbles, gravels, pebbles, grit, embedded in sand, silt and clay. They are fluvial, fluvio-glacial, lacustrine and colluvial deposits. (After Ameta and Swain, 1979-80) (Fig. 6). The litho-stratigraphic succession is in Table 10.

Table 10: The litho-stratigraphic succession of study area (After Ameta and Swain, 1979-80)

Age	Group	Formation	Lithology
Middle Pleistocene to	Quaternary	Undifferentiated Quaternary	Consolidated and unconsolidated sediments, fluvial, fluvio-glacial,

Holocene			lacustrine and colluvial comprise clay silt and boulder beds
Cambrian	Haimanta	Rakcham Granitoids	Medium grained, mesocratic foliated non-foliated biotite granite with leucocratic and pegmatitic differentiates
Neo Proterozoic	Sundernagar	Batal	Phyllite, grey quartzite and carbonaceous phyllite
		Mandi Volcanics	Schistose to massive basaltic flow with arenite band
Paleo Proterozoic	Rampur	Manikaran Quartzite	Quartzite with bands of metabasalt
	Kulu	Khokhan	Phyllite, quartzite
		Ghar	Gneiss, minor quartzite, phyllite
		Khamrada	Carb-phyllite, limestone, quartzite
Undifferentiated Proterozoic	Vaikrita	Chamba	Phyllite, slate
		Shaisu	Quartzite, schist band
		Morang	Schist, quartzite
		Kharo	Sillimanite, kyanite-biotite schist, quartzite, gneiss, Migmatite
	Jutogh	Jaknoti	Schist, gneiss, amphibolite, marble
		Khirki	Quartz schist, carb phyllite, limestone, amphibolites
		Bhotli	Quartzite
		Taradevi	Slate, phyllite, quartzite
		Manal	Quartzite, carbonaceous phyllite
		Panjerli	Carbonaceous phyllite, schist limestone, quartzite
		Jeori-Wangtu Bandal Gneissic Complex	Granitoids, gneisses and Migmatite

(e) Seismicity of Study area

Kinnaur being a part of the young folded mountains of the Himalayas is very seismically active. The district is located in seismic zone IV and V with high risk of damage (MSK VIII) and very high risk of damage (MSK IX or higher) (BMTPC Vulnerability Atlas for

Himachal Pradesh). A strong earthquake (Kinnaur earthquake) shook the Indo-china border on January 19, 1975. It had a magnitude of 6.8 and caused enormous damage in parts of the Kinnaur, Lahaul and Spiti districts (Singh et.al., 1975). The study area is also close to Himalayan tectonic and regional features, such as the Main Central Thrust (MCT). In view of immature topography and active fluvio-glacial processes, the landslide area possesses a fragile geo-environment condition. The area has been identified as High landslide susceptibility zone by Geological Survey of India (Rahul et.al., GSI, 2019).

(f) The landslide incidence

The details of the landslide studies carried out at various locations along the Rampur-Khab National Highway-05 Road Corridor are as below.

8.1 Baruni Khad, Rampur, Shimla District, Himachal Pradesh

The Barauni Nala area falls in the Survey of India (SoI) Toposheet No. 53E/11 and is approx. 130 kms NE of Shimla City. The locality lies within the geo coordinates $31^{\circ}29'6.00''\text{N}$ & $77^{\circ}41'26.00''\text{E}$ and is in a close proximity to the Jhakri town. The landslide incidence along the Barauni Nala is reported to be active since 1990s, due to which a continuous road stretch of approximately 850m along both the flanks of this Nala have been facing regular issues of slope stability resulting mainly due to its toe cutting especially during the monsoon season (Fig. 21(i)). The road frequently gets blocked causing inconvenience to the commuters and transport vehicles. The recent incidences of heavy precipitation in the month of August 2023 have led to number of slope failures along this whole stretch. The heavily flooded Barauni Nala had triggered toe erosion in the downslope area of NH-05 due to which culverts and retaining walls got washed away.

During the last two decades number of residential buildings towards Jhakri town has reportedly been damaged due to active land subsidence in the area. As per the Macroscale National Landslide Susceptibility Mapping (NLSM) studies carried out by GSI during the FS: 2017-18, the presently affected area lies in high landslide susceptible zone.



Fig. 21 (i) Google Earth Imagery depicting the location of Barauni Nala Slide Zone

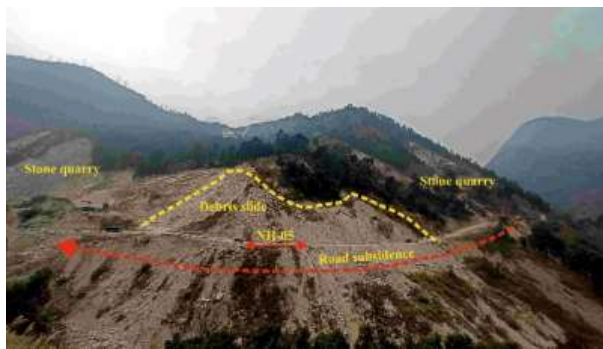
Geologically the Barauni Nala area exposes pale white quartzite and phyllite of Manikaran Formation of Rampur Group of Palaeo-Proterozoic age. Thick bands of pale quartzite can be very well observed along the NH-05 road section which are presently being mined for house building stone and aggregates for road construction. The Manikaran quartzite is having a thrust contact with gneisses and migmatites belonging to Jeori-Wangtoo Gneissic Complex. Addition to this, a thick overburden cover comprising of loosely compacted palaeo-debris material and highly disintegrated and weathered rock mass having an approx. thickness of 3-5m has also been observed along the NH-05 road section.

The salient features of the affected slopes around Barauni Nala

The road stretch along the NH-05 has been facing ground subsidence mostly during the monsoon season, due to which the National Highway Division of HPPWD has to frequently carry out land fill to maintain the road level for smooth traffic flow (Fig. 2a). Approximately 0.25 sq. km area is found to be prone to land subsidence and sliding. As per the officials of NH PWD, large scale creep/ground subsidence has been observed especially during the current monsoon season due to extreme rainfall event during the month of July and August 2023. The Nation Highway has subsided by approx. 3m-4m which was later on refilled and levelled by the public works department (Fig. 21b). As a result of toe erosion triggered by the high discharge of Baruni Nala, number of retaining

structures and culverts have been damaged and dislocated from their original position (Fig. 21c).

Baruni Nala is an actively flowing perennial stream which gets flooded during the peak rainy season, which ultimately destabilises the slopes in its vicinity (Fig. 21d). Though no insitu rock exposures were observed along the road stretch, valley dipping joint planes could be visualised around the stone quarry from the road level towards Jhakri side (Fig. 21e). A planar failure of both jointed rock mass and overburden cover along these planes can be well anticipated. The slopes along the road stretch towards Jhakri town expose moderately compacted debris, while the road stretch towards Rampur expose loosely compacted debris cover with a number of rolled boulders resting above the road. (Fig. 21g&h). A few damaged houses have been observed along the NH towards Jhakri town near the road bend which indicates active ground subsidence till this point (Fig. 21f).



e) Panoramic view of the landslide affected stretch to NH-05



f) Ground subsidence along the NH-05



g) Failed retaining structures along the NH-05



h) Perennial flowing nala across the NH-05

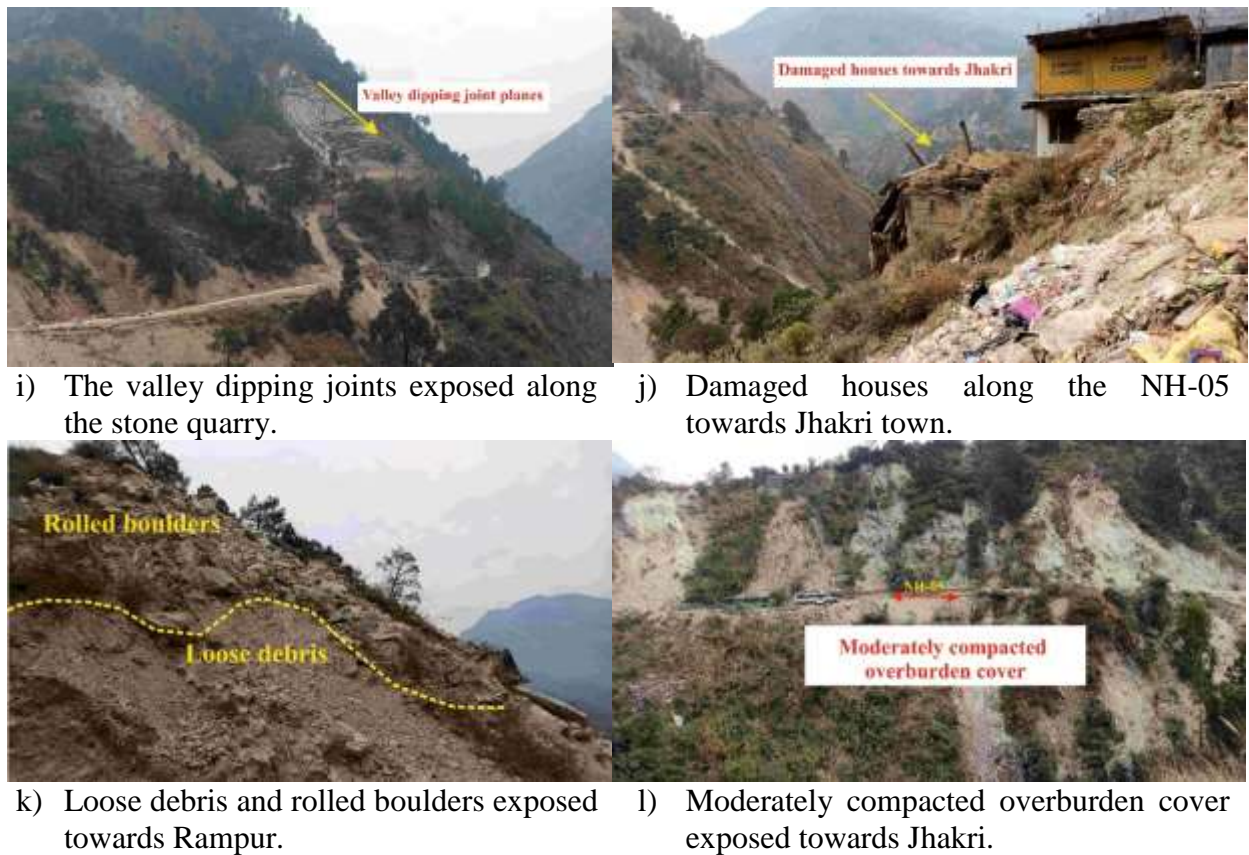


Fig. 21 Field photographs from the Barauni Nala slide.

Future Menace

The terrain generally exhibits moderate to steep valley slopes and in view of presence of thick loose debris, the stretch is seemed to remain unstable and required to be dealt carefully and scientifically. The road stretch towards Jhakri is mainly prone to road subsidence, while the hill slopes along the road are comparatively stable. The stretch towards Rampur is comparatively more destabilized and further subsidence and debris slide incidences have very high probabilities. Therefore, the safety of commuters still lies in a great risk, especially during the high precipitation.

Geoscientific Causes

- A. Prima facie, it appears that the distressed slopes along the 850m road stretch of National Highway 05 have resulted primarily due to the toe cutting/ erosion by the perennial stream of Barauni Nala. Under such a scenario, the surrounding slopes exposing loose to moderately compacted debris material and rolled boulders have become highly prone to further slope failure.

- B. The landslide affected area lies in the close vicinity of a thrust zone where the rocks belonging to Manikaran Formation of Rampur Group are thrust over the high-grade rocks of Jeori-Wangtu Gneissic Complex.** The ground signatures of this thrust zone in the form of disturbed/ unstable terrain can be very well visualised in the field.
- C. Apart from National Highway-05, the affected area above the road stretch is exposed to anthropogenic activities in form of stone quarries at multiple locations, which is a matter of serious concern regarding the stability of surrounding slopes.

Recommendations

1. The actively flowing Baruni Nala needs to be channelized effectively to avoid any ground water saturation. Provision of suitable retaining structure at the toe portion of the slope, i.e along the main drainage should be made in consultation with design engineers.
2. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. can be installed below the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions.
3. Sufficient drainage arrangements must be provided along the affected slopes, especially along road stretch towards Rampur. Catch water drains or chute drains must be provided above the crown of the landslide to divert runoff water.
4. The settlements below the road level towards Jhakri side needs to be monitored for any ground cracks or any damage to the building. The drain water from individual houses must be channelized effectively to avoid any ground water saturation.
5. In order to monitor small levels of ground creep, installation of a geodetic system may be considered at first in consultation with site geologist/ geotechnical engineers.
6. The surrounding area susceptible to further slope failure along with the buffer zone may be identified and no new construction/ mining activity or slope modification work should be carried out in this zone.
7. In view of the instability conditions along this road stretch, possibilities for realigning the road through the safer/ stable slopes must be taken into consideration. To avoid this unstable zone, the right bank of River Sutlej can be explored for an alternate road connectivity.

8. The area is highly fragile in nature and bears a complex geological problem due to the presence of NW-SE trending thrust zone and thus formulating any long-term remedial measure needs a Detailed Geological & Geotechnical Investigation.

8.2 Jeori Rock Fall and subsidence, Shimla District, Himachal Pradesh

The site affected by landslide is located at N latitude 31°32'19.20" & E longitude 77°47'1.91" along a steeply inclined hill slope having a general slope direction of ~72°/N240°. During the field work, it was observed that the slope failure has taken place from a moderate to steeply inclined hill slope. As per information provided by the Local public, this slide initiated on September 2021 and reactivated on 14th August 2023 after incessant rainfall. The present rock failure took place from a moderately dissected hill slope. The rocks exposed at the site exhibited three set of joints. The details of the joints sets tabulated as below in table 11.

Table 11. Details of joints characteristics around the landslide affected area at Jeori, Rampur, Shimla, Himachal Pradesh.

Joint Sets	Dip and Direction	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J1 (Foliation parallel)	70°→N120°	70-80	5-50	1.5	Clay & loose soil	Dry
J2	60°→N10°	50-60	2-30	3.0	Clay	Dry
J3	50°→N245°	40-50	8-10	2.0	Clay	Dry

The main reason attributed to the failure is wedge failure condition. The joints are comparatively more open towards the upper part than the lower part. The Joints plane are curvilinear due to the crenulation in the rocks along the foliation planes. The rocks are highly shattered in the lower part due to extensive slope cut. The landslide occurred due to unplanned modification of natural slope to a critical angle, moderately weathered and jointed rock mass resting over steep slope become oversaturated and got triggered during excess rainfall.

The overburden type is slope wash with maximum thickness 1-1.5 m as per field observations with precarious rock blocks resting along this slope. The Landuse/Landcover is mostly characterized by sparse vegetation and extensive cut slope for road widening. No previous retaining structure and proper drainage alignment observed at the time of study.

Water seepage also observed along valley dipping joint plane which poses a great threat for the slope instability.

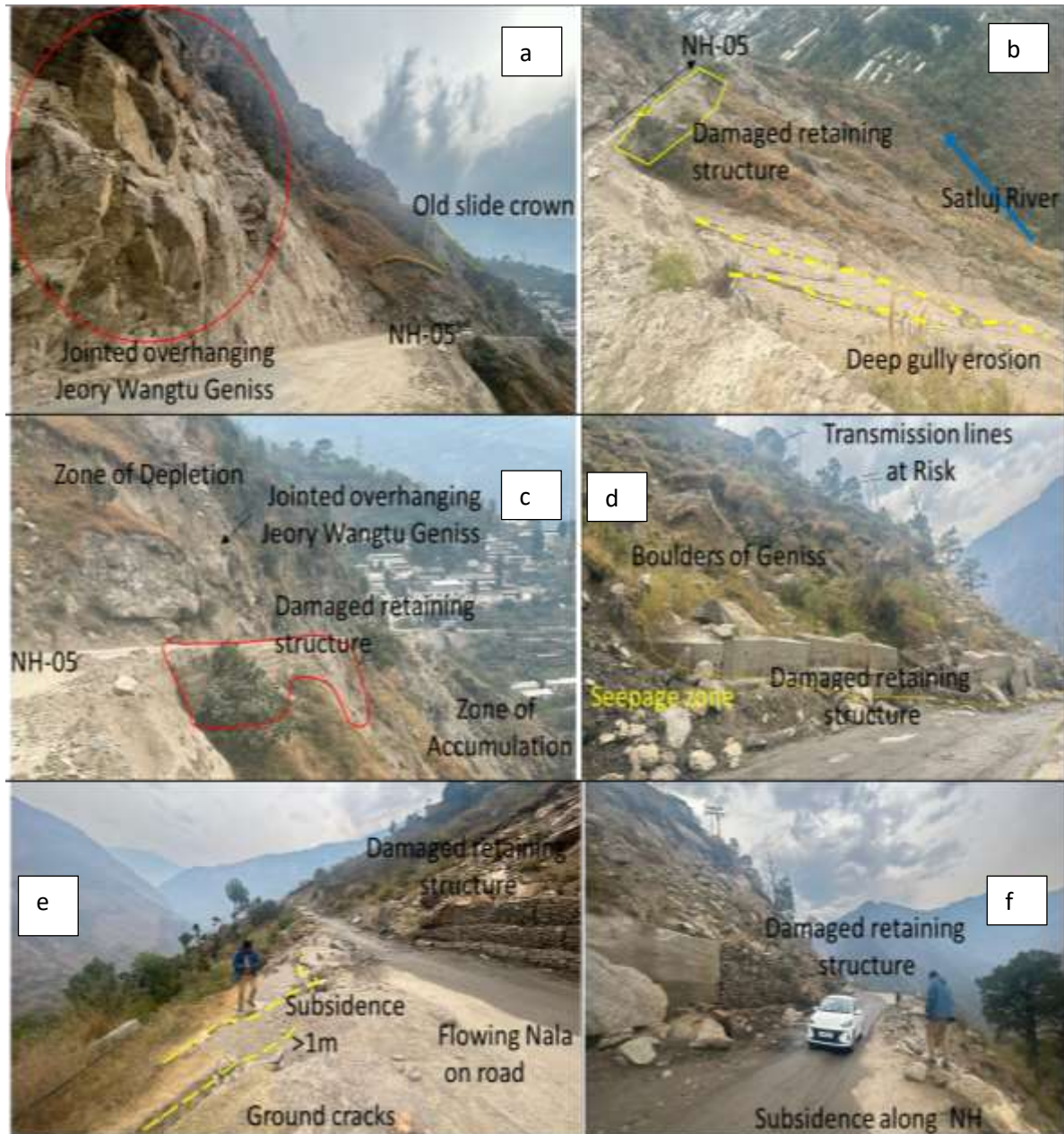


Figure 22(a) Highly jointed rocks of Jeori Wangtu Gneissic complex loosely hanging over National Highway-05

Figure 22(b) Downslope of Jeory slide showing toe cutting by Satluj river and deep gully erosion

Figure 22(c) Damaged retaining structures along the slide zone.

Figure 22(d) boulders of geniss causing slide

Figure 22(e) Subsidence in road section and flowing nala on road

Figure 22(f) Caved in portion of NH-05

The length, width and height of the slide, as observed during field observations, were $\pm 35\text{m}$, $\pm 40\text{m}$ and $\pm 20\text{m}$ approximately. The runout distance is $\pm 320\text{m}$ upto the Satluj

River. The type of movement is as shallow translational slide (2-3m depth) and distribution is widening, and retrogressive. The widening nature of the slide can be confirmed from the creation of the subsidence zone 200 m ahead of the slide area. The subsidence is due to the toe cutting action of the Satluj river downslope. Huge ground cracks have been developed on the road section trending 261 ° W and are 10 cm to 5 cm wide at places and 10-12 m long. The damp zones have been identified at N latitude 31°32'32" & E longitude 77°47'9". Subsidence of about 1 to 1.5 m has been observed on the road stretch.

Salient Features

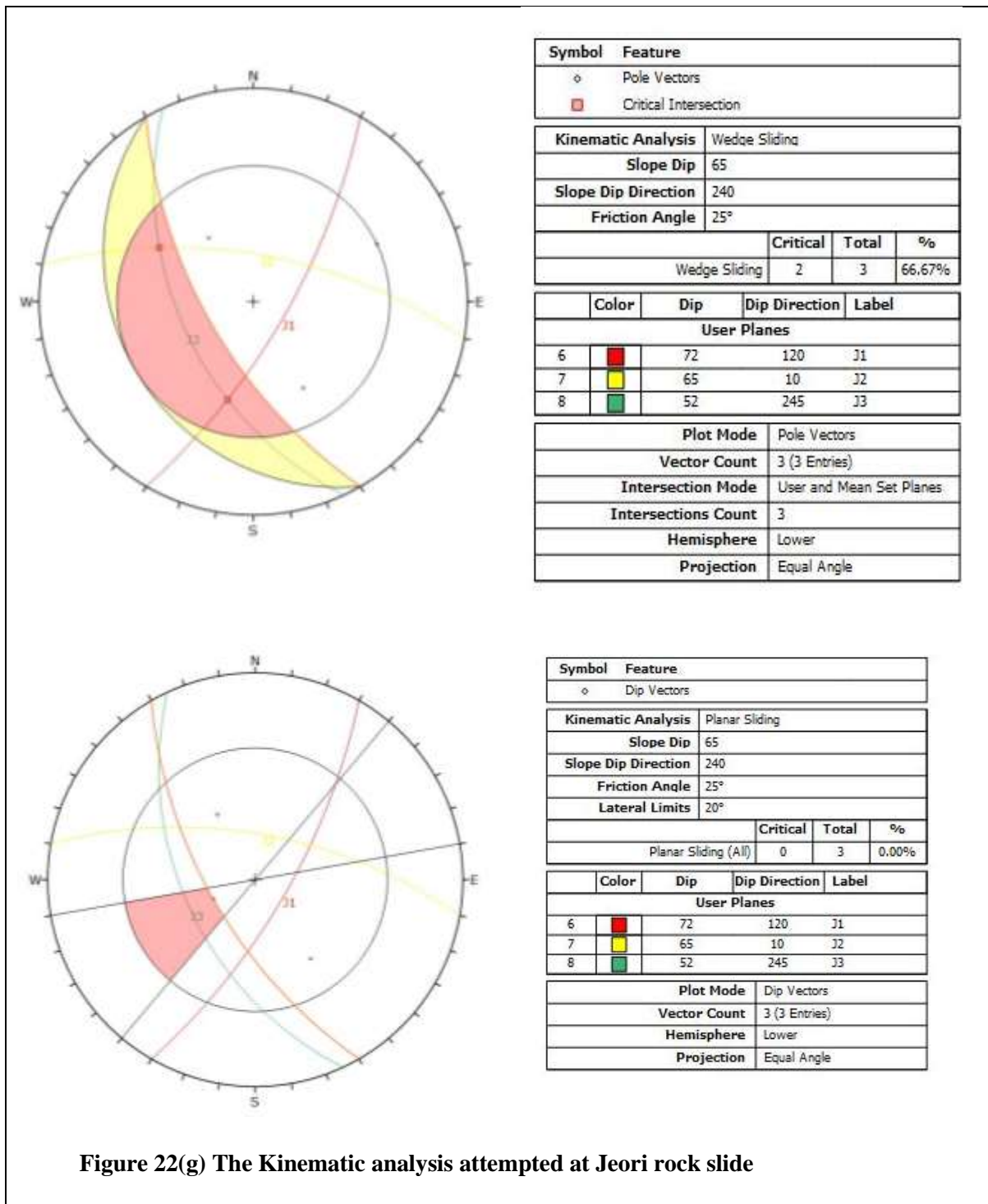
1. The present area already falls in high susceptible zones of Macroscale LSM studies during NLSM studies and Meso scale studies.
2. As per field observations the prime cause of the slope failure is anthropogenic as well as natural. The slope observed is unplanned modified to a critical angle during road widening and without treatment to the weathered and jointed rock mass lying over the steep slope.
3. The rocks exposed in the region exhibit three set of joints which are very open in nature and are susceptible for failure.
4. Absence of proper drainage network, excessive rainfall spells and seepage along valley dipping joints plane have caused the slope failure.

Kinematic Analysis

The Kinematic analysis has been attempted at Jeori rock slide for graphically analyzing the orientations of structural elements by using stereographic projection techniques shown in Fig 22(g). As per the Markland's failure criteria, the following planes satisfy wedge failure conditions at Jeori slide area.

1. J1-J3 wedge failure
2. J2-J3 wedge failure

The J3 plane satisfy planar failure condition



Future Menace

The observations along the upslope revealed presence of lot of jointed rocks, open in nature transferring the rocks precariously disposed on the slope. In view of the steep gradient of the upslope part of jointed rocky slope that leads to wedge failure of the present landslide, the recurrence of rock fall incidence cannot be ruled out. In this effect or

in case of any seismic jolt or heavy rainfall, the area should be kept under close monitoring.

Recommendations:

Based on geological assessment of the slope failure affected site, following remedial measures are suggested to contain the rock fall incidence.

For rock slide Zone

1. Scaling and removal of precariously resting the loose rock blocks along the slope immediately.
2. Appropriately designed retaining structures of suitable size and dimension at road level and near toe of the slide.
3. Appropriately designed guide wall along river below to prevent erosion.
4. Proper channelization for water in adjoining affected slope on either side to avoid its further ingress at the earliest.
5. Rock bolting followed by shotcrete in the poor rock mass to stabilize the failed rock mass
6. Vigil should be maintained by concerned authorities and local residents regarding slope instability phenomena/ development of slope instability signatures (e.g. bulging, cracks, landslips etc.) & timely intimation to concerned authority.
7. Installation of rain gauge stations, proper recording and maintaining by State Govt./Dist. Admin. would be very useful in future.
8. Appropriately designed rock bolting at crown portion to avoid further rock failure

For road subsidence zone

1. The cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area.
2. The damp zones, which are the probable zones of seepage of water, should be properly treated and coated with an impervious layer of clay or cover with plastic sheet to avoid water ingress into the slide area.
3. Appropriately designed retention structures at suitably identified locations at lower level as support to failing mass with weep holes at different levels.

8.3 Chaura Rock slide and Chaura Tunnel, Kinnaur District, Himachal Pradesh

A massive rock fall incidence occurred at the Chura tunnel and on the National Highway-05 near Chaura Village on the left bank of Satluj River, on Rampur-Reckong Peo, NH05 road, district Kinnaur, Himachal Pradesh, on 14th of August 2023. The study area (Chaura village) falls in the Survey of India Toposheet No.53E/14. The landslides at the two locations effected approximately 260m stretch of NH-05 causing disruption of communication of hilly terrain with foothill areas and thus severely effecting the socio-economic activities in the area.



Figure 23(a) Highly jointed rocks of Jeori Wangtu Gneissic complex loosely hanging over National Highway-05 near old slide zone of 2021.



Figure 23(b) Highly jointed rocks of Jeori Wangtu Gneissic complex loosely hanging over National Highway-05 near Chaura tunnel.



Figure 23(c) Vertical open joints with cracks near Chaura tunnel.

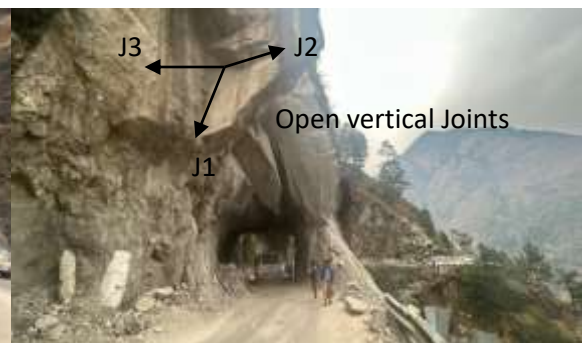


Figure 23(d) Three set of joints near Chaura tunnel.

Field assessment of landslide incidence area

The rock-fall area is located on the left bank of Sutlej River, near to Chaura village, constitutes a steep sun-shadow hill slope comprising major scarp on uphill side. The rock-failure occurred in upper part of a major escarpment represented by highly jointed gneiss of the Jeori Wangtu Geissic Complex of Higher Himalayan Crysatallines. The rocks are highly

fractured due to different sets of joints transforming them in a distress rock mass. In particular, the valley dipping joints and the foliation joints which leads to different wedge as well as planar failures in the area. The joint details of the rock mass as follows in table 12.

Table 12. Details of joints characteristics around the landslide affected area at Chaura, Kinnaur, Himachal Pradesh.

Joint Sets	Dip Amount & Dip Direction (degree)	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J ₁ (Foliation parallel)	50 →350	100-110	10	>10	Rock fragment & loose soil	Damp
J ₂	60 →125	80-90	5	1.5	Rock fragment & loose soil	Damp
J ₃	85 →50	60-70	3	2	loose soil	Damp

Kinematic Analysis

Chaura Rock Slide

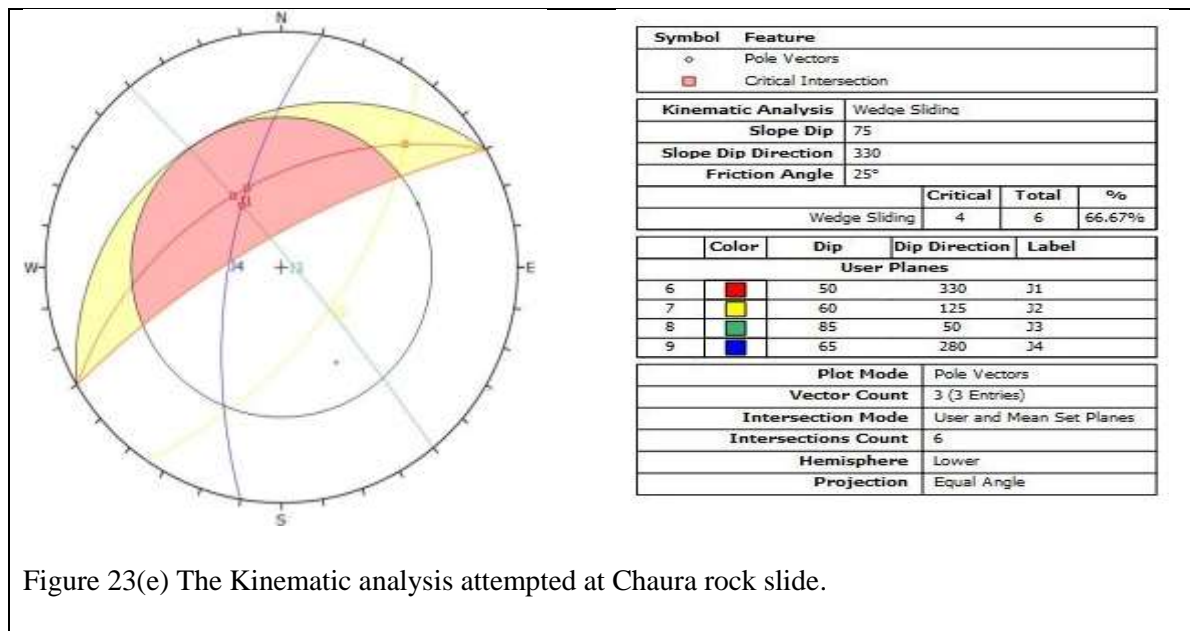


Figure 23(e) The Kinematic analysis attempted at Chaura rock slide.

The Kinematic analysis has been attempted at Chaura rock slide for graphically analysing the orientations of structural elements by using stereographic projection techniques (Fig 23(e)). As per the Markland's failure criteria, the following planes satisfy wedge failure conditions at Chaura slide area.

1. J1-J3 wedge failure

2. J1-J4 wedge failure
3. J3-J4 wedge failure

Chaura Tunnel

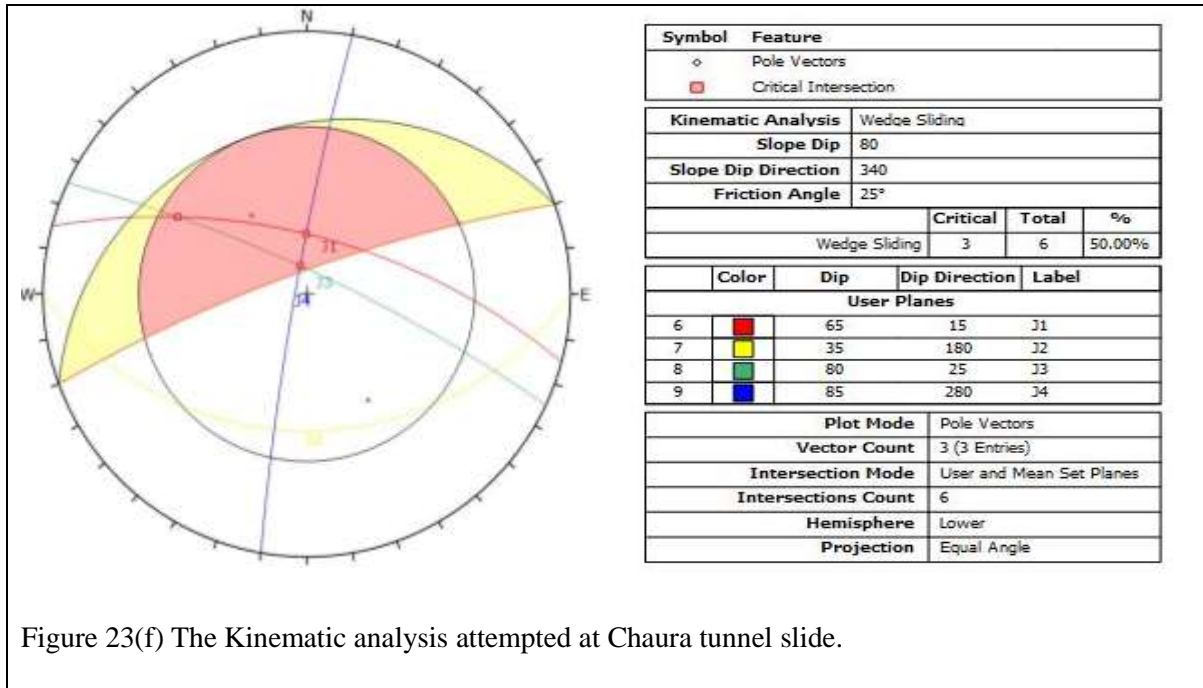


Figure 23(f) The Kinematic analysis attempted at Chaura tunnel slide.

The Kinematic analysis has been attempted at Chaura tunnel location for graphically analysing the orientations of structural elements by using stereographic projection techniques Fig. 23 (f). As per the Markland's failure criteria, the following planes satisfy wedge failure conditions at Chaura tunnel slide area.

1. J1-J3 wedge failure
2. J1-J4 wedge failure
3. J3-J4 wedge failure

The salient feature of the rock fall has been enumerated below-

1. The Chaura village with elevation approx. EL ±1660 m, constitutes a moderate altitude area. It is manifested with highly jointed rock of Jeori Wangtu gneissic complex along with Pleistocene to Sub-Recent glacial landforms and fluvio-glacial deposits.
2. Sun-facing hill slopes are steeper, highly dissected, barren to sparsely forested and covered with loose to semi compact slope material scree aprons composed of small to boulder size rock fragments. Sun-shadow side are generally gentler and with colluviums/ debris cone, thick soil cover, agriculture, forest and village settlements.

3. In view of immature topography and active fluvio-glacial processes, the Sutlej valley area possesses a fragile geo-environment condition. The area including Chaura locality has already been identified as High landslide susceptibility zone by Geological Survey of India (GSI, 2018-2019).

4. The Sutlej valley in recent years, has witnessed a remarkable jump in increase of infrastructural development and tourist influx. In view of the inherent natural processes of seasonal fluvio-glacial weathering and erosion, the area warrants a comprehensive strategy to minimize the associated hazard and risk.

5. The landslide area exposes highly jointed gneiss of Jeori Wangtu Gneissic Complex. The incidence has been identified as rock fall caused by planar failure along a major joint plane

Geoscientific Causes

1) The failure mechanism appears to be planar failure from jointed major escarpment composed of gneiss of Jeori Wangtu Gneissic complex.

2) The geoscientific causes worked out be rock slide occurred in highly jointed contact of gneiss aggravated by seasonal fluvio-glacial and rain water related weathering and erosion.

Future Menace

The observations along the upslope revealed presence of lot of hanging blocks of gneisses precariously disposed on the slope. The joints are open and in view of the steep gradient of the upslope part of jointed rocky slope that leads to planar failure of the present landslide, the recurrence of rock fall incidence cannot be ruled out. In this effect or in case of any seismic jolt, the area should be kept under close monitoring.

Moreover, it was revealed that the site has been converted into a major tourist attraction following the shooting of a major Bollywood movie and attracts a lot if tourists. A dhaba located at the vicinity also adds as a major attraction for the tourists. In view of the vulnerability of the site to rock fall, vigilance must be ensured for safeguarding the lives of the visitors.

Recommendations

It is recommended that for implementation of site specific remedial and protective measures, the available live video of incidence may also be analyzed. The various recommendations deduced are as per below-

1. Removal of precariously disposed rock mass from the source/trajectory area.
2. Scaling of remaining part of the hanging block/ bolting of the blocks of rocks whose joints are opened.
3. Rock bolting with wire mesh to hold the rock from the wedge or planar failure.
4. Rock face can be shotcreted using steel reinforced shotcreting (SFRS) with provision of drainage holes
5. During rainy season, the traffic movements under strict onsite and offsite slope monitoring.
6. Installation of sign boards/ banners at appropriately identified vulnerable locations for cautioning to the commuters.
7. Tourist activity around the slide area should be restricted to avert any major mishappening.

8.4 Panvi Bridge Rock Fall, Kinnaur District, Himachal Pradesh

A massive rock slide incidence occurred on the National Highway 5 km ahead of Nathpa enroute to Reckong Peo at Latitude 31°32'22.00"N and longitude 78° 0'50.00"E, district Kinnaur, Himachal Pradesh, around 21:30 hrs on 14th of August 2023.

The study area falls in the Survey of India Toposheet No.53E/14. The site is located 62km from Reckong Peo (district HQ) and is approachable by all-weather road via Rampur-Reckong Peo. The landslide effects approximately 100m stretch of NH-05 causing disruption of communication of hilly terrain with foothill areas and thus severely effecting the socio-economic activities in the area. The morphometry of the slide is given in Figure 24(a)

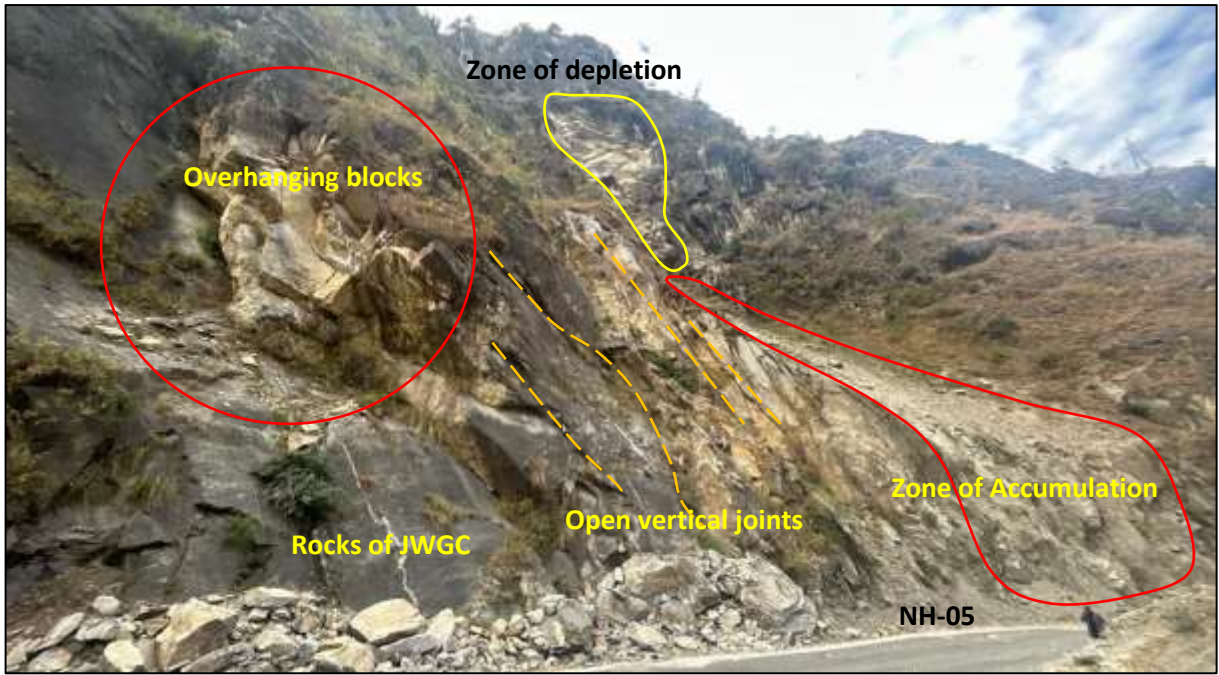


Figure 24(a) Morphometry of Panvi Bridge Rock Fall, Kinnaur District, Himachal Pradesh



Figure 24(b) Three set of joints of Panvi Bridge Rock Fall, Kinnaur District, Himachal Pradesh



Figure 24(c) ECS at Panvi Bridge Rock Fall, Kinnaur District, Himachal Pradesh

Field assessment of landslide incidence area

The rockfall area is located on the left bank of Sutlej River, constituting a steep sun-shadow hill slope. The rockfall, in fact a wedge and planar failure occurred in upper part of a major escarpment represented by highly jointed gneiss of the Jeori Wangtu Geissic Complex. The rocks are highly fractured due to different sets of joints transforming them in a distress rock mass, the valley dipping joints and the foliation joints which leads to different wedge (J2 and J3 as well as planar failures (J1) in the area (Fig.24 (b)). The extensive road cutting also contributed to the rock failure (Fig. 24 (c)). The joint details of the rock mass is given in table 13.

Table 13. Details of joints characteristics around the landslide affected area at Panvi, Kinnaur, Himachal Pradesh.

Joint Sets	Dip Amount & Dip Direction (degree)	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J ₁ (Foliation parallel)	55→5	110-120	10	>15	Rock fragment & loose soil	Dry
J ₂	80→250	80-90	10	3	Rock fragment & loose soil	Dry
J ₃	75→185	70-80	5	10	loose soil	Dry

Kinematic Analysis

Panvi Rock Slide

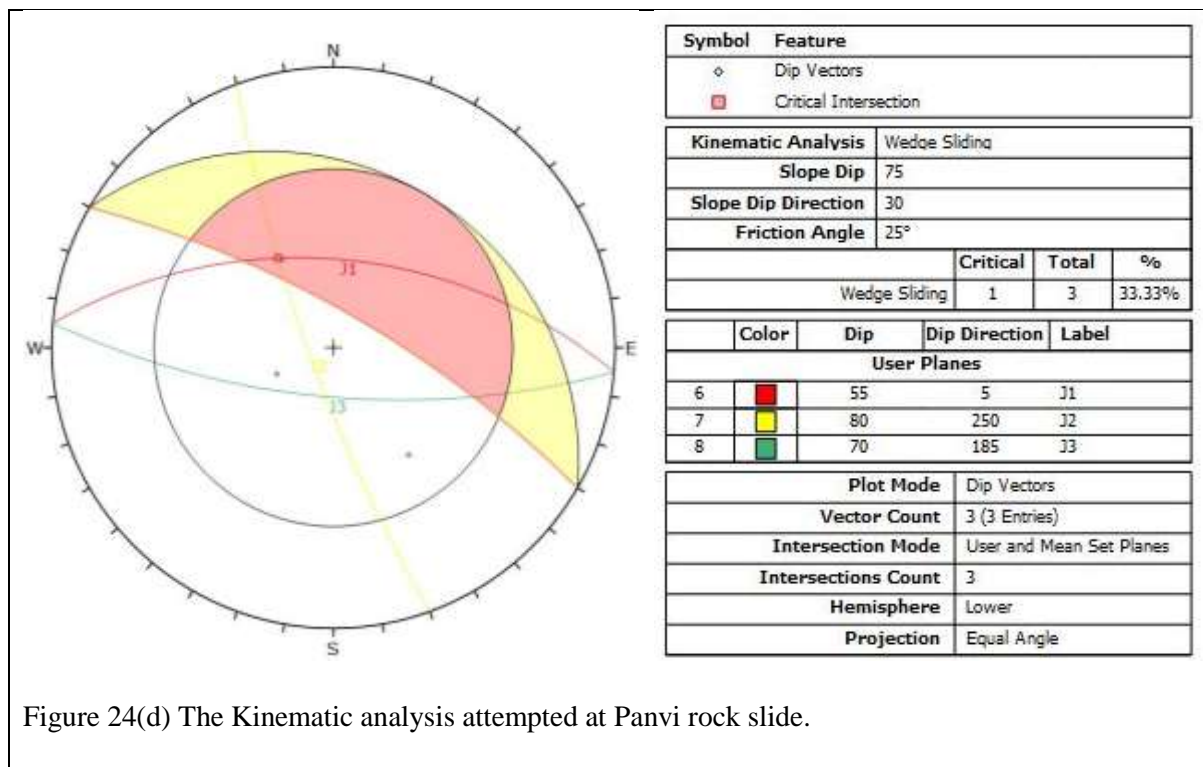


Figure 24(d) The Kinematic analysis attempted at Panvi rock slide.

The Kinematic analysis has been attempted at Panvi rock slide zone for graphically analysing the orientations of structural elements by using stereographic projection techniques (Fig 24(d)). As per the Markland’s failure criteria, the J1-J2 planes satisfy wedge failure conditions at Panvi slide area.

The salient feature of the disastrous rock fall has been enumerated below-

- 1) The rock slide/planar failure occurred from the upper part of a major valley facing joint.
- 2) The failure mechanism appears to be planar failure from jointed major escarpment composed of gneiss of Jeori Wangtu Gneissic complex.
- 3) The geoscientific causes worked out be rock slide occurred in highly jointed contact of gneiss aggravated by seasonal fluvio-glacial and rain water related weathering and erosion.

Future Menace

The observations along the upslope revealed presence of lot of hanging blocks of gneisses precariously disposed on the slope. In view of the steep gradient of the upslope part of jointed rocky slope that leads to planar failure of the present landslide, the recurrence of rock fall incidence cannot be ruled out.

Recommendations

It is recommended that for implementation of site specific remedial and protective measures, the available live video of incidence may also be analyzed. The various recommendations deduced are as per below-

1. Removal of precariously disposed rock mass from the source/tectory area.
2. Scaling of remaining part of the hanging block/ bolting of the blocks of rocks whose joints are opened.
3. Concrete/ masonry retaining structure all along the road stretch with adequate drainage holes.
4. Rock bolting with wire mesh to hold the rock from the wedge or planar failure.
5. Provision of catch fence and ditches to hold the loose falling boulders.
6. During rainy season, the traffic movements under strict onsite and offsite slope monitoring.
7. Installation of sign boards/ banners at appropriately identified vulnerable locations for cautioning to the commuters.

8.5 Nathpa Jhula Rock Fall, Nichar, Kinnaur District, Himachal Pradesh

On the 27th of October, 2023, a major rock slide took place on the National Highway, near the Nathpa Jhula causing the road blockage for three consecutive days and damaging the retaining walls (Figure 25 (b)). The slide was still active during the visit with debris and loose rock material sliding of the belly portion of the slide following minor rains or winds. Preliminary studies of Nathpa landslide was carried out to assess the potential threat.

The Nathpa landslide is a rock slide at National Highway-05 near Nichar village, district Kinnaur, Himachal Pradesh and nearly 80 km from Reckong-Peo in Lesser Himalayan terrain and falls in the Survey of India Toposheet No.53E/14.

The slide zone is located on the left bank of Sutlej River on NH-05 around 1.3 km north of Nathpa Village. The observations revealed the landslide to be a rock slide predominantly activated due to slope saturation on rain-water ingress. The morphometry of the slide is given in Figure 25(a). The slide area is very critical since the slide zone is located just above the reservoir and inlet of the SJVNL HEP as shown in Figure 25 (c), (d) and (f).

The area exhibits steep to moderately steep slopes. The rock slide/planar failure occurred from the upper part of a major valley facing joint (Figure 25 (b)). The failure mechanism appears to be planar failure from jointed major escarpment composed of gneiss of Jeori Wangtu Gneissic complex. The geoscientific cause of the slide worked out be rock slide occurred in highly jointed contact of gneiss aggravated by seasonal fluvio-glacial and rain water related weathering and erosion.

The presence of highly jointed fragile rock mass with large open joints with overhanging rock blocks acts as a catalyst to engrave the size of landslide. The steep escarpment is the source for rock material, which during heavy rainfall (Figure 25 (g)), destabilizes the zone further. The bed rock mostly comprises rocks of Jeori-Wangtu gneiss. The rocks are highly jointed and dipping N265 that is towards the valley (Figure 25 (e)).

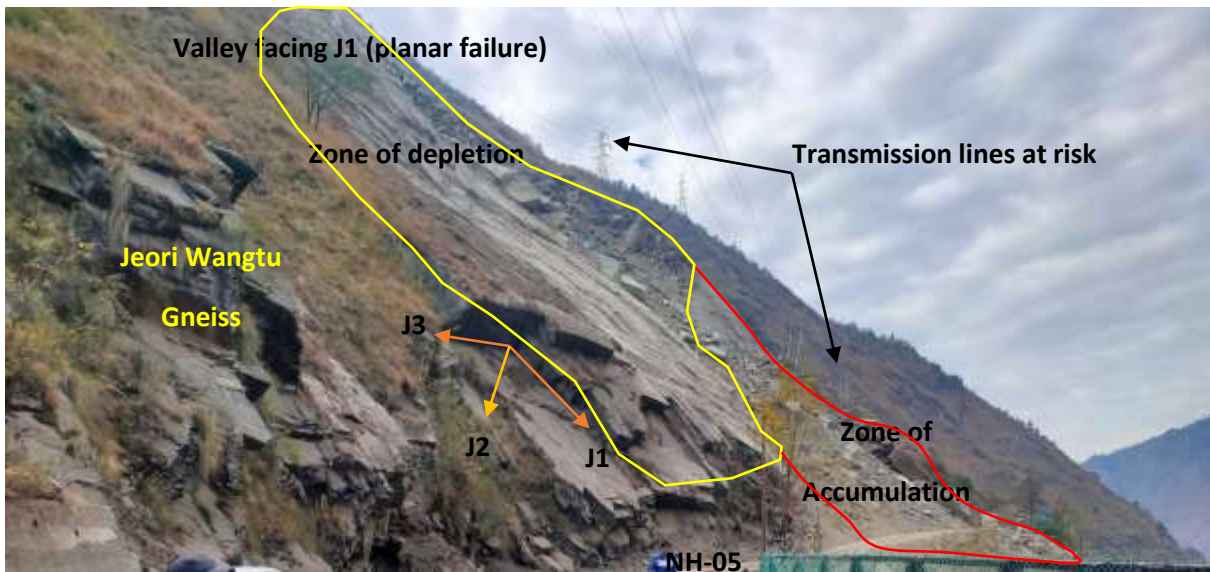


Figure 25(a) Morphometry of Nathpa Rock Slide, Kinnaur District, Himachal Pradesh



Figure 25(b) Crown of Nathpa Rock Slide, Kinnaur District, Himachal Pradesh



Figure 25(c) Toe of Nathpa Rock Slide, Kinnaur District, Himachal Pradesh



Figure 25(d) SJVNL dam reservoir below Nathpa Slide



Figure 25(e) Open and persistent Valley facing joints



Figure 25(f) Damage to SJVNL dam

Figure 25(g) Loose boulders at the landslide site.

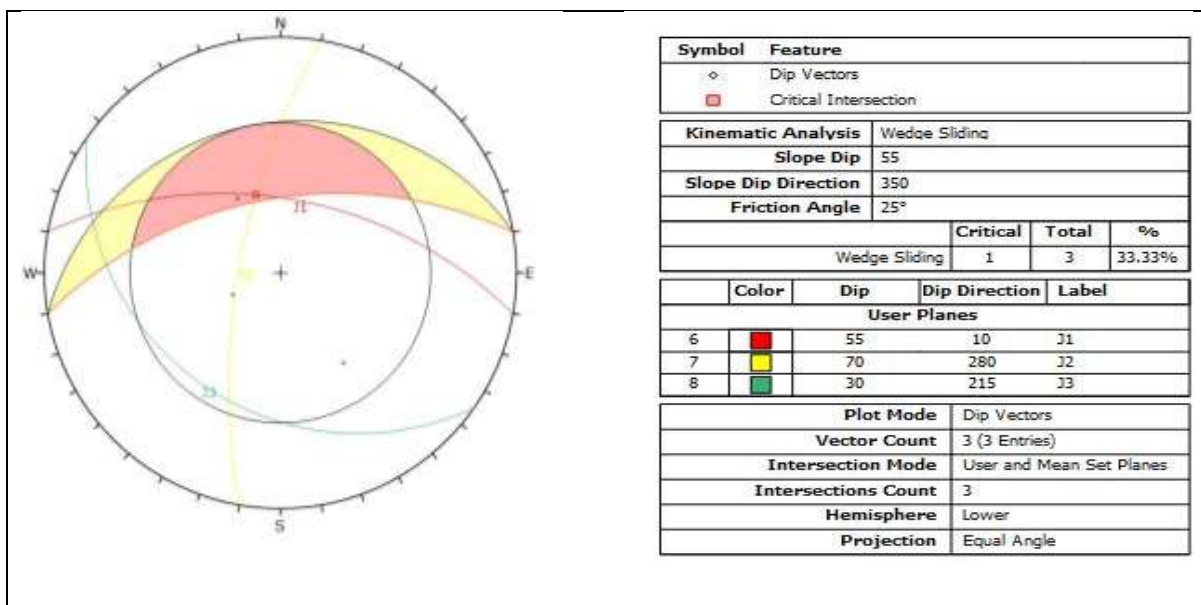
The joint details of the rock mass are given in table 14.

Table 14. Details of joints characteristics around the landslide affected area at Nathpa, Kinnaur, Himachal Pradesh.

Joint Sets	Dip Amount & Dip Direction (degree)	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J ₁ (Foliation parallel)	55→10 (valley dipping)	80-90	5-8	6-7	Rock fragment & loose soil	Damp
J ₂	70→280	60-70	3-5	3	loose soil	Damp
J ₃	30→215	50-60	1-3	5	Clay	Damp

Kinematic Analysis

Nathpa Rock Slide



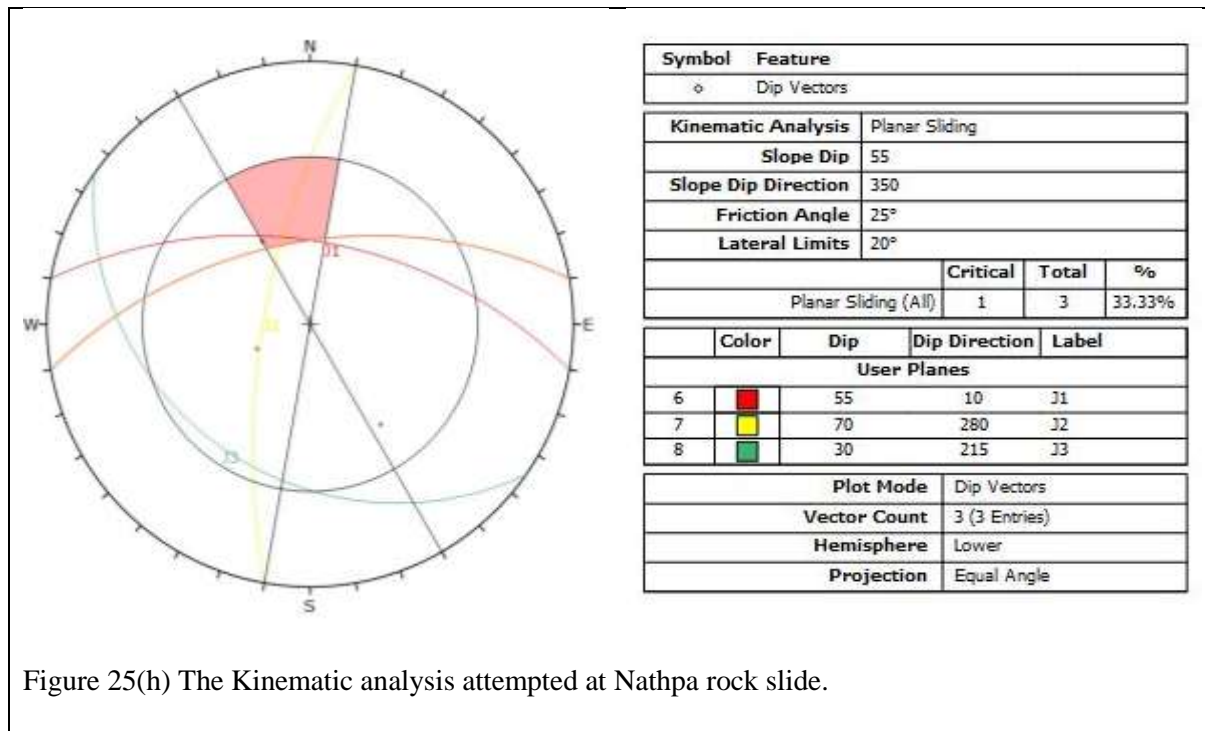


Figure 25(h) The Kinematic analysis attempted at Nathpa rock slide.

The Kinematic analysis has been attempted at Nathpa rock slide zone for graphically analyzing the orientations of structural elements by using stereographic projection techniques Fig 25 (h). As per the Markland’s failure criteria, the J1-J2 planes satisfy wedge failure conditions while the valley dipping J1 plane satisfies planar failure condition.

The future menace

The terrain exhibits moderate to steeply dipping slope. In view of presence of highly open valley facing joints and loose overburden material lying on the planar surface, the stretch is highly unstable and requires careful and scientific studies for slope stabilization.

Salient features

1. The Sutlej River valley with elevations from 1830m (Karcham) to 1630m (Nathpa), constitutes a high-altitude area is manifested with Pleistocene to Sub-Recent glacial landforms and fluvio-glacial.
2. The slide is located in a slope depression and drained by seasonal nala.
3. The landslide is geo-genic in nature exhibited with presence of highly open valley facing joints.

4. Area exhibits generally steep to moderately steep slopes dipping toward the valley. The debris slide is attributed weakened rock mass due to heavy rain and snow melt at the crown of the slide.

Recommendation

1. The landslide exhibit retrogressive nature and further retrogression upward may adversely affect the orchards and settlements. To contain further adverse effect, the exposed bare rock face can be shot-creted using steel reinforced shot-creting (SFRS) with provision of drainage holes
2. All the leakage of surface water to the slide zone through orchards should be stopped immediately by constructing proper lining drainages parallel to contour line above crown and diverting them away from the slide area to ensure no water ingresses into the slide zone.
3. Provision of wire mesh and catch fence may be installed at various levels to ensure the muck and heavy boulders do not affect the road.
4. Several critical loose boulders present on the slope area between crown and road can be removed manually and modified slope in to terraces for at least four levels using adequate retaining wall structure with a provision of wall holes. Followed by bio restoration in consultation with Botanist coupled with wire netting and rockfall/debris fall barriers.
5. The damp zones, which are the probable zones of seepage of water, should be properly treated and coated with an impervious layer of clay or cover with plastic sheet to avoid water ingress into the slide area.
6. The crown reaches may be stabilized by means of bio restoration measures.
7. The upslope must be monitored for development of cracks and the crack/ opening should be immediately sealed using impervious material and ensure that no surface water be allowed to drain/ discharge in those area.
8. Installation of sign boards/ banners at appropriately identified vulnerable locations for cautioning to the commuters.

8.6 Khab Slide, Pooh, Kinnaur District, Himachal Pradesh.

The study area falls in Pooh tehsil of Kinnaur district, Himachal Pradesh and falls in the Survey of India Toposheet No.53I/09. The site is located at EL \pm 2595 m MSL at Location

Latitude 31°48'38.00"N and longitude 78° 38'11.00"E along left bank of Sutlej River on NH-05 which is a strategically important road at the confluence of Sutlej and Spiti River.

Field assessment of landslide incidence area

The rock-slide area is located on the left bank of Sutlej River, constitutes a steep sun-facing hill slope as shown in Fig 26(a). The rock-fall, in fact rock wedge failures frequently occurs in the upper part of a major escarpment represented by highly jointed quartzite and phyllite of Morang Formation of Vaikrita Group intruded by Nako Granite (Fig 26 (b)).

The rocks are highly fractured due to different sets of joints transforming them in a distress rock mass, particularly the valley dipping joints and the foliation joints which leads to different wedge (J2 & J3) as well as planar (J1) failures in the area (Fig 26 (c) & (d))



Figure 26(a) Rock slide at Khab, Kinnaur



Figure 26(b) Large boulders along NH-05, Kinnaur



Figure 26(c) Wide open cracks and overhanging blocks at NH-05, Kinnaur



Figure 26(d) Wide open and persistent cracks at NH-05, Kinnaur

The rock mass exhibited three set of joints including the foliation joints which are as given in table 15.

Table 14. Details of joints characteristics around the landslide affected area at Khab, Kinnaur, Himachal Pradesh.

Joint Sets	Dip Amount & Dip Direction (degree)	Spacing (cm)	Aperture (cm)	Persistence (m)	Filling	Hydrological Condition
J ₁ (Foliation parallel)	25→40	70-80	.1-5	10-40	Clay	Dry
J ₂	65→240	60-70	2	15-40	Clay	Dry
J ₃	35→170	70-80	5	10-15	Rock fragment & clay	Dry

Kinematic Analysis

Khab Rock Slide

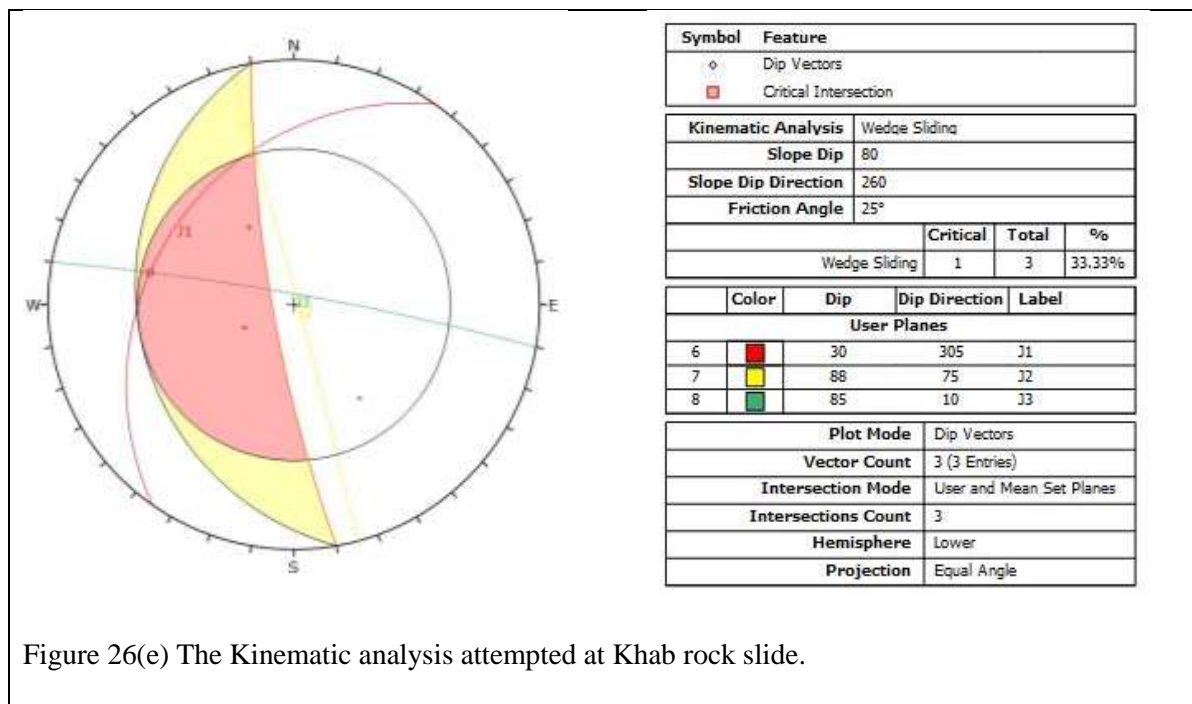


Figure 26(e) The Kinematic analysis attempted at Khab rock slide.

The Kinematic analysis has been attempted at Khab rock slide zone for graphically analyzing the orientations of structural elements by using stereographic projection techniques (Fig 26(e)). As per the Markland’s failure criteria, the J1-J3 planes satisfy wedge failure conditions.

The salient feature of the disastrous rock fall has been enumerated below-

1. The rock slide/planar failure occurred from the upper part of a major valley facing joint.
2. Sun-facing hill slopes are steeper, highly dissected, barren to sparsely forested and covered with loose to semi compact slope material scree aprons composed of small to boulder size rock fragments.
3. The landslide area exposes highly jointed quartzite rock of Morang Formation. Interbedded with Nako granites. The failure mechanism appears to be planar failure from jointed major escarpment composed of Morang quartzite.

Geoscientific Causes

The geoscientific causes worked out be rock slide occurred in highly jointed contact of Moorang quartzite and the Nako granites aggravated by seasonal fluvio-glacial and rain water related weathering and erosion. The unscientific extensive rock cutting due to construction of the National Highway without provision of any support to the loosely jointed rock mass also has led to the rock failure.

The Future Menace

The observations along the upslope revealed presence of lot of hanging blocks of quartzites and granites precariously disposed on the slope and in in view of the steep gradient of the upslope part, the recurrence of rock fall incidence cannot be ruled out.

Recommendations

1. Removal of precariously disposed rock mass from the source/trajectory area.
2. Scaling of remaining part of the hanging block/ rock bolting of the jointed blocks of the rock, as per the suggestion of the design engineer
3. Provision of shotcreting to provide strength to the highly jointed rock mass.

ANNEXURE-I

A NOTE ON THE MEETING HELD WITH THE DEPUTY COMMISSIONER, KINNAUR AND OTHER OFFICIALS DURING THE FIELD VISIT

During the course of field work along the Kalka-Khab Nation Highway-05, in parts of District Kinnaur (H.P), the field officer Lalit Mohan, Sr. Geologist & Shreyasi Mahapatra, Sr. Geologist held a meeting with Deputy Commissioner, Kinnaur, Ms. Torul S Raveesh at the DC office Reckong Peo on 28th November 2023. The DC Kinnaur was briefed about the work being carried out during the course of this investigation and some of the important observations along the NH-05 stretch of Kinnaur area were discussed which area as follows:

1. During the course of field work, one small natural rock tunnel near Chaura, Kinnaur along the NH-05 was observed along with the official of NH, where a rock slide had occurred during the current monsoon season. The locality is being developed as a tourist spot by local people, due to which a large number of tourists gathering could be seen, possibly making a stoppage for photographs along the NH-05 and for having snacks at a small restaurant in the vicinity of this spot. The road stretch has steep slopes exposing highly jointed granitic gneisses belonging to Jeori-Wangtu Gneissic Complex of Palaeo-Proterozoic age. Detailed kinematic analysis of joint planes have been discussed in the description part of Chaura Landslide in this report which primarily suggests that the area satisfies multiple wedge failure conditions and the surrounding slopes are highly susceptible to further rock sliding. Though, a signboard, alerting people of possible rock slide has been installed at this place, but the tourist crowd was found to be ignoring it and roaming around this zone. DC Kinnaur has been appraised about the situation and its criticality for further necessary action.
2. Regarding the Sector 26 landslide (Road subsidence) near Nigulsari, it has been conveyed that GSI has already carried out a detailed site-specific study in this location in the FS: 2021-22 and the relevant report has been already submitted to the district administration for implementing necessary remedial measures.
3. The situation at Nathpa Rock Slide location and its failure mechanism was discussed and it was conveyed that the necessary short term mitigation measures will be covered in the present report.

4. DC Kinnaur was of the opinion that the GSI should involve in the scrutiny of Geotechnical part of the Detailed Project Reports (DPR) of the locations which have been studied by this department at preliminary/ detailed stage. In this connection, she had requested the field officers to go through the DPR of slope stabilization work proposed at Nesang Village where GSI has made a preliminary study regarding the ground instability along the valley facing slopes of village. While examining the above mentioned DPR, it was found that, the slope stabilization work has been proposed by the HPPWD along the hill side of the approach road to the village, citing the recommendation at point no. 6 & 7 of the preliminary report submitted by GSI. Though, no slope stabilization measures have been formulated for treating the affected slopes along the downslope areas of village, where ground cracks have been observed during the field visit of GSI. The matter has been conveyed to the ADC, Pooch and DDMA officials during the meeting held on 29.11.2023. It has been conveyed that a copy of aforesaid DPR should be mailed to Director, Landslide Studies Division and Director, Engineering Geology Division, GSI Chandigarh, and their observations in this DPR should also be taken into account as they have made the site visit in affected area and carried out preliminary studies.
5. Deputy commissioner was appraised about the slope stability studies carried out by GSI at the district headquarter Reckong Peo. It was conveyed that as per the observations of field officers (authors of this report), the effective drainage arrangements around Reckong Peo town were lacking or not being maintained upto the satisfactory level, which is very crucial in terms of slope instability issues in this area. DC Kinnaur requested to hold a meeting with Executive Engineer, IPH Department stationed at Reckong Peo regarding this. On the very next day, a meeting was held with the SDO & JE of IPH Dept. as the Executive Engineer, IPH was unavailable, during which various issues regarding the effective drainage managements around Reckong Peo town were discussed. The GSI field officer, Sh. Qurban Ali Tariq, Senior Geologist also attended the meeting, who had carried out Meso Scale, Landslide Susceptibility Mapping around the Reckong Peo town during the FS: 2021-22. The officials of IPH Dept. Kinnaur conveyed that no master plan for effective drainage management of Reckong Peo town has been formulated till now. Previous studies have suggested that the slopes of Reckong Peo area comprise dominantly of thick fluvio-glacial deposits cover, which have already suffered slope failure incidences in the year 2010 (Kumar et. Al 2012). A large portion of Reckong Peo

town was subjected to distress and ground cracks were reported around ITBP ground, Degree Collage area and downslope of petrol pump area. A circular mode of failure in the fluvioglacial material has been interpreted in the aforesaid studies which got triggered due to recharging of slopes with flowing water. Regarding this, it has been suggested to the IPH Department officials to prepare a master plan for the drainage arrangements of Reckong Peo town for which, GSI can be consulted as and when required. It has been conveyed that the Irrigation water should only be channelised in the suitably designed concrete lined drains of sufficient capacity so that no overflow and seepage occur. Maintenance and clearance of chocked drains around Reckong Peo town should be the utmost priority. Sh. Qurban Ali Tariq, Senior Geologist observed that the field note of the preliminary studies of Sapni village landslide, which he himself has carried out during the FS: 2022-23 was missing in the DPR. He also pointed out that this DPR covers mitigation only for the stretches along the Baspa River for mitigating toe erosion and does not address issues of actual landslide affected slopes around Sapni village.

6. As desired by the Deputy Commissioner, Kinnaur, the authors of this report held a meeting with SDM, Nichar on 30th November 2023 and inquired about any slope stability issue in the areas under their jurisdiction. It was informed to the authors that the landslide related issues were along the National Highway only, which have been already covered during this visit.

ANNEXURE II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
DATYAR ALONG NH 05, DISTRICT SOLAN, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SOL/53B13/2023/01
2	State	Himachal Pradesh
3	District	Solan
4	Toposheet	53B13
5	Name of the slide	Datyar Slide
6	NH/SH/Locality	NH-05
7	Latitude	30°50'47.00"N
8	Longitude	76°59'43.00"E
9	Length	290m
10	Width	170m
11	Height	260m
12	Area	
13	Depth	5m
14	Volume	
15	Run out distance	100m
16	Type of Material	Debris
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	8 th – 11 th July 2023.
24	Geomorphology	Moderately dissected hill slope and steep road cuts.

25	Geology	<i>Sandstone and mudstone with minor clay bands of Dagshai Formation of Sirmur Group.</i>
26	Structure	Three prominent joint sets and one random set. S0 J1 30° → 330° J2 80° → 250° J3 75° → 180° (Valley dipping) J4 → 50° → 85°
27	Land use/ Land cover	Four lane National Highway along the Forest cover area.
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	Commuters using the NH
32	Live-stock loss	Nil
33	Communication	Valley side lane of NH washed out.
34	Infrastructure	Road stretch approx. 30-35m in length along with the retaining walls washed out. Kalka-Parwanoo Railway Track is passing approx. 50m above the NH.
35	Agriculture/forest/Barren	Forest cover
36	Geo-scientific causes	<ol style="list-style-type: none"> 1) Over Saturation of water within the fragile and loose material of slope forming material during heavy precipitation. 2) The absence of proper drainage network has played a crucial role in inducing the slope failure. 3) The steep slope having an inclination of approx. 45°-50° further facilitated the rapid movement of debris material and erosion of surrounding hill slope. 4) Toe cutting action by Ghaggar river further added to the damage.
37	Remedial measures	<ol style="list-style-type: none"> 1. Identifying the sound rock for foundation of erecting adequate retaining wall. 2. Provision of suitable retaining structure at the toe portion of the slope should be constructed in consultation with design engineers. 3. Proper Drainage management system should be implemented. Catch water drains or chute drains may be provided above the crown of the landslide to divert or channelize the water away from the slide area. 4. Geojute/Geotextile may be used to protect the overburden face from further weathering and erosion on the slope affected by the incidence. 5. The surrounding area susceptible to further slope failure along with the buffer zone may be identified for monitoring developments of new ground cracks or subsidence of land. The


		<p>cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area.</p> <p>6. Tilt meters to be installed in one or more locations of the retaining wall/building falling within zone of influence. It measures any change in slope inclination near cracks and areas of maximum anticipated rotational movement.</p>
38	Remarks, if any	<p>The Kalka-Shimla Railway Line is in a close vicinity of slide and any retrogression of steep road cuts in near future may affect the stability of this railway line.</p>
39	Photos. Sketch of Plan & section of the slide	
40	Summary/Abstract	<p>A debris slide triggered on 8th July 2023 after the extremely heavy and widespread rainfall event took place around many parts of Himachal Pradesh. The observations revealed the landslide to be a debris slide, which is a rotational failure presently triggered due to slope saturation. The landslide is active with its toe terminating in mid hill part. The area exhibits generally moderate to steep slope. The debris slide is attributed to weakened slope debris due to water ingress and subsequent slope saturation by heavy rain. One nala is present in the vicinity of slide, approx. 100m towards Shimla where the culvert has been choked by debris material during the same rainfall event. It appears that the heavily flowing run off rainwater has possible diverted from this nala to the nearby location which ultimately triggered the debris slide. During study of the satellite imagery, it was observed that the location of the landslide incidence during the construction of the four lane was used as a dumping site, wherein the loose unconsolidated material was dumped. The loose material during the unprecedented rainfall during the month of August, 2023 failed and led to complete collapse of a stretch of the National Highway. Necessary remedial measures including erection of appropriate retaining wall with utmost care of deep foundations</p>

		<p>upto the bed rock level has been suggested. The nearby nala needs to be properly dealt with where the culvert is found to be of smaller in size as compared to the amount of debris generated during the rainy season. A box culvert, comparative bigger in size can be installed to facilitate the unrestricted flow to debris material. The flat ground towards the valley side of NH along the nala has been prepared by dumping huge muck from the hill cuttings. Though a culvert has been installed for the drainage purpose but the natural drainage along this nala has definitely been obstructed, which is a matter of serious concern. This nala has very high discharge during the monsoons, therefore the amount of water needs to take care off. The toe portion of Datyar slide needs to be protected from the action of high discharge in the adjoining nala, as a loose overburden material which is possibly the dumping of muck.</p>
41	Pdf	
42	Landslide category II	

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
DIMPLE DHABA & AAA ALONG NH 05, DISTRICT SOLAN, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SOL/53B13/2023/01
2	State	Himachal Pradesh
3	District	Solan
4	Toposheet	53B13
5	Name of the slide	Dimple Dhaba & AAA Slide
6	NH/SH/Locality	NH-05
7	Latitude	30°53'12.00"N
8	Longitude	77° 0'17.00"E
9	Length	55m
10	Width	65m
11	Height	50m
12	Area	
13	Depth	
14	Volume	
15	Run out distance	
16	Type of Material	Debris
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	Initiated on 7 th July, 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Inter-banded Shale and sandstone of Subathu Formation.
26	Structure	Three prominent joint sets and one random set. S0 J1 35→ 40 J2 40→ 15


		J3 70→ 240 (Valley dipping)
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	Local residents below the road level and daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has subsided.
34	Infrastructure	Three building below road level, one lane of NH & electric poles.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	
37	Remedial measures	<ol style="list-style-type: none"> 1. Clearing out of the collapsed Dimple Dhabha building material from the slope 2. Cracks developed on the crown portion should be sealed by consulting geotechnical engineers. 3. Protection of surrounding slope from further ground water saturation is of the utmost requirement at this particular stage. Catch water drains or chute drains may be provided above the crown of the landslide to divert or channelize the water away from the slide area. Proper Drainage management system should be implemented around the settlements. 4. Provision of suitable retaining structure at the toe portion of the slope in consultation with design engineers. 5. Geojute/Geotextile may be used to protect the overburden face from further weathering and erosion on the slope affected by the incidence. 6. Area above the crown of landslide needs to be monitored for development of any new ground cracks. Under such conditions, the ground cracks need to be covered up effectively in order to avoid any further rain water percolation. The cracks must be sealed either by filling them with puddle clay or other impervious fill. Bentonite or other natural material to reduce further permeability

		<p>can be used so that surface water does not pond in the area.</p> <p>7. Since the overall area is covered with very thick debris/overburden, it should be ensured during nay new construction, that foundation in the soft ground does not undergo shear failure during or under the loading the structure especially in the saturated wet conditions.</p> <p>8. The Tell-tales crack monitoring gauge is also suggested to be installed between the cracks to observe the vertical and horizontal movement across a crack.</p>
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	
40	Summary/Abstract	<p>It was observed that there is creep movement for most parts along the hill slopes along which the road twirls. The evidences of creep movement such as tilted trees, bulging in retention structures/walls, differential settlements etc. were observed during the uphill and downhill trekking. It was found that the buildings were constructed over the unconsolidated debris material comprising silty sand matrix. The slope instability affected locations are in the form of a slip circular failure. The manifestation of the same on ground was in the form of arcuate subsidence zones prevailing at least at two levels as observed during field study. Several wide cracks were observed at the Dimple dhaba. The cracks were trending 25° and upto 6 -10 m long and 1m wide. The subsidence in the land was upto 3m. the dimple dhaba had completely collapsed due to the slide.</p>
41	Pdf	
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
TUTIKANDI, BANGALI BAGICHA LANDSLIDE IN SHIMLA URBAN,
DISTRICT SHIMLA, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Shimla
4	Toposheet	53E04
5	Name of the slide	Tutikandi, Bangali Bagicha Landslide in Shimla Urban Slide
6	NH/SH/Locality	NH-05, Shimla Bye Paas Road
7	Latitude	<i>N</i> 31° 5' 50" and
8	Longitude	<i>E</i> 77° 9' 13"
9	Length	80m
10	Width	30m
11	Height	60m
12	Area	
13	Depth	<5m
14	Volume	
15	Run out distance	100m
16	Type of Material	Debris
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Retrogressive
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	4 th August
24	Geomorphology	Moderately dissected hill slope.
25	Geology	Phyllite of Botli Formation of Jutog Group.
26	Structure	Four prominent joint sets


		J1 12→ 170 J2 40→ 40 J3 45→ 200 J4 75→ 90
27	Land use/ Land cover	Forest cover
28	Hydrological condition	Damp
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	Residents below the road level. Three people were injured.
32	Live-stock loss	07 cows dead and one cow shed damaged.
33	Communication	Shimla Bye Pass Road.
34	Infrastructure	Railing along the road
35	Agriculture/forest/ Barren	Forest along with Urban settlements
36	Geo-scientific causes	Shallow rotational failure triggered due to the super saturation of the overburden cover material.
37	Remedial measures	<ul style="list-style-type: none"> i. The newly created nalah must be channelized away from the slide zone. The water may be diverted to the already existing lined drainage along the right bank ii. Construction of proper lined drainage along hill side to arrest maximum infiltration of water surface water into distressed zone. It is also suggested that the trained drainage should be connected with the main Khad to avoid surface water discharge on the distressed slope iii. The broken drain/sewer line along with the agricultural pipe must be shifted to a suitable site. iv. Reconstruction of breast and retaining structures along the road with adequate filter and drainage, in particular, when constructed in debris filled mass. v. Vigilance must be maintained during monsoons regarding the safety of the dwellers of the habitants of the houses constructed along the 1st order streams vi. No further construction may be allowed in the first order stream.
38	Remarks, if any	

39	Photos. Sketch of Plan & section of the slide	 <p>own of slide at the road level</p>
40	Summary/Abstract	<p>The slide was primarily caused by oversaturation of the loose overburden material owing to the incessant rains and the blocked drain. The debris slide is attributed to weakened slope debris due to water ingress and subsequent slope saturation by heavy rain. The landslide is active having its toe terminating in mid hill part with its debris material running to the houses beneath. The landslide incidence caused deaths of 6 livestock (cows) and injury to several people. The cow shed located just below the slide zone was completely damaged. Many trees (Forest Numbered) were also uprooted. Shallow rotational failure triggered due to the super saturation of the overburden cover material. The creation of the new nalah along the steep slope will further widen during the successive monsoon season. Necessary remedial measures have been suggested to contain the road to cave in further which included Construction of proper lined drainage along hill side to arrest maximum infiltration of water surface water into distressed zone. It is also suggested that the trained drainage should be connected with the main Khad to avoid surface water discharge on the distressed slope.</p>
41	Pdf	
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
RAJVIR MOTORS LANDSLIDE IN SHIMLA URBAN,
DISTRICT SHIMLA, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Shimla
4	Toposheet	53E04
5	Name of the slide	Rajvir Motors Landslide in Shimla Urban Slide
6	NH/SH/Locality	NH-05, Shimla Bye Paas Road
7	Latitude	<i>31° 5'43.00"N</i>
8	Longitude	<i>77°10'13.00"E</i>
9	Length	40m
10	Width	50m
11	Height	30m
12	Area	
13	Depth	<5m
14	Volume	
15	Run out distance	50m
16	Type of Material	Debris
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Retrogressive
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	23 rd August 2023
24	Geomorphology	Moderately dissected hill slope.
25	Geology	Phyllite & schist of Panjerli Formation of Jutog Group.
26	Structure	Four prominent joint sets J1 35→ 60



		J2 70→ 230 J3 85→ 280
27	Land use/ Land cover	Forest cover
28	Hydrological condition	Damp
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	Residents below the road level.
32	Live-stock loss	-
33	Communication	CPWD link road & Shimla Bye Pass Road.
34	Infrastructure	Parking lot, Hyundai Showroom, Retaining wall.
35	Agriculture/forest/ Barren	Forest along with Urban settlements
36	Geo-scientific causes	Super saturation of unconsolidated overburden covered slopes due to extreme rainfall.
37	Remedial measures	<ul style="list-style-type: none"> i. Proper channelization for water to avoid its further ingress at the earliest away from the sliding zone. ii. The benching in uphill debris mass as well as in rock mass, may be carried out very carefully, scientifically along with their simultaneous effective stabilization. iii. The up-slope hill mass and village establishments must be put to frequent observations with regards to any ground signature of instability such as developments of tension crack, joint openings/ widening, land sinking, development of crack in building, collapse of soil along slope or nala, tilting of trees, sudden appearance or disappearance of surface stream or reduction in water volume etc. iv. Immediate filling of transverse and contour parallel tension cracks with appropriate impervious material immediately. v. Altering the geometry of the steep slope by flattening and benching along with draining out any ingressing nala or rain water. vi. Use of soil nailing, grouting, wire mesh draping, biotechnical slope stabilization measures (plantation of suitable trees with deep rooted species, application of geo-jute/geo-mats etc) in the slope debris mass of the uphill and downhill (road/ dump filling). vii. The suitable retaining structures must be provided with adequate filter and drainage, in particular, when constructed in debris filled mass.
38	Remarks, if any	


39	Photos, Sketch of Plan & section of the slide	
40	Summary/Abstract	<p>The slide was primarily caused by oversaturation of the unconsolidated overburden material owing to the incessant rains. The debris material charged with large boulders brought down by a flood like situation washing away a major portion of the CPWD road, retaining structures and vehicles on the downslope. The adjoining landmasses on right flank have also been disturbed due the incidence. It has been observed that the adjoining hill masses also suffered moderate landslides of smaller magnitude. It was observed that the area was still damp and the ground water was very shallow at the site. Landslide is a result of rotational mass failure occurred due to slope failure of unconsolidated slope material and saturation due to rainwater ingress and excessive erosion by the nalas. A retrogressive rotational failure is confirmed by presence of tension cracks at the crown of the slide as confirmed by the locals. The slide is retrogressive and enlarging in nature and confirmed by the development of tension cracks on the upslope. Remedial measures including proper channelization for water to avoid its further ingress at the earliest away from the sliding zone and the benching in uphill debris mass as well as in rock mass have been suggested.</p>
41	Pdf	
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LAND SUBSIDENCE
INCIDENCE AT COMELY BANK ROAD, ON NATIONAL HIGHWAY,
DISTRICT SOLAN, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	SHIMLA
4	Toposheet	53E04
5	Name of the slide	Comely Bank
6	NH/SH/Locality	NH-05
7	Latitude	31°06'27"N
8	Longitude	77°09'47"E
9	Length	-
10	Width	200 m
11	Height	-
12	Area	
13	Depth	5-7 m
14	Volume	
15	Run out distance	
16	Type of Material	Debris
17	Type of movement	Subsidence
18	Rate of movement	Slow
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	Initiated on July, 2020, reactivated on 14 th -15 th August 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Schist, quartzite and dolomite of Manal Formation belonging to Jutog Group

26	Structure	-
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall and dumping zone
30	Death of persons	Nil
31	People affected	daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	Connecting road for communication sinking
34	Infrastructure	Houses, parking lot, old school and road
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	<p>1. Prima facie it appears that the extensive rainfall had led to the super saturation of thick overburden material exposed in the area. A deep rotational failure has been apprehended which ultimately caused the ground to subside.</p> <p>2. The area lies in the close vicinity of a tectonically active zone where the rocks of Jutog Group are having a thrust contact with the rocks of Baliana Group. Though no insitu rock exposures have been observed around the landslide affected area, the impact of this thrust zone located in the vicinity of landslide can't be ruled out.</p>
37	Remedial measures	<p>1. The ground cracks need to be covered up effectively in order to avoid any further rain water percolation. The cracks must be sealed either by filling them with puddle clay or other impervious fill or some trenches can be excavated along the tension cracks and backfilled with the impervious material. Small quantities of bentonite or other natural material to reduce further permeability can be used so that surface water does not pond in the area. Impervious membrane may be used as an emergency or temporary measure.</p> <p>2. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. can be installed below the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions.</p> <p>3. Sufficient drainage arrangements must be provided along the affected slopes, especially along the Comely Bank Road. Catch water drains or chute drains may be provided above the crown of the landslide to divert runoff water.</p> <p>4. The drain water from individual houses must be channelized effectively to avoid any ground water saturation.</p> <p>5. Regular inspection and maintenance are required in case of</p>



		<p>continued movement, since it may cause previously sealed cracks to reopen. Therefore, in order to monitor small levels of ground creep, installation of a geodetic system may be considered at first in consultation with geotechnical engineers.</p> <p>6. The surrounding area susceptible to further slope failure along with the buffer zone may be identified and no new construction activity or slope modification work should be carried out in this zone.</p> <p>7. Provision of suitable retaining structure at the toe portion of the slope, i.e along the main drainage should be made in consultation with design engineers.</p>
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Damaged road stretch</p>  <p>Ground cracks</p>


		 <p>Cracks on houses</p>
41	Pdf	Attached
42	Landslide category	

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
INDIAN INSTITUTE OF ADVANCED STUDY AT,
DISTRICT SHIMLA, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SOL/53B13/2023/01
2	State	Himachal Pradesh
3	District	Shimla
4	Toposheet	53E/04
5	Name of the slide	Indian Institute of Advanced Study
6	NH/SH/Locality	Shimla Urban
7	Latitude	31°06'12"N
8	Longitude	77°08'28"E
9	Length	350 m
10	Width	250 m
11	Height	300 m
12	Area	
13	Depth	5m
14	Volume	
15	Run out distance	550 m
16	Type of Material	Debris
17	Type of movement	Subsidence
18	Rate of movement	Slow
19	Activity	Active
20	Distribution	Widening
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	14 th August 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Phyllite, schist and quartzite of Bhotli Formation belonging to Jutog Group

26	Structure	Three prominent joint sets and one random set. S0 J1 10° →N295° J2 80°→N80° J3 80° →N170° (Valley dipping)
27	Land use/ Land cover	Urban settlement.
28	Hydrological condition	Damp
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	
32	Live-stock loss	Nil
33	Communication	Communication road
34	Infrastructure	Garden area of IIS and retaining walls
35	Agriculture/forest/ Barren	Archaeological Building
36	Geo-scientific causes	1) Super saturation of loosely compacted ground mass present along the valley facing slopes during heavy precipitation. 2) The steep slope towards the Shiv Mandir side having an inclination of approx. 50°-60° further facilitated the rapid movement of debris material and erosion of surrounding hill slope. .
37	Remedial measures	1) At the western flank, a sound rock mass needs to be intercepted/Identified for the foundation of retaining structures. 2) Sufficient drainage arrangements should be made to channelize the water away from the slide area. Catch water drains or chute drains may be provided above the crown of the landslide to divert runoff water. 3) Provision of suitable retaining structure at the toe portion of the slope (road level) may be made in consultation with design engineers. 4) Geojute/Geotextile may be used to protect the overburden face from further weathering and erosion on the slope affected by the incidence. 5) At the southern flank towards the main entrance area, the surrounding area susceptible to further slope failure along with the buffer zone may be identified for monitoring developments of new ground cracks or subsidence of land. The cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area. 6) In order to monitor small levels of ground creep, installation of a geodetic system may be considered at first in consultation with site geologist and design engineers. 7) The further development of ground cracks need to be monitored

		<p>frequently.</p> <p>8) Tilt meters can be installed to monitor the retaining walls which are prone to any further tilting or failure.</p> <p>9) It is recommended to carry out detailed geotechnical studies around the premises of IIAS for deciphering the sub surface geology and the depth of bedrock. Suitable geophysical studies can be carried out in accordance with the site conditions; however, it should determine the depth of bedrock and thickness of overburden material</p>
38	Remarks, if any	
39	<p>Photos. Sketch of Plan & section of the slide</p>	 <p>Slope failure at the western flank of IIAS below which the Shiv Madir Slide had occurred in the month of August 2023.</p>  <p>Easterly facing affected zone.</p>

		 <p data-bbox="598 645 1385 683">Westerly facing affected zone</p>
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LAND SUBSIDENCE AT
VIDHAN SABHA TO ANNADELE HELIPAD ROAD IN SHIMLA URBAN,
DISTRICT SHIMLA, HP**


No	Field Observations	
1	Slide No (LS .No.)	HP/SOL/53B13/2023/01
2	State	Himachal Pradesh
3	District	Shimla
4	Toposheet	53E/04
5	Name of the slide	Vidhan Sabha
6	NH/SH/Locality	Shimla Urban
7	Latitude	31°06'27"N
8	Longitude	77°09'47"E
9	Length	200m
10	Width	150m
11	Height	200m
12	Area	
13	Depth	5m
14	Volume	
15	Run out distance	-
16	Type of Material	Debris
17	Type of movement	Subsidence
18	Rate of movement	Slow
19	Activity	Active
20	Distribution	Widening
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	14th-15th August 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Phyllite, schist and quartzite of Bhotli Formation
26	Structure	

27	Land use/ Land cover	Urban settlement along the Forest cover area.
28	Hydrological condition	Damp
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	Habitants
32	Live-stock loss	Nil
33	Communication	Communication road subsided
34	Infrastructure	Road stretch approx. 30-40m in length subsided Some cracks observed on buildings
35	Agriculture/forest/ Barren	Settlement and Forest cover
36	Geo-scientific causes	The most significant causative factor for the triggering and development of landslide is the continuous heavy rainfall leading to saturation of thick slope wash debris material/highly weathered rock and poor drainage system.
37	Remedial measures	<ol style="list-style-type: none"> i. Provision of sturdy retaining structures with staggered drains and weep holes at the hillside road level to prevent soil erosion. ii. Sealing of ground cracks with impervious material to minimize water infiltration and further damage. iii. Retrofit and reinforce existing structures in the village, including roads and buildings to improve their resistance to seismic events or ground movements thereby enhancing their structural integrity. iv. Installation of monitoring devices to constantly track ground movements, slope stability and soil moisture levels for timely intervention and hazard mitigation. v. Improve drainage system to efficiently manage surface water runoff, mitigating the risk of slope destabilization. Design proper drainage channels to divert water away from vulnerable regions.
38	Remarks, if any	

39	<p>Photos. Sketch of Plan & section of the slide</p>	
	<p>Minor slides and creeping in trees</p> 	
	<p>Damage to the foundation of the house and retaining wall</p>  <p>Subsidence observed along road section</p>	
41	Pdf	
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
MOHAN MEKIN LANDSLIDE ON NATIONAL HIGHWAY,
DISTRICT SOLAN, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Solan
4	Toposheet	53F01
5	Name of the slide	Mohan Mekin Landslide
6	NH/SH/Locality	NH-05
7	Latitude	30°55'24.00"N
8	Longitude	77° 6'40.00"E
9	Length	60 m
10	Width	150 m
11	Height	55 m
12	Area	
13	Depth	3-5 m
14	Volume	
15	Run out distance	80m
16	Type of Material	Debris
17	Type of movement	Slide & Subsidence
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	Initiated on 7 th July, 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Balani Formation and Infra Krol Formation of Baliana Group
26	Structure	Three prominent joint sets and one random set.

		<p>S0 J1 22° →N60° J2 60°→N230° J3 78° →N210° (Valley dipping)</p>
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	PHC below the road level and daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has subsided.
34	Infrastructure	Oone lane of NH, retaining & electric poles.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	<ol style="list-style-type: none"> 1. Construction of road within highly weathered material without any sound foundation. 2. Construction of retaining wall without proper sound rock foundation. 3. Slope saturation and slush generated from seepage of water.
37	Remedial measures	<ol style="list-style-type: none"> 1. The Nallah needs to be trained and channelized properly. 2. Identifying the sound rock for foundation of erecting adequate retaining wall. 3. Concrete retaining structure all along the debris cone material with adequate drainage holes. 4. Afforestation should be done to stabilize the debris cone.
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Morphometry of Mohan Mekin Landslide, Solan Dist. Himachal</p>

Pradesh.



Contact zone between Infra Krol Fm. And Blaini Fm.





Damaged culverts and transmission lines at Mohan Mekin Landslide, Solan Dist. Himachal Pradesh.

41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LAND SUBSIDENCE
INCIDENCE AT MANSAR LAND SUBSIDENCE ON NATIONAL HIGHWAY,
DISTRICT SOLAN, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Solan
4	Toposheet	53F01
5	Name of the slide	Mansar Landslide
6	NH/SH/Locality	NH-05
7	Latitude	30°56'33.00"N
8	Longitude	77° 7'45.00"E
9	Length	-
10	Width	300 m
11	Height	-
12	Area	
13	Depth	5-7 m
14	Volume	
15	Run out distance	-
16	Type of Material	Debris
17	Type of movement	Subsidence
18	Rate of movement	Slow
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	Subsided in July, 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Rock mass constituting of argillaceous shale interbedded with limestone of Mahi Formation of Krol Group



26	Structure	Three prominent joint sets and one random set. S0 J1 15° → N210° J2 70° → N80° J3 65° → N25° (Valley dipping)
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	Daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has subsided.
34	Infrastructure	One lane of NH, retaining & electric poles.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	<ul style="list-style-type: none"> i. Steep slope of the order of ~45° ~75° below road level. ii. Construction of NH-05 within loose debris material and vertical pressure exerted to the slope from perennial heavy vehicular movement might be another factors leading to bulging and tilting of erected gabion walls below road level. iii. Extensive gully and rill erosion in a distressed slope indicate absence of proper channelized lined drainage above. iv. The Kuhl/artificial nala constructed parallel to the road (hill side) for draining of waters is clogged at certain portion of the subsidence zone which overflows along NH-05 and contribute towards sinking of the road. v. Several seepages point are identified in this zone which could lead to piping out of finer sand, silt and clay material of the slope are also likely to contribute to subsidence. vi. Saturation of loosed debris slope material during incessant rainfall events can reduces the shear strength of above material.
37	Remedial measures	<ol style="list-style-type: none"> 1. The cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area. 2. Appropriately designed retention structures at suitably identified locations at lower level as support to failing mass with weep holes at different levels. 3. In crown portion, along the main sinking zone at road level, the constructed lined drainage is observed to be choked This need to be cleaned at regular intervals of time to collect maximum surface runoff water from upslope at the earliest to arrest any

		<p>further infiltration of surface water into distressed zone.</p> <p>4. On the upslope of the slide an orchard and nursery plantation practices is observed. Thus, proper channelized lined drainage must be assured to avoid excess infiltration /percolation/saturation of surface water within debris material. Also the aligned drainage for discharge of surface water should be avoided into the distressed slope</p> <p>5. Several seepages were present at different level on the distressed zone and it is observed that it could lead to piping out of finer slope material slowly leading to continue sinking/subsidence of the slope. Therefore, it is highly recommended to carry out Geophysical survey to determine the ground water condition in consultation with Hydrologist to what best it can be done to reduce the seepage effect on the distressed slope</p>
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Subsiding National Highway at Mansar, Solan Dist. Himachal Pradesh showing wide open cracks</p>  <p>Damp zones and orchards on upslope of Mansar slide</p>
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
KARIBANGLA LANDSLIDE ON NATIONAL HIGHWAY,
DISTRICT SOLAN, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Solan
4	Toposheet	53F01
5	Name of the slide	Karibangla
6	NH/SH/Locality	NH-05
7	Latitude	30°59'28.35"N
8	Longitude	77°5'34.20"E
9	Length	70 m
10	Width	180 m
11	Height	65 m
12	Area	
13	Depth	3 m
14	Volume	
15	Run out distance	80m
16	Type of Material	Rock
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Translational failure
23	History	Initiated on July, 2020
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Shale and siltstone of Chhaosa Formation belonging to Shimla Group


26	Structure	Three prominent joint sets and one random set. So J1 35°→N J2 65°→210° J3 60°→160°
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has blocked
34	Infrastructure	One lane of NH,.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	<ol style="list-style-type: none"> 1. Prima facie, it appears that the distressed slopes along the 150m road stretch of National Highway 05 exposing very poor rock maas have slided due to the supersaturation by extreme rainfall. 2. The anthropogenic activity in form of back cutting for construction has initiated the slope instability. 3. The landslide affected area lies in the close vicinity of NW-SE trending Krol Thrust zone which is an important tectonic feature passing approx. 1.5 kms. S of the affected area. The ground signatures of this thrust zone in the form of disturbed/unstable terrain and a poor rock mass condition can be observed.
37	Remedial measures	<ol style="list-style-type: none"> 1. Provision of suitable light weight retaining structures at the road level along with proper drainage arrangements should be made in consultation with design engineers. 2. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. can be installed above the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions. 3. Catch water drains or chute drains must be provided above the crown of the landslide to divert runoff water. 4. Sufficient drainage arrangements must be provided along the affected slopes between the road and the under-construction house. 5. The nearby settlements below the road level needs to be monitored for any ground carcks or any damage to the building. The drain water from individual houses must be channelized

		effectively to avoid any ground water saturation. 6. Above the crown portion, the cracks must be sealed either by filling them with clay or other impervious fill like Bentonite to reduce further permeability to ensure surface water does not pond in the area.
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Poor rock mass exposed along the road cut section</p>  <p>Affected road stretch and downslope area</p>
41	Pdf	Attached
42	Landslide category	

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF ROCKFALL INCIDENCE AT
NANGAL DEVI LANDSLIDE ON NATIONAL HIGHWAY,
DISTRICT SHIMLA, HP**


No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Shimla
4	Toposheet	53E8
5	Name of the slide	Nangal Devi
6	NH/SH/Locality	NH-05
7	Latitude	31° 7'11.00"N
8	Longitude	77°20'5.00"E
9	Length	65 m
10	Width	100 m
11	Height	60 m
12	Area	
13	Depth	3-5 m
14	Volume	
15	Run out distance	80m
16	Type of Material	Rock
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Translational failure
23	History	Initiated on Monsoon of 2020
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Quartzite and slate of Basantpur Formation

26	Structure	Three prominent joint sets and one random set. So J1305°→225°N J2 70°→330° J3 80°→75°
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	daily commuters using the NH, habitants
32	Live-stock loss	Nil
33	Communication	One lane of NH has blocked
34	Infrastructure	One lane of NH,.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	The failure mechanism appears to be planar failure from jointed major escarpment. 3) The geoscientific causes worked out be rock slide occurred in highly jointed contact aggravated by seasonal fluvio-glacial and rain water related weathering and erosion.
37	Remedial measures	<ol style="list-style-type: none"> 1. The crown of landslide exhibits retrogressive in nature and further retrogressive upward may adversely affect the settlements. To contain further adverse effect, the exposed bare rock face can be shotcreted using steel reinforced shotcreting (SFRS) with provision of drainage holes 2. Several critical loose boulders present on the slope area between crown and toe can be removed manually followed by wire netting and rockfall/debris fall barriers 3. Rock mesh net with proper support can be suggested to stable the rock mass of the slide area. 4. Several vertical cracks/opening was present along the steep slope, this need to be sealed with impervious material at the earliest and arrest any further surface water percolation to those cracks by constructing lined drainage (contour parallel) above cut

		slope
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Morphometry of Nangal Devi Slide</p>
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LAND SUBSIDENCE
INCIDENCE AT HIMFED PETROL PUMP, ON NATIONAL HIGHWAY,
DISTRICT SHIMLA, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	SHIMLA
4	Toposheet	53E04
5	Name of the slide	Himfed Petrol Pump
6	NH/SH/Locality	NH-05
7	Latitude	31° 7'37.00"N
8	Longitude	77°20'22.00"E
9	Length	800
10	Width	200 m
11	Height	-
12	Area	
13	Depth	5-7 m
14	Volume	
15	Run out distance	
16	Type of Material	Debris
17	Type of movement	Subsidence
18	Rate of movement	Slow
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	Initiated on July, 2020, reactivated on 14 th -15 th August 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Quartzite and slate of Basantpur Formation
26	Structure	-

27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	Connecting road for communication sinking
34	Infrastructure	road
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	1. Prima facie it appears that the extensive rainfall had led to the super saturation of thick overburden material exposed in the area. A deep rotational failure has been apprehended which ultimately caused the ground to subside.
37	Remedial measures	<ol style="list-style-type: none"> 1. Removal of loose and precarious boulders along the road bench to enhance safety. 2. Provision of sturdy retaining structures with staggered drains and weep holes at the hillside road level to prevent soil erosion. 3. Sealing of ground cracks with impervious material to minimize water infiltration and further damage.
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Road subsidence at Himfed Petrol Pump</p>



Ground cracks along Road at Himfed Petrol Pump



Alternate bands of quartzite and slate of Basantpur Formation



Gentle downslope of slide area having seepage zones.

41	Pdf	Attached
42	Landslide category	

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
RAHIGHAT-KIARTOO LANDSLIDE ON NATIONAL HIGHWAY,
DISTRICT SHIMLA, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Shimla
4	Toposheet	53E08
5	Name of the slide	Rahighat-Kiartoo Slide
6	NH/SH/Locality	NH-05
7	Latitude	31° 7'42.00"N
8	Longitude	77°20'56.00"E
9	Length	50 m
10	Width	40 m
11	Height	65 m
12	Area	
13	Depth	3 m
14	Volume	
15	Run out distance	90m
16	Type of Material	Debris
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Translational failure
23	History	13 th August 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Quartzite and slate of Basantpur Formation belonging to Shimla Group

26	Structure	
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	daily commuters using the NH, Habitants
32	Live-stock loss	Nil
33	Communication	One lane of NH has subsided
34	Infrastructure	One lane of NH,.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	<ol style="list-style-type: none"> 1. Prima facie, it appears that the slide had triggered due to the supersaturation of thick overburden cover material exposed along the steep valley facing slope. 2. The high discharge along one of the major drainage situated at the site had facilitated the favourable hydrological conditions during the heavy rainfall.
37	Remedial measures	<ol style="list-style-type: none"> 1. The damaged portion of drainage needs to be channelized effectively to avoid any ground water saturation. 2. The concrete retaining walls should be constructed only after affirming the suitable bed rock at foundation level. In present scenario, deep foundations are strongly recommended as a thick overburden cover is dominant in the area. 3. The toe portion of slide needs to be effectively dealt with, as further deterioration of downslope areas can affect the stability of retaining structures to be reconstructed. For this check dams should be constructed in the downslope areas. 4. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. can be installed below the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions.

- 5. Sufficient drainage arrangements must be provided along the affected slopes, especially along old NH-05. Catch water drains or chute drains must be provided above the crown of the landslide to divert runoff water.
- 6. The drain water from nearby houses must be channelized effectively to avoid any ground water saturation.

38 Photos. Sketch of Plan & section of the slide



The stretch of washed out link road.

Failed retaining walls Damaged public toilets

Steep Slope

Old NH-05


Failed retaining structures and damaged houses along the old NH-05

		 <p>The damaged culvert</p>  <p>Main drainage across the slided area</p>
39	Remarks, if any	
41	Pdf	Attached
42	Landslide category	
42	Landslide category	

**POINT GEO-PARAMETRIC ATTRIBUTES OF LAND SUBSIDENCE AT BARAUNI
NALA ON NATIONAL HIGHWAY,
DISTRICT SHIMLA, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Shimla
4	Toposheet	53E/11
5	Name of the slide	Barauni Nala
6	NH/SH/Locality	NH-05
7	Latitude	31°29'6.00"N
8	Longitude	77°41'26.00"E
9	Length	-
10	Width	600 m
11	Height	-
12	Area	
13	Depth	8-10 m
14	Volume	
15	Run out distance	-
16	Type of Material	Debris
17	Type of movement	Subsidence
18	Rate of movement	Slow
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Rotational failure
23	History	Reactivated on 11 th July 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.
25	Geology	Pale white quartzite and phyllite of Manikaran Formation of Rampur Group

26	Structure	-
27	Land use/ Land cover	Urban
28	Hydrological condition	Flowing
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	Daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has subsided.
34	Infrastructure	One lane of NH, retaining & electric poles.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	<ol style="list-style-type: none"> 1. Prima facie, it appears that the distressed slopes along the 850m road stretch of National Highway 05 have resulted primarily due to the toe cutting/ erosion by the perennial stream of Barauni Nala. Under such a scenario, the surrounding slopes exposing loose to moderately compacted debris material and rolled boulders have become highly prone to further slope failure. 2. The landslide affected area lies in the close vicinity of a thrust zone where the rocks belonging to Manikaran Formation of Rampur Group are thrust over the high-grade rocks of Jeori-Wangtu Gneissic Complex. The ground signatures of this thrust zone in the form of disturbed/ unstable terrain can be very well visualised in the field. 3. Apart from National Highway-05, the affected area above the road stretch is exposed to anthropogenic activities in form of stone quarries at multiple locations, which is a matter of serious concern regarding the stability of surrounding slopes.
37	Remedial measures	<p>Recommendations</p> <ol style="list-style-type: none"> 1. The actively flowing Baruni Nala needs to be channelized effectively to avoid any ground water saturation. Provision of suitable retaining structure at the toe portion of the slope, i.e along the main drainage should be made in consultation with design engineers. 2. Suitable geotextiles/ geosynthetic material such as geonet, geogrid, geo-composites etc. can be installed below the road level as they provide enhanced drainage, protection, reinforcement, filtration and barrier functions. 3. Sufficient drainage arrangements must be provided along the affected slopes, especially along road stretch towards Rampur. Catch water drains or chute drains must be

		<p>provided above the crown of the landslide to divert runoff water.</p> <ol style="list-style-type: none"> 4. The settlements below the road level towards Jhakri side needs to be monitored for any ground cracks or any damage to the building. The drain water from individual houses must be channelized effectively to avoid any ground water saturation. 5. In order to monitor small levels of ground creep, installation of a geodetic system may be considered at first in consultation with site geologist/ geotechnical engineers. 6. The surrounding area susceptible to further slope failure along with the buffer zone may be identified and no new construction/ mining activity or slope modification work should be carried out in this zone. 7. In view of the instability conditions along this road stretch, possibilities for realigning the road through the safer/ stable slopes must be taken into consideration. To avoid this unstable zone, the right bank of River Sutlej can be explored for an alternate road connectivity. 8. The area is highly fragile in nature and bears a complex geological problem due to the presence of NW-SE trending thrust zone and thus formulating any long-term remedial measure needs a Detailed Geological & Geotechnical Investigation.
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Panaromic view of the landslide affected stretch to NH-05</p>
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF ROCKFALL INCIDENCE AT
JEORI LANDSLIDE ON NATIONAL HIGHWAY,
DISTRICT SHIMLA, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Kinnaur
4	Toposheet	53E14
5	Name of the slide	Jeori
6	NH/SH/Locality	NH-05
7	Latitude	31°32'19.20"
8	Longitude	77°47'1.91"
9	Length	35 m
10	Width	4m
11	Height	25 m
12	Area	
13	Depth	2-5m
14	Volume	
15	Run out distance	80m
16	Type of Material	Rock
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Translational failure
23	History	Initiated on July, 2021 and reactivated on 14 th August 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.



25	Geology	gneiss of Jeori Wangtu Gneissic complex
26	Structure	Three prominent joint sets and one random set. So J1 70°→120°N J2 60°→10° J3 50°→255°
27	Land use/ Land cover	Urban
28	Hydrological condition	Flowing
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has subsided
34	Infrastructure	One lane of NH,.
35	Agriculture/forest/ Barren	Urban
36	Geo-scientific causes	The failure mechanism appears to be planar failure from jointed major escarpment composed of gneiss of Jeori Wangtu Gneissic complex. 3) The geoscientific causes worked out be rock slide occurred in highly jointed contact of gneiss aggravated by seasonal fluvio-glacial and rain water related weathering and erosion.
37	Remedial measures	<ol style="list-style-type: none"> 1. Scaling and removal of precariously resting the loose rock blocks along the slope immediately. 2. Appropriately designed retaining structures of suitable size and dimension at road level and near toe of the slide. 3. Appropriately designed guide wall along river below to prevent erosion. 4. Proper channelization for water in adjoining affected slope on either side to avoid its further ingress at the earliest. 5. Rock bolting followed by shotcrete in the poor rock mass to stabilize the failed rock mass 6. Vigil should be maintained by concerned authorities and local residents regarding slope instability phenomena/ development of slope instability signatures (e.g. bulging, cracks, land slips etc.) & timely intimation to concerned authority. 7. Installation of rain gauge stations, proper recording and maintaining by State Govt./Dist. Admin. would be very useful in future. 8. Appropriately designed rock bolting at crown portion to avoid further rock failure

38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	<p>Jointed rocks of Jeori Wangtu Gneissic complex loosely hanging over National Highway-05 Downslope of Jeory slide showing toe cutting by Satlej river and deep gully erosion Damaged retaining structures along the slide zone. boulders of geniss causing slide Subsidence in road section and flowing nala on road Caved in potion of NH-05</p>
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF ROCKFALL INCIDENCE AT
CHAURA LANDSLIDE ON NATIONAL HIGHWAY,
DISTRICT KINNUAR, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Kinnaur
4	Toposheet	53E14
5	Name of the slide	Chaura
6	NH/SH/Locality	NH-05
7	Latitude	31°32'19.20"
8	Longitude	77°47'1.91"
9	Length	30 m
10	Width	5 m
11	Height	25 m
12	Area	
13	Depth	2-5m
14	Volume	
15	Run out distance	30m
16	Type of Material	Rock
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Translational failure
23	History	14 th August 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.

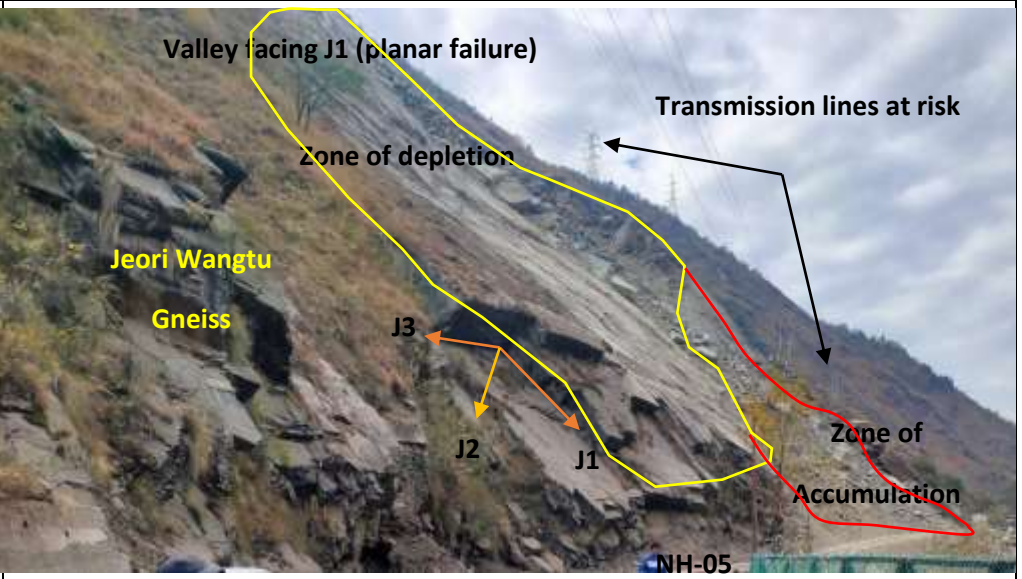
25	Geology	gneiss of Jeori Wangtu Gneissic complex
26	Structure	Three prominent joint sets and one random set. So J1 70°→120°N J2 60°→10° J3 50°→255°
27	Land use/ Land cover	Urban
28	Hydrological condition	Flowing
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has subsided
34	Infrastructure	Tunnel
35	Agriculture/forests/ Barren	Urban
36	Geo-scientific causes	1) The failure mechanism appears to be planar failure from jointed major escarpment composed of gneiss of Jeori Wangtu Gneissic complex. 2) The geoscientific causes worked out be rock slide occurred in highly jointed contact of gneiss aggravated by seasonal fluvio-glacial and rain water related weathering and erosion.
37	Remedial measures	1. Removal of precariously disposed rock mass from the source/trajectory area. 2. Scaling of remaining part of the hanging block/ bolting of the blocks of rocks whose joints are opened. 3. Rock bolting with wire mesh to hold the rock from the wedge or planar failure. 4. Rock face can be shotcreted using steel reinforced shotcreting (SFRS) with provision of drainage holes

		<p>5. During rainy season, the traffic movements under strict onsite and offsite slope monitoring.</p> <p>6. Installation of sign boards/ banners at appropriately identified vulnerable locations for cautioning to the commuters.</p>
38		 <p>Highly jointed rocks of Jeori Wangtu Gneissic complex loosely hanging over National Highway-05 near old slide zone of 2021.</p> <p>Highly jointed rocks of Jeori Wangtu Gneissic complex loosely hanging over National Highway-05 near Chaura tunnel.</p>  <p>Vertical open joints with cracks near Chaura tunnel.</p> <p>Three set of joints near Chaura tunnel.</p>
39	Photos. Sketch of Plan & section of the slide	
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
NATHPA LANDSLIDE, DISTRICT KINNAUR, HP**

No	Field Observations	Description
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Nathpa
4	Toposheet	53E/14
5	Name of the slide	Nathpa
6	NH/SH/Local ity	NH-05
7	Latitude	31°33'44.31"N
8	Longitude	77°58'55.46"E
9	Length	180 m
10	Width	150 m
11	Height	160m
12	Area	
13	Depth	3-5 m
14	Volume	
15	Run out distance	250m
16	Type of Material	Rock
17	Type of movement	Fall
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Translational failure
23	History	Initiated on 27 August, 2023

24	Geomorphology	Moderately dissected hill slope and steep road cuts.																								
25	Geology	Jeori Wangtu Gneissic Complex																								
26	Structure	<p>Three prominent joint sets.</p> <table border="1"> <thead> <tr> <th>Sr. No.</th> <th>Dip (degree)</th> <th>Dip Direction (degree)</th> <th>Persistence (m)</th> <th>Apperture (cm)</th> <th>Hydrological Condition</th> </tr> </thead> <tbody> <tr> <td>J₁</td> <td>55</td> <td>10</td> <td>6-7</td> <td>10-20</td> <td>Damp</td> </tr> <tr> <td>J₂</td> <td>70</td> <td>280</td> <td>3</td> <td>5</td> <td>Damp</td> </tr> <tr> <td>J₃</td> <td>30</td> <td>215</td> <td>5</td> <td>3</td> <td>Damp</td> </tr> </tbody> </table>	Sr. No.	Dip (degree)	Dip Direction (degree)	Persistence (m)	Apperture (cm)	Hydrological Condition	J ₁	55	10	6-7	10-20	Damp	J ₂	70	280	3	5	Damp	J ₃	30	215	5	3	Damp
Sr. No.	Dip (degree)	Dip Direction (degree)	Persistence (m)	Apperture (cm)	Hydrological Condition																					
J ₁	55	10	6-7	10-20	Damp																					
J ₂	70	280	3	5	Damp																					
J ₃	30	215	5	3	Damp																					
27	Land use/ Land cover	Urban																								
28	Hydrological condition	Damp and water following at crown and belly of slide																								
29	Triggering Factor	Extreme rainfall																								
30	Death of persons	Nil																								
31	People affected	daily commuters using the NH																								
32	Live-stock loss	Nil																								
33	Communication	NH																								
34	Infrastructure	Road, SJVNL Dam reservoir and input, Railings, electrical transmission lines, apple orchards at crown.																								
35	Agriculture/forest/ Barren	Urban																								
36	Geo-scientific causes	<ol style="list-style-type: none"> The slide is located in a slope depression and drained by seasonal nala. The landslide is geo-genic in nature exhibited with presence of highly open valley facing joints. Area exhibits generally steep to moderately steep slopes dipping toward the valley. The slide is attributed weakened rock mass due to heavy rain and snow melt at the crown of the slide. 																								

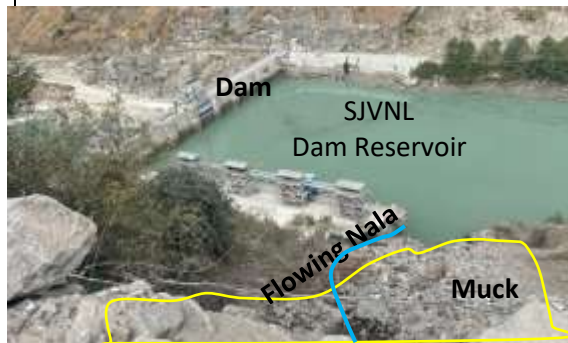
37	Remedial measures	<ol style="list-style-type: none"> 1. The landslide exhibit retrogressive nature and further retrogression upward may adversely affect the orchards and settlements. To contain further adverse effect, the exposed bare rock face can be shot-creted using steel reinforced shot-creting (SFRS) with provision of drainage holes 2. All the leakage of surface water to the slide zone through orchards should be stopped immediately by constructing proper lining drainages parallel to contour line above crown and diverting them away from the slide area to ensure no water ingresses into the slide zone. 3. Provision of wire mesh and catch fence may be installed at various levels to ensure the muck and heavy boulders do not affect the road. 4. Several critical loose boulders present on the slope area between crown and road can be removed manually and modified slope in to terraces for at least four levels using adequate retaining wall structure with a provision of wall holes. Followed by bio restoration in consultation with Botanist coupled with wire netting and rockfall/debris fall barriers. 5. The damp zones, which are the probable zones of seepage of water, should be properly treated and coated with an impervious layer of clay or cover with plastic sheet to avoid water ingress into the slide area. 6. The crown reaches may be stabilized by means of bio restoration measures. 7. The upslope must be monitored for development of cracks and the crack/ opening should be immediately sealed using impervious material and ensure that no surface water be allowed to drain/ discharge in those area. 8. Installation of sign boards/ banners at appropriately identified vulnerable locations for cautioning to the commuters.
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	 <p>Morphometry of Nathpa Rock Slide, Kinnaur District, Himachal Pradesh</p>



Crown of Nathpa Rock Slide, Kinnaur District, Himachal Pradesh



Toe of Nathpa Rock Slide, Kinnaur District, Himachal Pradesh



SJVNL dam reservoir below Nathpa Slide



Open and persistent Valley facing joints



Damage to SJVNL dam



Loose boulders at the landslide site.

40 Summary


On 27th of August, 2023 a huge slide took place in the NH-05 just above the SJVNL HEP at Nathpa in Kinnaur District, HP disrupting the traffic. The observations revealed the landslide to be a rock slide predominantly activated due to slope saturation on rain-water ingress. The slide area is very critical since the slide zone is located just above the reservoir and inlet of the SJVNL HEP. The area exhibits steep to moderately steep slopes. The rock slide/planar failure occurred from the upper part of a major valley facing joint. The failure mechanism appears to be planar failure from jointed major escarpment composed of gneiss of Jeori Wangtu Gneissic complex. The geoscientific cause of the slide worked out to be rock slide occurred in highly jointed contact of gneiss aggravated by seasonal fluvio-glacial and rain water related weathering and erosion. The presence of highly jointed fragile rock mass with large open joints with overhanging rock blocks acts as a catalyst to engrave the size of

		<p>landslide. The steep escarpment is the source for rock material, which during heavy rainfall, destabilizes the zone further. The bed rock mostly comprises rocks of Jeori-Wangtu gneiss. The rocks are highly jointed and dipping N265 that is towards the valley.</p> <p>The Kinematic analysis has been attempted at Nathpa rock slide zone for graphically analysing the orientations of structural elements by using stereographic projection techniques. As per the Markland's failure criteria, the J1-J2 planes satisfy wedge failure conditions while the valley dipping J1 plane satisfies planar failure condition.</p>
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF ROCKFALL INCIDENCE AT
PANVI LANDSLIDE ON NATIONAL HIGHWAY,
DISTRICT SOLAN, HP**


No	Field Observations	
1	Slide No (LS .No.)	HP/SHI/53E04/2023/
2	State	Himachal Pradesh
3	District	Kinnaur
4	Toposheet	53E14
5	Name of the slide	Panvi
6	NH/SH/Locality	NH-05
7	Latitude	78° 0'50.00"E
8	Longitude	31°32'22.00"N
9	Length	90 m
10	Width	30 m
11	Height	65 m
12	Area	
13	Depth	3 m
14	Volume	
15	Run out distance	80m
16	Type of Material	Rock
17	Type of movement	Slide
18	Rate of movement	Rapid
19	Activity	Active
20	Distribution	Widening & enlarging
21	Style	Single
22	Failure mechanism	Translational failure
23	History	Initiated on 11 July, 2023
24	Geomorphology	Moderately dissected hill slope and steep road cuts.

25	Geology	gneiss of Jeori Wangtu Gneissic complex
26	Structure	Three prominent joint sets and one random set. So J1 55°→5°N J2 80°→220° J3 70°→185°
27	Land use/ Land cover	Urban
28	Hydrological condition	Dry
29	Triggering Factor	Extreme rainfall
30	Death of persons	Nil
31	People affected	daily commuters using the NH
32	Live-stock loss	Nil
33	Communication	One lane of NH has blocked
34	Infrastructure	One lane of NH,.
35	Agriculture/forests/ Barren	Urban
36	Geo-scientific causes	The failure mechanism appears to be planar failure from jointed major escarpment composed of gneiss of Jeori Wangtu Gneissic complex. 3) The geoscientific causes worked out be rock slide occurred in highly jointed contact of gneiss aggravated by seasonal fluvio-glacial and rain water related weathering and erosion.
37	Remedial measures	<ol style="list-style-type: none"> 1. Removal of precariously disposed rock mass from the source/tectory area. 2. Scaling of remaining part of the hanging block/ bolting of the blocks of rocks whose joints are opened. 3. Concrete/ masonry retaining structure all along the road stretch with adequate drainage holes. 4. Rock bolting with wire mesh to hold the rock from the wedge or planar failure. 5. Provision of catch fence and ditches to hold the loose falling boulders. 6. During rainy season, the traffic movements under strict onsite and offsite slope monitoring. 7. Installation of sign boards/ banners at appropriately identified vulnerable locations for cautioning to the commuters

38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	
Morphometry of Panvi Bridge Rock Fall, Kinnaur District, Himachal Pradesh		
41	Pdf	Attached
42	Landslide category	II

**42-POINT GEO-PARAMETRIC ATTRIBUTES OF LANDSLIDE INCIDENCE AT
KHAB, DISTRICT KINNAUR, HP**

No	Field Observations	
1	Slide No (LS .No.)	HP/KINN/53E04/2023/
2	State	Himachal Pradesh
3	District	Kinnaur
4	Toposheet	53I/09
5	Name of the slide	Khab Slide
6	NH/SH/Locality	NH05
7	Latitude	31°48'38.00"N
8	Longitude	78°38'11.00"E
9	Length	~15m
10	Width	~20m
11	Height	~12m
12	Area	
13	Depth	2-3m
14	Volume	
15	Run out distance	~5m
16	Type of Material	Rock
17	Type of movement	Slide
18	Rate of movement	Very Rapid
19	Activity	Active
20	Distribution	Retrogressive
21	Style	Single
22	Failure mechanism	Shallow translational Failure
23	History	
24	Geomorphology	Dissected hill slope
25	Geology	Interbedded quartzite and schist of Morang Formation intruded by Nako Granite.

26	Structure	
27	Land use/ Land cover	Barren land
28	Hydrological condition	Dry
29	Triggering Factor	Anthropogenic activity for road cutting.
30	Death of persons	Nil
31	People affected	Local villagers and daily commuters.
32	Live-stock loss	Nil
33	Communication	NH-505
34	Infrastructure	
35	Agriculture/forest/ Barren	Barren
36	Geo-scientific causes	Steep road cutting for road widening Inadequate slope support
37	Remedial measures	Rock bolting, Shotcrete, scaling of the upslope area.
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	
40	Summary/Abstract	The rock-fall area is located on the left bank of Satluj River, constitutes a steep sun-facing hill slope. The rock-fall, in fact rock wedge failures frequently occurs in the upper part of a major escarpment represented by highly jointed quartzite and phyllite of Morang Formation of Vaikrita Group intruded by Nako Granite.

		The rocks are highly fractured due to different sets of joints transforming them in a distress rock mass, particularly the valley dipping joints and the foliation joints which leads to different wedge (J2 & J3) as well as planar (J1) failures in the area.
41	Pdf	
42	Landslide category	II