हिमाचल प्रदेश केन्द्रीय विश्वविद्यालय
CENTRAL UNIVERSITY OF HIMACHAL PRADESH
[Established Under Central Universities Act 2009]

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To

The Secretary
Revenue cum Disaster Management
State Disaster Management Authority
Shimla

Sub: Submission of Preliminary landslides investigations report as per notification no Rev (DMC) (f) 11-09/2021- LM Department of Revenue (DM cell), Govt of Himachal Pradesh.

Dear Sir,

Please find attached the preliminary report as per notification for the slide zones that trigger in 2023 monsoon in Kangra and Chamba District.

With Kind Regards

Prof Ambrish Kumar Mahajan

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A REPORT

ON

PRELIMINARY INVESTIGATIONS OF LANDSLIDES ZONES IN KANGRA AND CHAMBA REGION AS PER NOTIFICATION NO REV (DMC) (F) 11-09/2021- LM DEPARTMENT OF REVENUE (DM CELL), GOVT OF HIMACHAL PRADESH.

Submitted to

STATE DISASTER MANAGEMENT AUTHORITY

GOVERNMENT OF HIMACHAL PRADESH

By

PROF. AMBRISH KUMAR MAHAJAN

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Email: akmahajan@rediffmail.com

DATE: 26TH February 2024

PRELIMINARY INVESTIGATIONS OF LANDSLIDES ZONES IN KANGRA AND CHAMBA REGION AS PER NOTIFICATION NO REV (DMC) (F) 11-09/2021- LM DEPARTMENT OF REVENUE (DM CELL), GOVT OF HIMACHAL PRADESH.

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The 2023 monsoon season in Himachal Pradesh has witnessed a significant rise in both human casualties and infrastructure damage compared to previous years. Although, intense and prolonged rainfall is a primary factor contributing to the situation in the western Himalayan state this year, however unplanned infrastructure development, increasing haphazard urbanization with poor drainage system and sewerage system have also played a crucial role.

Presently the this hilly state of Himachal Pradesh has gradually recovered from a tumultuous monsoon season, but still lot of habitants are residing in tents due to facts that their houses have been damaged to large extents leaving them unsuitable for the habitation. The financial repercussions of the monsoon havoc have surpassed all previous records with financial loss in the current monsoon season has reached Rs. 86 billion (Rs. 8,679 crore), nearly 8.5 times more than the average monsoon season loss over the previous six years, according to official data.

The recent surge in landslide occurrences, particularly in August and September, across districts such as Shimla, Mandi, Kullu, Chamba, Sirmaur, and Kangra in Himachal Pradesh, highlights the urgent need for a scientific understanding of this natural hazard phenomenon. Situated within the intricate geological conditions of the Kangra-Chamba region, both old and new slide zones have become activated. While historical data on these activities is limited, elderly residents have confirmed the presence of land fissures and previous slide movements in various zones

The Himalayan region is known for its active tectonics, with three major tectonic features running along the foothills of the Himalayas. Continuous northeastward movement and accumulated strains contribute to seismic and aseismic movements between these thrust zones. Recent observations indicate heightened activity within these tectonic zones, coinciding with prolonged periods of intense rainfall, particularly evident in the Kangra region where all slides occurred on August 14, 2023

Given the threat of tectonic changes to the Himalayan terrain, it is imperative to conduct action research to ascertain the root causes of the escalating landslide incidents and implement mitigation measures. This may involve adapting land use patterns based on factors such as geology, tectonism, fluvial geomorphology, and climate change-induced rainfall

According to local residents, numerous slide zones have developed land fissures in the upper reaches, contributing to the formation of scarps and significant lateral movement of landmasses ranging from meters to tens of meters. To comprehensively assess both districts, fieldwork has been planned, including surveys in Kangra and Chamba districts, covering various identified slide zones and locations.

District Kangra		Chamba District
Dheera	Parmar Nagar to Kaluna	Annai village, Close to Dramman in Bhatiyat constituency Kamladi Kali Dhar, close to Lahru, Bhatiyat Brampala –just 100 m north of Kalidhar towards Chowari Keru pahad (Tunnu Hatti)
Dehra sub division	Dhanger Village	
Jawalamukhi	Ambada of Tehsil Khundiyan Chounki, Dodru sub Tehsil Lagru Village Bhatal khurd, Mannu of sub the Majeen	Chamba- Tissa Road Churah (MDR-85) Pangola Nala Tissa Bridge Junas ghar (Tarela-Boundary-Mangli Road)

		Churah- Nagkrot-khaduga thalli road Langera ghar
Jawali	Anuhi, Niangal	Bharmaur Road Kashmiri mohalla Bagga (NH 15A) Lothal (NH 15A)
Nurpur	Jaunta, Ladauri and Minjhgran	
Nagrota Bagwan	Sarotri and Palera	
Palampur	Garhthulli	

Landslides region of Kangra districts

The contemporary surface morphology of the Kangra Re-entrant is characterized by a distinctive arrangement of (sub) parallel ridges running northwestward, interspersed with wide, relatively flat valleys that run parallel to these ridges. This topographical pattern is particularly evident in the southern segment of the Fold-Thrust Belt (FTB) region, situated between the Himalayan Frontal Thrust (HFT) and the Jwalamukhi Thrust (JMT). Here, the ridges exhibit a nearly consistent northwest-to-southeast elongation, closely mirroring the orientation of the HFT (Fig.1). As one moves northward from the JMT, while the ridge-valley arrangement persists, there is a noticeable curvature likely corresponding to the strike of the Main Boundary Thrust (MBT). This section of the terrain presents a distinct surface expression, with less prominent features due to the masking effect of Quaternary alluvial deposits and fan formations originating from adjacent mountain ranges. Additionally, the topography in this region is shaped by the interaction between tectonic forces and surface processes, notably influenced by climatic factors (Dey et al., 2016). The JMT serves as a significant tectonic boundary, delineating the Sub-Himalayan wedge, with its activity primarily understood through neo-tectonic investigations and terrace dating (Singh et al., 2012; Mukherjee, 2015; Dey et al., 2016)

Among the key topographic parameters influencing the taper of the Sub-Himalayan wedge, the forward slope of the modern topographic envelope ('a') emerges as crucial. For the Kangra reentrant, the current topographic slope 'a' has been determined to be $0.9° \pm 0.2°$ through analysis of topographic maps and Digital Elevation Models (Singh et al., 2012)

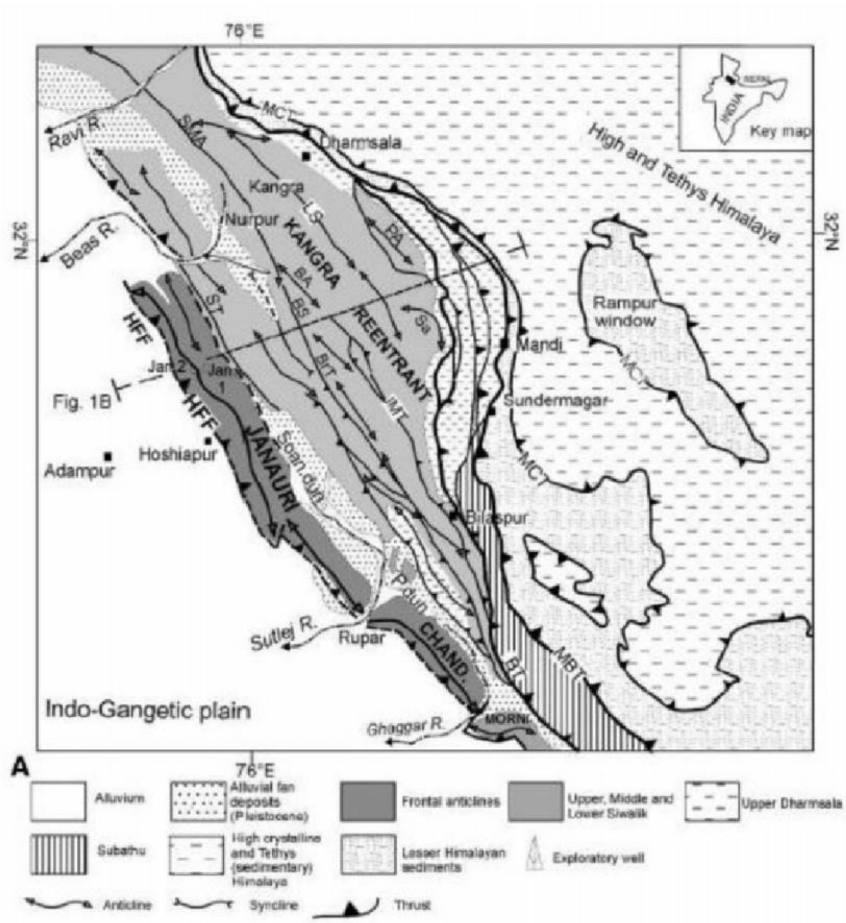

Fig.1 Geological map of Kangra re-entrant region covering all landslide zones triggered during 2023 monsoon.

The sites situated within the Dehra, Nurpur, and Jawalmukhi tehsil areas of Kangra district predominantly consist of Middle Siwalik rock formations characterized by buff to grey-colored sandstone. This entire region is geologically active due to movements along the Jawalamukhi Thrust and other transverse features present in the vicinity. The Sub-Himalayan zone, known as Siwalik, comprises molasses sediments sourced from the emerging Himalayas, deposited in elongated formations within a narrow foreland basin (Mukhopadhyay and Mishra, 1999). The Sub-Himalayan Kangra Basin is delineated to the north by the Main Boundary Thrust (MBT) and to the south by the Jwalamukhi Thrust (Dey et al., 2016)

In Dehra Tehsil, for instance, the village of Danger lies to the south of the Jawalamukhi Thrust, while sites in Khundian Tehsil of Jawalamukhi tehsil are situated north of the Jawalamukhi Thrust. Conversely, all sites within Nurpur tehsil, such as Minjgran, Jaunta, Anuhi, and Laduri, lie south of the Jawalamukhi Thrust. South of the MBT, various faults displace the Siwalik strata, with occasional visibility of the Himalayan Frontal fault where it intersects the surface of the Siwalik strata. However, more commonly, it functions as a blind thrust fault, resulting in strain release manifested through anticline formation, causing upward folding of rock layers (Powers et al., 1998)

The Siwalik formations are further classified into three sub-groups: Lower Siwalik, composed of sandstone and mudstone alternations transitioning into sand-dominated successions; Middle Siwalik, featuring medium to coarse-grained sandstone, conglomerates interbedded with mudstone, and large conglomerates; and Upper Siwalik, characterized by large conglomerates (Kumar et al., 2004). The Siwalik Group comprises a sedimentary sequence of conglomerates, sandstones, and shales exceeding 5000 meters in thickness, accompanied by nearly equal proportions of piedmont plains and hills (Yadav et al., 2015). Alluvial fans represent significant depositional features in the Kangra region (Srivastava et al., 2009), with the sedimentary cover exceeding 6000 meters in thickness (Gokaran et al., 2002). As per notification no. rev (DMC) (f) 11-09/2021- l department of revenue (DM cell), Govt of Himachal Pradesh from SDMA to conduct preliminary investigation, the investigation were started during the month of August from Parmar nagar sites in Dheera village and later after the receipt of letter from DM cell investigation started in December from village Dhangar, Dehra Tehsil and completed the sites from Kangra and Chamba region in the end of January 2024. Although the subject for preliminary investigation to identify sites for further investigation but considering the needs of the hour some of the sites have been completed in details and in other recommendation have been given for mitigation measures or for detailed investigation.

LANDSLIDES SITES AND THEIR DESCRIPTIONS OF KANGRA DISTRICT

Parmar Nagar , Dheera

A Preliminary survey had been carried out in Parmar Nagar, (Dheera-Nora region) on 24th August, 2023 by Central University of Himachal Pradesh, Dharamshala in consultation with District Kangra administration authority. In compliance with the Central University's commitment to continuous innovative research and community engagement, the university is acting as a helping hand in carving a path towards a safer as well as more informed future for the vulnerable region's inhabitants. Some glimpses of Parmar Nagar , Dheera.

As the drone-based LiDAR technology has emerged as a transformative tool in disaster research and mapping. Therefore, in the regions of Himachal Pradesh, where natural disasters are becoming increasingly frequent and intense and areas are unapproachable due to forest cover and clear line of sight, the Central University is taking pioneer efforts in the use of Drone-based LiDAR technology for carrying out a landslide survey and its efficacy for landslides investigation in compliance with the Drone policy of Himachal Pradesh 2022. The policy has emphasized the usefulness of the Drones in this hilly state with respect to disaster management real time monitoring for mapping of impacted zones, therefore this survey was a contributory effort in this direction too. The drone integrated with LiDAR becomes even more transformative, offering several advantages over traditional ground-based and airborne LiDAR techniques, however it has been observed that the Drone based Lidar survey must be accompanied with Terrestrial survey so that a slide zones can be properly investigated. This is because of the fact the drone based Lidar survey can only provide general slope of the area, elevational level and its variation, which cannot be provided by Terrestrial Lidar survey as general overview of the area so identifying individual slide and its parameters needs terrestrial Lidar survey. This technology is quite helpful in providing high resolution data, detailed 3D models which aids in the identification of terrain deformations, erosion patterns, also in identifying potential landslide scarps development zones.

During the survey, the Drone was programmed to fly over three main selected zones (decided on the basis of on-spot preliminary field observations). The drone-based LiDAR technology has advantages over the traditional survey methods in areas covered with forest, high slope angle, area located on ridges and in such areas where it is difficult to reach by Human beings. And line of sight is not clear. For example, Drones has the ability to fly over remote and inaccessible areas by human for the efficient data collection in less time in comparison to the Terrestrial Lidar survey methods where struggle involved for capturing accurate data in densely forested or challenging terrains is huge and often time-consuming process as well. Fig.2-4 shows the LiDAR survey is being setting up in Parmar nagar.

Fig. 2 Showing LiDAR Receiver setup placed at Parmar Nagar, Dheera-Nora Region during the preliminary survey by Central University of Himachal Pradesh Team.

Fig3 showing LiDAR Receiver setup placed at Parmar Nagar

Fig 4 Showing Drone programming for the Survey

Fig 5 showing damage scenario after landslide at Parmar Nagar, Dheera-Nora region

During the field investigation, three main scarps zones have been identified and the data has been collected for the all using both physical investigation and Lidar survey. There has been extensive damage reported in this area, numerous houses have been collapsed, the agricultural land found subsided and caused devastation to crops (Fig.5-6).

Fig 6 (a) and 6 (b) showing damages caused to the houses during the landslide incident in Parmar region. The development of cracks in the walls and floor indicated subsidence cracks.

There are 3 main scarps identified during the investigation, all were having circular scarp and rotational types slide on a very loose alluvial lithology. The lithology mainly comprises of alluvial soil (soil with cobble, small quarzitic boulder and pebbles). In the first slide zone almost 12 houses were collapsed due to subsidence of the landmass by 18-20 ft. This was due to continuous rain fall in the past months which have oversaturated the soil. At the same time house hold water from wash rooms and toilets get infiltrated into the soil since their constructions which have also paved the ways for the slide along the slip surface. Each family of six persons daily uses approximately 500 lt of water from wash rooms and toilet and it means daily 6000 lt of water goes directly into the soil (alluvial soil) which is much more than the infiltration due to rain fall. However, due to porous nature of the soil the area could sustain sliding in the past because water seeps downs the slope due to high porosity nature of the gravelly soil. However, this year's continuous rain fall since April 2023 has led to over saturation of the soil and allows the landmass to subside along the slope angle (steep slope angle > 65^0). Thus, the soil loses its frictional strength and moved along the slope. Secondly the Nalla flowing at the toe of the village also added to movement of the landmass because of removal of material from the toe area. Due to heavy rainfall in the past three months, the soil has achieved saturation level and resulted in water logging condition. The steep slope angle and trend of the contours decides the scarp zone which gave rise to the present shape and disastrous scenario in that region. According to the preliminary field observation, the first slide one near the main Parmar Nagar is not suitable for any residential purpose any more (Fig. 4-5). At the same time the second zone where one house had developed wide cracks also falls within the scarp zone and found to be unsuitable for the residential accommodation as the land mass may move any time this year or in subsequent years due to the slope angle and heavy burden of the material which has already moved by few meters (Fig 7).

Fig. 7 Shows the scarp in the second slide zones and house with in the slide zone.

The third zone which is on extreme left of the Parmar Nagar has slided the landmass by 15-18 ft but the scarp has taken a turn before a building located in the region. The contour map develop suing Lidar in this indicate slope and the slide has followed the contours (Fig. 7). There is no serious threat to this building at present as the contours have taken a turn towards the east from the corner of that house (Fig.8). However, further detailed studies are required to be done to furnish complete reports of the third slide zone, which may require detailed investigation on geotechnical and geophysical ERT and seismic survey of the slide zone. The Lidar survey report is still awaited as it needs three four days for processing which will be submitted on its arrival. Hope the administration may be benefitted by the preliminary investigation and suggestions provided and will help to provide assistance to the local communities.

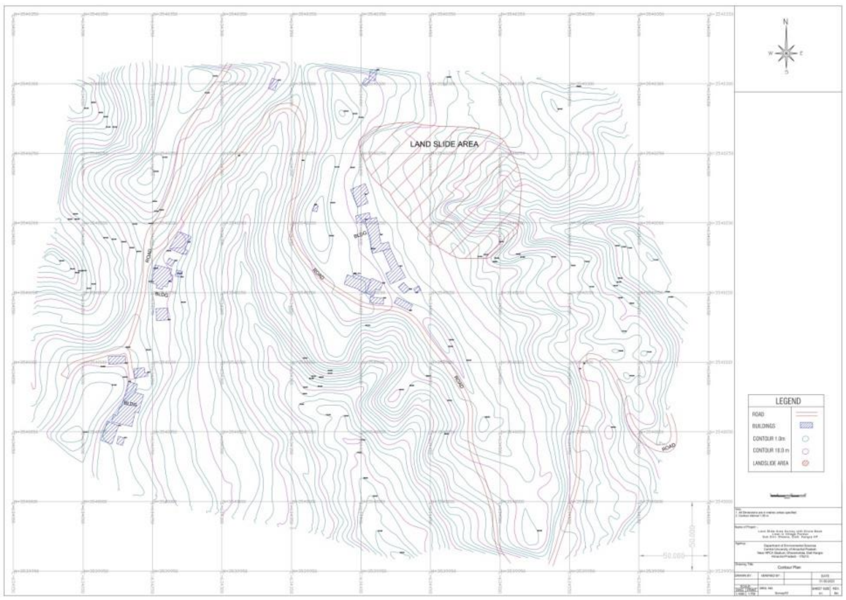

Fig.8 Shows the contour map landslide portion of slide zone 3 with contours of the Parmar Nagar

The field investigations have revealed that the scar was developed on the crest part and lot of water was accumulated near the scar indicating saturation level, although the soil has very good permeability due to gravelly soil (Fig.9 & 10). The slide has followed the contour. This has been validated using LiDAR survey as well. The heavy rain fall during July –August 2023 has increase the moisture content in the soil and the toe erosion have allowed the mass to move downslope due to gravitation force along the slip surface. The increased water content decreases the frictional strength of the soil (rich in clay and pebbles) allow the mass to subside. At the same time increasing urbanisation in the region has increased the moisture content in the landmass due to sewerage system which had already saturated the soil and heavy rainfall has only trigged the slide. Thus in soil gets subsided by 15-20 m down slopes and causing damage to the residential areas. At the same houses located closes to the Parmar Nagar on western side sustain the damage as the soil under this houses was not much saturated as compared to the villages where more than 10-15 families were residing.

Fig 9 showing full panoramic view of landslide event and subsequent land subsidence at site no 3

Fig. 10. Showing development of wide fissures in the agricultural land with titling of trees indicating deeper slip surface.

So the major causes of landslides in Parmar nagar were:

1. Poor Drainage system and Natural drainages are blocked by construction activity.
2. Increasing water saturation due to Sewerage system
3. Heavy rain fall
4. Toe erosion.

Recommendation:

1. To protect the area, drainage system needs to be improved, divert all water to follow the contour

2. There should be proper sewerage system in place and

3. A Parmar Nagar resident needs to be relocated.

4. To protect the land from toe erosion detailed survey is required for proper mitigation measures to be suggested.

5. Detailed investigation are required for mapping the whole region in terms of tectonics and depth of slip surface using geophysical, geological and geotechnical investigations.

Sarotri village, Nagrota Bagwan Tehsil

This site is located at Baloona village on road head side (at coordinates 320.27' N and 760.19'49" E), in which retaining wall of the houses was found displaced downslope on August 14, 2023(Fig.11). The movement was attributed to the steep slope angle, poor frictional strength of the soil and continuous rainfall. The retaining wall, constructed by the owner, proved inadequate given the slope angle and the loose, gravelly soil lithology, leading to its failure under the combined influence of gravity and heavy rainfall. Actually the load of the retaining wall was quite high and it was on the crest of the slope, which itself increased the load on the soil and slope underneath. Despite the soil's poor water retention capacity, its strength is also compromised.

Recommendation: To safeguard the area, a recommendation is to install 5-6 bench retaining walls downstream from the riverbank. The lower retaining walls should be constructed from concrete, extending their length along both sides of the hillock followed by Gabion wall to have enough porosity for water to move.

Additionally, two more slides were identified along the roadside, attributed to heavy rainfall, lithology, and slope angle. This section of the National Highway requires protection by erecting bench retaining walls, again preferably constructed from concrete, extending from the lower side to the upper portion Although the soil exhibits very poor retention capabilities, the continuous rainfall in preceding months has caused wide fissures to develop in the upper portion. These fissures likely accumulated water, facilitating mass movement downhill

Recommendation: To safeguard the area, a recommendation is to install 5-6 bench retaining walls downstream from the village path. The lower retaining walls should be constructed from concrete, extending their length along both sides of the hillock followed by Gabion wall to have enough porosity for water to move.

Fig. 11 Shows the lithology of the slide zone, characterized by gravelly soil, is evident in the displacement of the retaining wall observed on the upper right-hand side, which occurred due to the combination of heavy load and rainfall on August 14, 2023. The upper left photo illustrates the slope angle and pattern, while the lower picture depicts a slide along the National Highway in the same village, just a few meters downstream. Once more, the inability of the lithology to withstand the high moisture content in the gravelly soil resulted in a loss of frictional strength, leading to downslope.

Gurhthulli, near Paror, Palampur Tehsil

The sites is situated at coordinates 320 03’ 21.89” N and 760 27’ 04.71” E, to the south of Paror village in Tehsil Palampur, this location experienced damage to houses due to waterlogging. The heavy rainfall resulted in the accumulation of water, which flowed towards the houses due to the contour and slope angle directing its path. Complicating matters, there was no existing drainage system to divert the water away from the houses. Consequently, water became trapped on the rear side of the concrete structures, particularly affecting areas with weaker lower portions (Fig.12). Conversely, nearby mud houses with sturdier foundations were better equipped to withstand the pressure of the waterlogging. However, the concrete buildings bore the brunt of the flooding. To mitigate the risk of future waterlogging incidents, it is crucial to install a proper drainage system at the rear of the houses to redirect water away from the structures.

Fig. 12 Shows the damage cause to the houses in Gurthali village a) shows the slope angle and ridge from where water came after heavy rain fall b) the back side of the houses where water was blocked, the mud houses could sustain the pressure but concrete houses could not sustain the water pressure due to soft storey at the bottom c and d) damage cause especially removal of lower portion of concrete house and havoc caused by blocked water in the down side agricultural land in front of the houses.

Recommendation: Proper drainage system needs to be planned to avoid blockage of any water behind the houses along the slope. .

DHANGER VILLAGE, DEHRA SUB DIVISION

Located approximately 25 km northeast of Guler railway station (at coordinates 320 01' 51.971''N and 760 10' 06.209'' E) and north of Haripur village, Village Dhanger was severely affected during the recent monsoon season. A scar has been observed on the hillock, leading to the downward movement of the entire landmass of the village. The area is characterized by debris material and abundant moisture, evident from the presence of springs

The displacement of the upper scar was initiated by movement from the toe region and tectonic disturbances, resulting in the displacement of buildings by several feet and causing damage to houses, village pathways, and extensive cracks in concrete walls (Fig.13 &14). The landslide is of a rotational nature. Residents reported observing wide cracks in the northern part of the hillock prior to the landslide movement, possibly indicating tectonic activity. Given the tectonic activity in the frontal part of the Himalayas, the role of tectonic disturbance cannot be discounted in the region.

Residents also noted that this slide had been active in the past but remained dormant for some time before being reactivated during the recent monsoon season, triggered by heavy rainfall on August 14, 2023. The slide, located on the footwall of the Jawalamukhi Thrust, suggests the involvement of non-tectonic factors. Heavy rainfall acted as a triggering agent, while tectonic movement and the presence of alluvial material along with hill slopes played significant roles in destabilizing the landmass. Once saturated, the alluvial material loses its strength and moves downslope, contributing to the landslide.

Fig. 13 a) Subsidence of retaining wall of the village path b) rugged and uneven slope due to displacement of material c) subsidence crack on back of house and d) damage to the cemented path of the village. All these features are developed due to deeper slip surface and movement along that surface.

Fig.14 Uprooting of trees and displacements of roads and it's downwards movement suggesting deeper slip surface b) Development of cracks in walls suggesting movement direction

Causes:

High intensity rainfall and poor drainage system; in place sewerage system and blockage of Natural drainages by construction activity and neo-tectonic activity.

Recommendation:

- This slide **needs to be studied in detail in respect of tectonics, estimating slip surface depth and it geometry and situation of material and its erosion level at toe area** using both geophysical, geotechnical and geological studies.
- Improving drainage system in the region and filling of land fissures with soil uphill will not allow the water to percolate along the slip surface and protect the slide. Since the debris material is

underlain by Middle Siwalik rocks which act as slip surface to so we need to avoid water enter along the landmass.

- Further the water from springs which is being spread in landmass should be channelized to follow the natural drainage.
- Sewerage system in the village needs to be taken care to avoid directed infiltration of water from houses to landmass which otherwise reached the slip surface, The rain fall only trigged the slide but otherwise the condition of sliding had been developed by our poor drainage system and sewerage system.

ANUHI VILLAGE (JAWALI TEHSIL, DISTT KANGRA)

The landslides in the Nurpur area occur within the Middle Siwalik belt, characterized by grey-coloured sandy sandstone, with much of the slides involving debris material except for Anuhi village. Across all sites, wide fissures have developed uphill, accompanied by movement along the toe region. While neo-tectonic activity is primarily responsible for most of the activity, heavy rainfall serves as a triggering agent at all sites (Fig 15&16). The slides predominantly exhibit rotational characteristics, except in Anuhi village where sandy rocks have separated apart due to water accumulation in fissures developed earlier in the sheet like bedrock. Local residents report that they have seen wide fissure in the rock along which the rock get displaced. It was also reported that theses fissures in Anuhi village originated during the 1905 Kangra earthquake. Presently, wide and deeper fissures have also seen developed behind residences of Mr. Moti Ram and Pawan Kumar's, posing a potential threat to the residents. The sandy nature of the hillock (weathered middle Siwalik Rocks) exacerbates the risk.

Additionally, the village's drainage and sewerage system require improvement to mitigate landmass movement. Further, toe erosion due to increased mining activity accelerated the mass movement and allows the landmass to move downslope. In Kangra district, all slides occurred on August 14th, indicating the potential role of aseismic tectonic movement. Geomorphological changes along the river side, including vertical slope modification to high-angle slopes due to toe cutting and mining activities, have contributed to landmass movement in the Anuhi village area. Excavation of material from the toe region and diversion of river courses due to mining activities have led to toe erosion and sliding of the entire landmass uphill.

Fig. 15 Sandstone rocks get displaced along the fissure and caused disastrous impact in the village. All houses located on this portion of the sheet like rock also displaced.

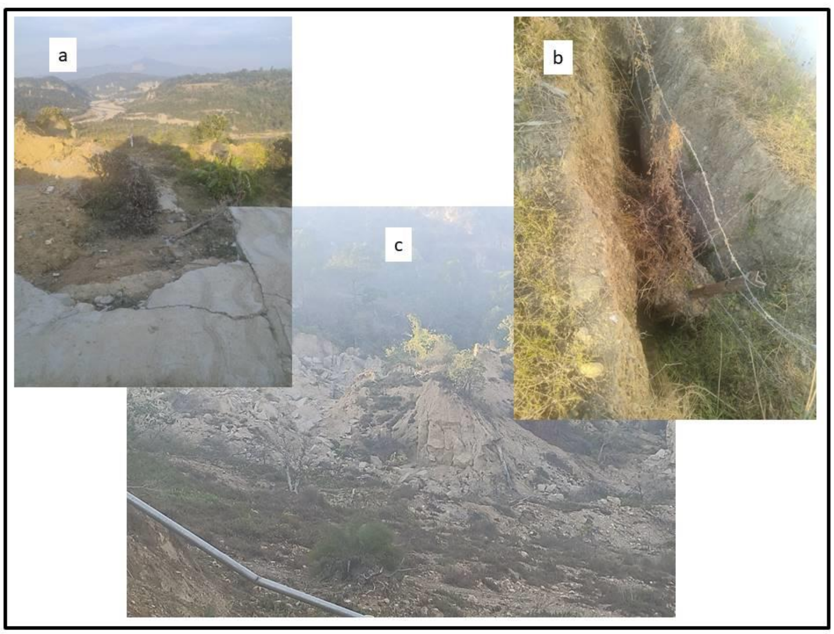

Fig. 16 a) Image depicts damage to the cemented road due to poor drainage system and b) development of wide fissure which is reminder for the next disaster. Similar features were developed on the on the displaced mass as noticed by local residents c) displaced material from the main mass and slope angle of the slide zone.

Causes: Neo-tectonic activity 2) increased mining activity 3) poor drainage system 4) and of course high intensity rain fall which trigger the slide.

Recommendation: Needs to protect the toe region from mining activity, avoid the houses from house hold water to enter into the slide mass and have proper drainage system to avoid water to enter into the sandstone rock fissures to protect the land.

NIANGAL VILLAGE (SOLDA SLIDE), JAWALI TEHSIL, KANGRA DISRICT (Detailed investigation)

The Soldha slide zones fall to the north of Niangal village district Kangra, form a part of the Bhed watershed, and fall in SOI toposheet no 52D/3 (Fig.1). This slide zone is situated in the sub-humid climate of the Kangra region thus, experiences maximum rainfall during the monsoon season, spanning from July to September. The Soldha landslide zone is an integral part of the Bhed Khad watershed, where all tributaries converge into the Beas River basin. It falls within the sub-humid regime, receiving an annual rainfall of up to 1750 mm, primarily concentrated in the monsoon months. Extending over 0.78 km along the displaced hillock, the landslide zone covers an area of 0.25 km², exhibiting altitudinal variations from 715 m at the toe to 977 m at the scarp zone (Fig.17)

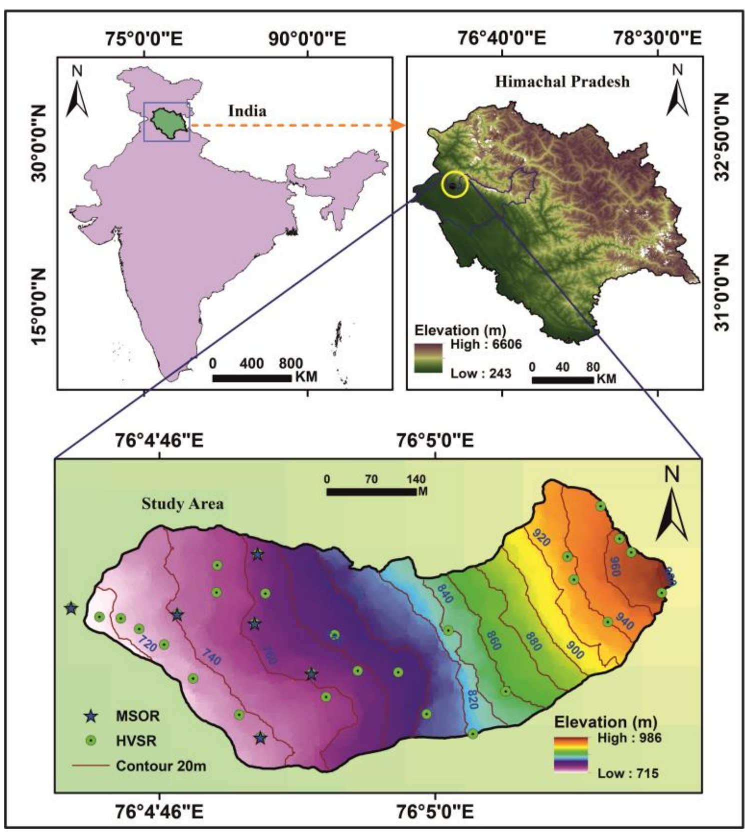

Fig. 17 Shows the location of Soldha slide zones (lower picture) in Himachal Pradesh, India. The location of the site covered under Horizontal-to-vertical spectral ratio (HVSR) analysis as green circles and multiple simulations with one receiver (MSOR) as a star are shown along with a contour interval of 20 m and elevation variation from 715 m (violet) to 986 m (dark mustard colour).

The Soldha landslide was triggered early on the 23rd of October, 2023. The region has been experiencing very high rainfall episodes since July 2013, which might have increased soil mass saturation level and reduced shear strength. The slide zone had developed alarming features such as surface cracks and land fissures, which allowed the villagers to move out before 23rd October night and save their lives. Geologically, the slide zone is situated on the hanging wall of the Jawalamukhi Thrust, acting as the division between the Middle Siwalik sandstone to the north and the Upper Siwalik Conglomerates to the south. Within the landslip area, the geological composition is characterized by Middle Siwalik Sandstone with clay intercalations, and the predominant surface material in the slide zones comprises rock fragments of buff-colored sandstone along with intercalations of clay stones. The slopes predominantly face southward, and the southern section of the slide zone is draped in debris material sourced from the first and second detachment zones of the slide, as documented by Mahajan et al. (2022).

The slide is very steep at the crown part and has moderate slopes in the lower part, with elevation variations from 715 m at the toe to 977 m at the crown region within a distance of 0.78 km. The slope gradient along section A' (inset) indicates steeper slopes with break-in slopes at different parts of the slide zones. Fig. 18 shows the general trend of the hill at various parts of the slide zone. The detachment zones at the crown and first scarp and the areas with debris material at different parts of the slide zone are shown along the elevation profile.

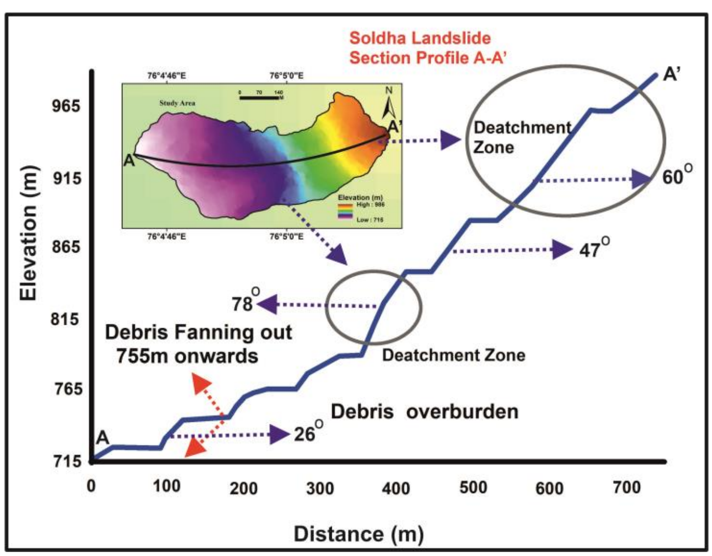

Fig. 18 Cross section of the slide zone depicting elevation variation along the A-A' section

This Soldha landmass moved downslope in two different stages; initially, the first scarp was developed a few meters down the crown portion, followed by the movement along the crown region, as stated by Mahajan et al., 2022. Lithologically, the landslide mass comprises sandy soil with weathered rock from the scarp region, gullies and uneven topography.

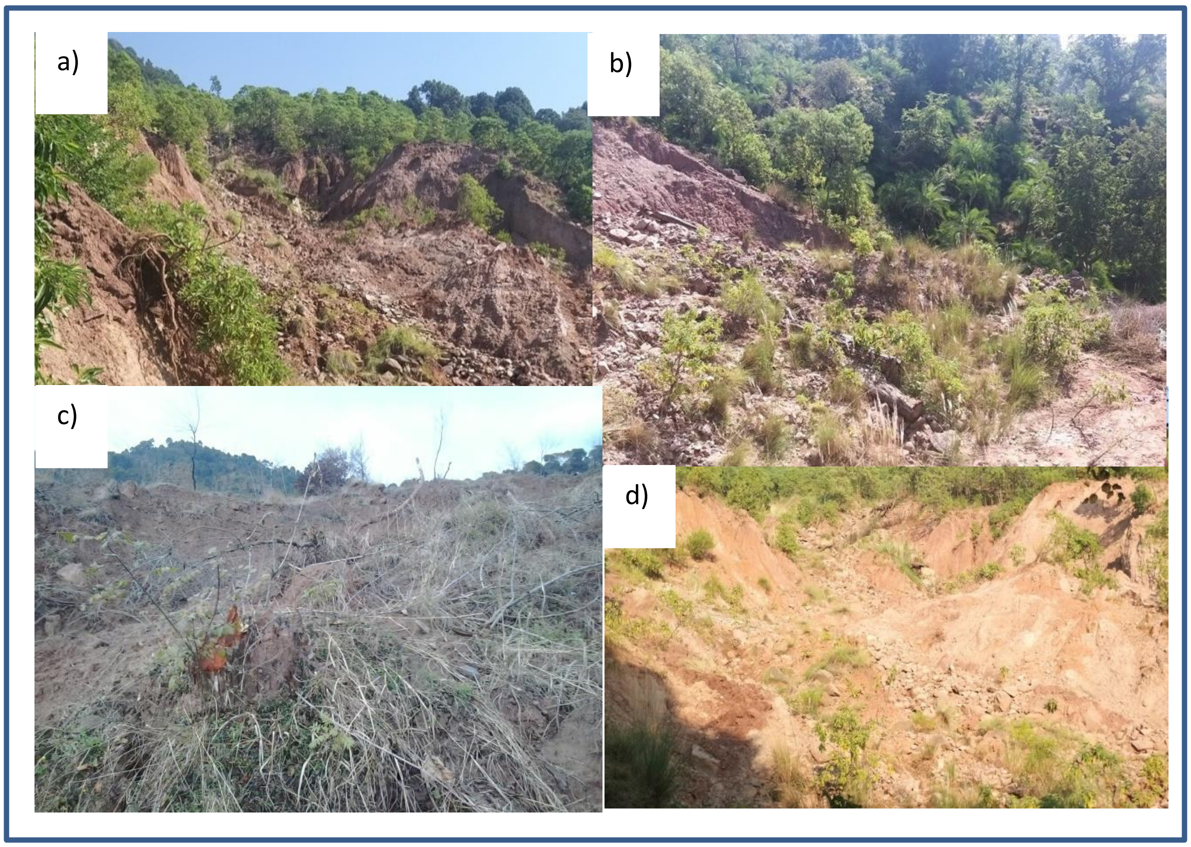

Fig. 19 Shows lithological characteristics of the slide zone: a) The area on the left of the slide zone, which was exposed due to the activity in the region; b) shows the presence of weathered rock material from the scarp region; c) the central part of the slide zones in the western side indicating weathered soil with uprooted trees and bushes, d) uneven topography on the southeast part of the slide in the slide zone with sandy to fine soil particles.

The material derived from the slide movement seems vast. It has a deeper slip surface that displaces physical and anthropogenic elements (houses, forest cover, etc.) by 40-60 m down the slope in different directions (Mahajan et al., 2022). Simultaneously, a large chunk of the landmass comprising highly jointed sandstone was exposed, and a prominent bend or scar developed in the western part of the slide zone (Fig.19a).

This study area contained precarious slopes at the scarp, although it stabilized a little after the deposition of eroded soil and rocks/debris at the middle and lower parts of the slide. During the investigation, stones and soil failure positions are documented as joints. The slide has resulted in large gullies, the undulatory nature of landmass and large-scale crevasses. The slide zone's crown part and western sides have rock exposures - which are highly jointed—the rock exposures of sandstone lie in different degrees of weathered conditions. The region's highly deformed and jointed rocks reflect the presence of geological discontinuities south of slide zones. According to various authors' investigations, minor earthquakes in the last few years have also made this area vulnerable to movement (Kumar and Mahajan, 2001; Mahajan et al., 2022).

The Soldha slide zone was triggered in October 2013 due to continuous rainfall in the preceding months, resulting in the downslope movement of the entire land mass by 40-60 m (Randhwava and Dhar 2013). Located on the hanging wall of Jawalamukhi Thrust, the area encounters slight movements attributable to ongoing tectonic disturbances. Characterized by high rainfall and a highly porous surface layer, the zone allows water to percolate deeply into the subsurface, potentially inducing movement along the slip surface. The rainfall analysis suggests a gradual slope failure attributed to the progressive reduction in shear strength of the predominantly sandy slope material followed by high-intensity rainfall in October 2013. The continuous downslope movement was instigated by heightened shear stress on the slip surface in the middle section of the landslide body. Moreover, removing the upslope toe (now forming the crown of the Soldha landslide) contributed to its further sliding.

The rotational nature of the slide, with varying slip depths and the presence of multidirectional joints and weathered rock material, indicates the rate of weathering. The slope angle, ranging from over 65° near the crown to gentle to moderate slopes at the centre and toe area, further influences the slide's dynamics.

Field investigations and hypsometer analysis by Sharma and Mahajan (2018) revealed high drainage density, signifying immature geomorphic features. The debris formed from Middle Siwalik sandstone rock fragments contributes to the rugged terrain of the slide zones. The area is characterized by gorges, depressions, and ridges, underlain by claystone and mudstone layers. The investigation supports a multidirectional slide movement, particularly in the southwest-eastern and southern directions.

The topsoil, comprising rock fragments and debris material, is sandy and highly porous, impeding water retention. The fine soil exists at deeper depths, creating an impermeable lower layer that facilitates moisture movement. Grain size analysis by Mahajan et al. (2022) revealed well-graded sand, gravel, and silt + clay components, with soil characteristics indicating alkalinity, deficient humus, and poor nutrient levels.

The analysis shows multidirectional joints indicating the complexity of the area (Fig. 6). The principal direction of the joint is either in the western or northern exposure, indicating the presence of stresses from the northeast-southwest or east-west, reflecting the role of both longitudinal and transverse features in the development of strains in the region. The multiple directional developments of joints reflect the level of stresses in the area that might lead to crown failure, and the gravity of the material allows its movement along the slip surface due to the increased water content.

The application of LiDAR has been increasing for landslide investigations (Derron and Jaboyedoff 2010; Heritage and Large (2009), and our experimental investigations on the Soldha slide zone also reveal south-eastward movement during the 2023 monsoon season and the rate of movement noticed using LiDAR vary from 0.032m in the northwest side to 0.398 m in the south-eastern direction in 44 hrs at point locations 5, 9 and 1(Fig.20). Further studies are required from the same region with month-long observation to establish its subsequent effects on the Niangal village for rescue measures.

Terrestrial LiDAR is widely used for creating highly accurate topographic maps, and built-in GPS and differential GPS help monitor the rate of movements on the surface. It captures detailed elevation information, including the shape and features of the terrain, which is crucial for understanding minor movements on the surface. In the present survey, the RIEGL VZ-2000i Terrestrial Laser Scanner is being used for data accusation, having a range of 2500 m with an accuracy of 5mm. The system has automatic on-board registration, including voxel extraction and merging scan position in the background to fasten the registration in open-pit mine surveying.

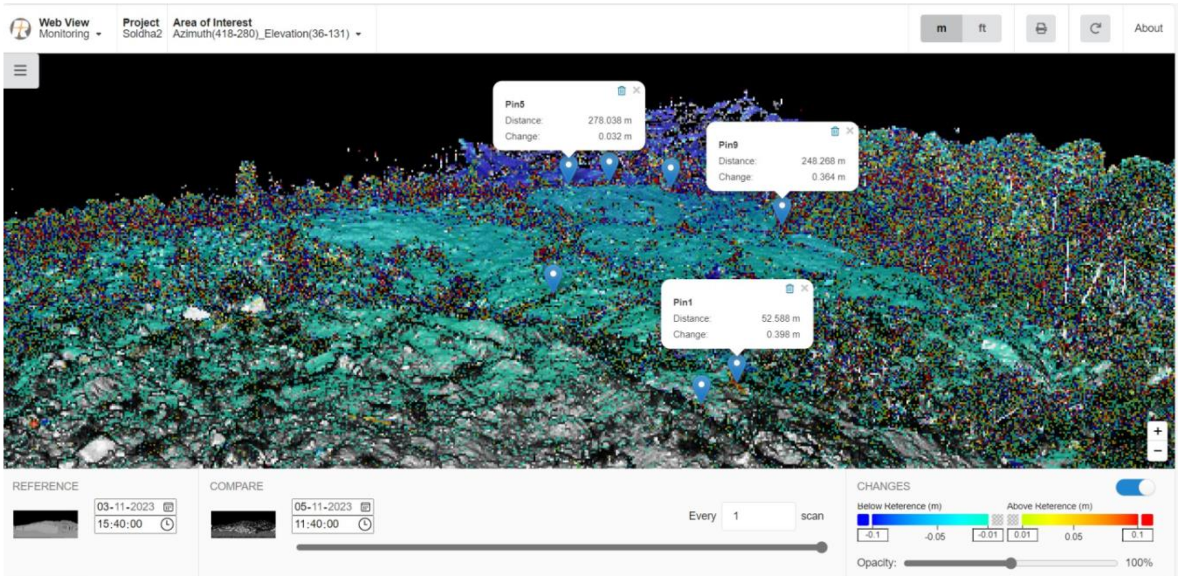

Fig. 20 Soldha (Himachal Pradesh) landslide's scan at 11:40 AM on 5th November 2023 after continuously monitoring the slide zone from 3th November, 2023. The values are highlighting the movements at various depicted places in 44 hours with respect to the reference scan. A total of 19 scans are taken. The rate of movement has been noticed which vary from 0.032m in the northwest side to 0.398 m in the south-eastern direction in 44 hrs indicating a very alarming rate of movement in the region.

The analysis of results from ambient noise measurements allowed information on the depth of the slip surface and shear wave velocity to be obtained by inferring the geometrical reconstruction of the noise recording along the profile. This information reveals the impedance contrast between the sliding body and the bedrock. The 1-D Vs profiles provide the shear wave velocity of the material involved in the gravity movement of the subsurface material. The HVSR spectra provide significant resonance peaks with a frequency range from 1.88-5 Hz, and amplitude varies in general 2-3. It goes up to 5 near the toe zone, possibly due to the transition between the landslide mass and the bedrock material. The directional component observed at different sites indicated multidirectional behaviour of slide mass. Various authors have also observed it while conducting such experiments in other parts of the world (Del Gaudio et al. 2013) Spudich et al. 1996). The surface material up to a few meters has shallow shear wave velocity (Vs = 200-250m/s), which is involved in the landslide mass. In contrast, it has increased (Vs-500-600m/s) at a depth of 40-45 m, which can be due to the presence of very stiff material or bedrock and considered as a transition between the surface material and bedrock.

The overall evaluation of the Soldha slide zone using various geological and geotechnical geophysical geochemical analyses reveals the soil's suitability for deep-root plant species, promoting vegetation growth and aiding in limiting water movement downward as the shear strength of the material increasing with depth as reflected in Vs profiles. Chemical analysis and grain size analysis emphasize the soil's dependency on ions, highlighting the spatial solid dependence of soil. The proposed application stabilizes the slide zones and contributes to ecosystem maintenance, carbon pool improvement, and global warming mitigation. To ensure stabilization, native plant species should be introduced, and invasive species with root-binding properties can be strategically utilized. The bioengineering approach, involving earth balls, seed broadcasting, or slip planting, offers a sustainable solution for stabilizing the slide zone and enhancing surface soil water-holding capacity, fostering ecological balance.

Causes: Neotectonic activity, lithology of the landmass, slope angle and of course high intensity rain fall which trigger the slide.

Recommendation:

- ***Regular monitoring is essential, utilizing LiDAR Survey and geophysical surveys, in addition to monitoring geomorphic changes. Improvement of drainage is imperative, particularly in the uphill region, with the implementation of channelization along natural drainage paths. It's crucial to manage the removal of material from the National Highway as it contributes to mass movement, potentially endangering the entire village of Niangal.***

Village Minjgran, Nurpur Tehsil

This village is situated northeast of Khanjian, along the Jaunta-Nurpur Road, at coordinates 32.2546940 degree N and 75.9556230 degree E. The damaged houses were positioned on very gentle slopes, suggesting that the primary cause of the damage could be attributed to issues with the drainage and sewerage system. There were no visible scars located to the north of the houses. Another contributing factor could be the presence of natural drainage channels situated at lower elevations relative to the houses (Fig.21). While this is not a major problem overall, two houses sustained significant damage and were deemed uninhabitable without proper remediation

The heavy rainfall experienced during the monsoon season in July-August 2023, followed by flooding in the natural drainage channels, led to toe erosion and localized flooding around the houses. The combination of tectonic movement and heavy rainfall likely contributed to the subsidence of the landmass. Although this slide exhibits localized characteristics, improving the drainage and sewerage systems may help alleviate the issue in the village. The displacement observed in three to four houses within a distance of 50 meters indicates movement at the subsurface level.

Fig. 21 Shows development of cracks in the tiles and displacement of walls b) the frontal part of the houses was totally damaged and the existing one developed wide cracks in the wall indicating subsidence cracks c) Again diagonal cracks in the walls and D) floors indicating subsidence features.

Recommendation:

- ***The primary causes of the slide are neo-tectonic activity, inadequate drainage systems, and intense rainfall. Therefore, it is crucial to enhance drainage systems in the uphill region and channelize them along natural drainage paths.***
- ***Detailed investigation are required for mapping the whole region in terms of tectonics and depth of slip surface using geophysical, geological and geotechnical investigations***

Ladauri and Jaunta (Nurpur Tehsil).

This village has also experienced significant mass movement, primarily initiated from a scar developed in the hillock range. Residents of the village noticed cracks in the hillock well before the rainy season began. Subsequent heavy rainfall in the preceding months increased moisture in the debris material, leading to soil solifluction and water movement along the slip surface. This allowed the land to move downward due to gravitational forces. A similar situation is observed in the Jaunta slide zone. These are inherently unstable topographies undergoing geomorphological changes due to tectonic activity along the Jawalamukhi Thrust.

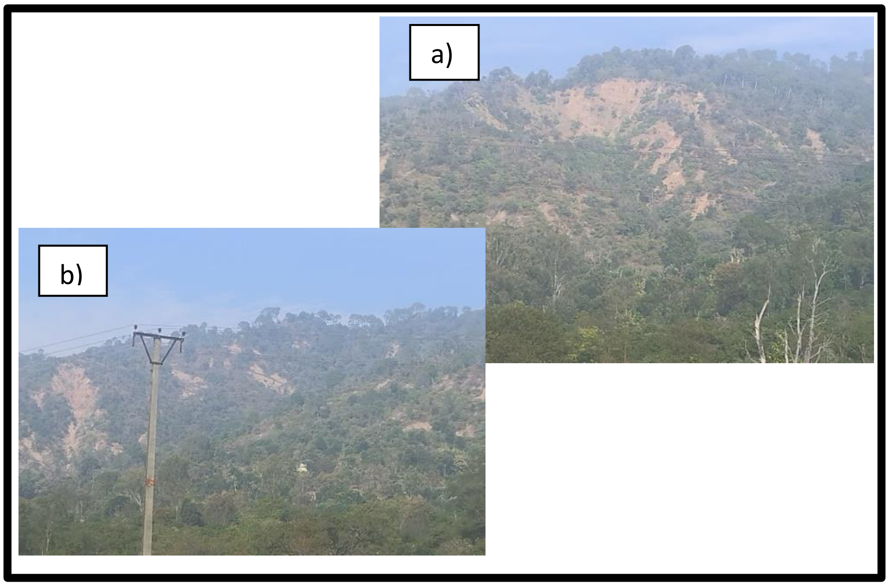

Fig. 22. Development of scars in the uphill region due to neotectonic activity north of Laduari and Jaunta villages

Causes: Neotectonic activity and poor drainage system and of course high intensity rain fall which trigger the slide, Natural drainages are blocked by construction activity.

Recommendations: Drainage system needs to be improved that will also take of high intensity rain fall to follows the natural drainages

JAWALAMUKHI AREA OF KANGRA DISTRICT

The region lies north of the Jawalamukhi Thrust, primarily composed of Siwalik sandstone overlain by debris material. A preliminary survey was conducted on December 28, 2023, to assess the aftermath of heavy rainfall on August 14, 2023. During this survey, seven sites within Tehsil Khundian and sub-tehsil Lagru were visited, revealing significant damage in these areas. Besides heavy rainfall, factors such as haphazard settlements, inadequate drainage systems, and poor irrigation practices in certain areas worsened the impact of geological and topographical conditions.

The geomorphology and lithology of the area are pivotal in landslide occurrences, especially in response to rainfall. The region boasts highly dissected hills and valleys, where the slope gradient significantly influences material movement triggered by rainfall, often causing damage to settlements within. The surveyed area falls within the Lower and Middle Siwalik zones, characterized by alluvial fan deposits, sandstone, pebble and boulder conglomerates, silt, and clay. Notably, it features uplifts and isolated pediments (uplifted-eroded Siwalik hills) surrounded by fan sediments. The investigated sites include: [list sites here)

Place Name: Dodhru, Sub- Tehsil: Lagru

The site is situated at Latitude: 31º56’52.203’’ N and Longitude: 76º19’51.630’’ E in Village Dodhru. Water accumulation was observed on the northern side of the road leading to the hillock, resulting in water logging and increased pore pressures in the debris material, thus causing subsurface movement. To prevent future sliding, proper drainage is needed to alleviate the water accumulation on the backside of the hillock. Key observations of the landslide zone include. Damage to the road and temple walls, with large fissures formed throughout the structure (Fig. 23). Settlements behind these structures also experienced cracking, with gaps of 4 to 5 cm appearing between them
Subsidence of the area up to 2 to 3 cm downwards and approximately 4 to 5 cm wide, extending up to 50 m downwards on the right-hand side of the road. Cracking was also observed in the cemented pathway
Collapse and damage of a dug well and a mud house found displayed a large crack on one side of its wall, with destruction of the lower side base.
Signs of land subsidence and upliftment were evident further towards the Mard region, resulting in cracking of the cemented pathway and increased separations between gaps (Fig.24).

The movement of debris material occurred along a shallow slip surface, displacing the cemented pathway and causing cracks in buildings. The impact of the movement was localized and concentrated towards the Mard village, with no transfer of effects to the western side of the village. Proper drainage along the road, implementation of a sewerage system in the village, and draining of water blocked behind the hillock can help stabilize the area

Fig. 23 Images showing hillock of the Middle Siwalik rock behind which the water was logged during heavy rain fall b) showing the damage caused to the temple due to subsurface movement. Land fissure developed in agricultural land downstream d) damage of cemented path leading to houses.

Fig: 24 Images showing damage of road leading to Mard village and development of cracks in walls of mud house, but house was not affected by the movement of the landmass because the major effect of movement was on eastern side.

Causes: High intensity rainfall, blockage of water behind the rocks lead to seepage underneath and movement along the slip surface. Since the debris material is underlain by bedrock which acts as slip surface**.**

Recommendation:

- ***Proper drainage system along the road, avoid forming any water pool on the headword side of the road and channelize the water to the natural drainage.***
- ***Detailed investigation are required for mapping the whole region in terms of tectonics and depth of slip surface using geophysical, geological and geotechnical investigations***

Site: Upper Mard, Sub-Tehsil: Lagru

GPS Location: Latitude: 31º57'00.514"N

Longitude: 76º19'43.962" E

In this site the slope angle was very high and heavy rains lead to the erosion of landmass downstream. The uprooting of tree and uneven topography's indicated deeper subsurface movement. There is no settlement there hence there is no significant human property loss except environmental degradation and deforestation.

Recommendation: Modification of slopes; afforestation and have drainage channelization upstream.

Site 3 Place Name: Lower Mard

The coordinates of sites are 31º57'15.873"N and 76º19'42.622"E. The damage observed in Lower Mard was a continuation of the activity seen in the Upper Mard slide zone. This event constituted a significant landslide and land subsidence in the region. Debris material from the upper areas moved downward and was washed away due to intense rainfall and infiltration. Vegetation cover, including trees and bushes, was affected, and footpaths were disrupted. Uprooted trees were scattered throughout the area, and one settlement suffered damage, prompting residents to relocate to a safer location (Fig. 25).

The heavy rainfall resulted in uneven slope topography, with some areas exhibiting very steep slopes and uneven land subsidence. Steep slides and erratic movement of materials downslope were observed in certain locations. The entire event was triggered by a flash flood, leading to substantial damage. Given the lack of significant importance or significance of the site, it does not warrant detailed investigation.

Fig.25. Shows the damage in lower Mard village hillock due to high intensity rainfall, uneven topography, uprooting of tree and developed of crevasses and depression indicated the pressure of rain fall on 14th August 2023.

Causes: high intensity rain fall, loose lithology and slope angle

Recommendation: Modification of slopes; afforestation and have drainage channelization upstream

Village Pukhru, Tehsil Khundian.

The village is located at 31º56’23.55’’N and 76º19’53.768’’E. According to the observation few hosues developed minor cracks but the damage is only due to blocking of water on back side of the hosues. Nothing much need to do for this site except proper draiange system in the area (Fig.26).

Fig.26. Shows subsidence crack in walls, and roads due to water logging and poor drainage system in the village. No doubt high intensity rainfall contributed to the damage but the moisture already present in the soil got accelerated by high intensity rainfall and thus developed subsidence crack at Pokhru village.

Causes: Poor drainage system and high intensity rain fall

Recommendation: Proper drainage system is the requirement of the village.

Chowki site, Tehsil Khundian

This site is situated in Tehsil Logru at Latitude: 31º56'02.134''N and Longitude: 76º20'17.666''E. The lithology of the region consists of weathered sandy rock, which was displaced from the main mass due to water logging in the cracks and land fissures caused by heavy rainfall. This led to the displacement of the rock mass downslope. The settlement located below the hillside was completely washed away, except for one house situated farther from this area

Local residents have noted that there was a crack along the hillside since the 1905 Kangra Earthquake. Previously, accumulated water would drain away along the nala in the region and slowly dissipate through a water channel situated below the area. However, due to heavy water accumulation and overflowing, the channel was unable to effectively disperse the water, resulting in the observed displacement

Fig.27 Shows displacement of rock chucks from the main mass (Middle Siwalik Sheet rock) uphill and caused damage to the village located lower side.

Causes: High intensity rain fall, neo-tectonic activity and presence of wide fissures in the sheet like sandstone which filled with water and increased pore pressure lead to displacement of large rock chunks from the main rock mass

Recommendation: Keep strong vigil on development of fissures in the Middle Siwalik rock sheet form and have proper drainage system to avoid any water to percolate along the fissures.

Village Ambada Tehsil Khundian

This village is located at latitude 31º54’26.756N, Longitude: 76º21’40.923E in Tehsil Khundian. The main observation in the slides zones are:

At the summit of the slide zones, a wide crevice has emerged, extending from east to west, showcasing uneven surfaces with discernible movement, notably in the toe region adjacent to Tahal Khad. Substantial displacement has been observed in this region, contrasting with the scarred sections of the slide zones where only deeper fissures have appeared (Fig.28). Structures within the affected zones, including houses, exhibit visible damage such as cracks in walls and shifts in pillars, with some pillars moving outward by approximately 6 to 7 centimeters. Moreover, beams and pillars have become distorted and detached, while cemented slabs covering drains have deformed, posing a risk to pedestrians. The narrow village roads and house drainage channels have also suffered, with sections of boundary walls showing damage.

A single-story house displays severe effects, with deformed pillars and widening wall cracks, while a neighboring double-story house has sustained extensive damage, with pillars and walls displaced outward and a complete absence of beams on one side, rendering it susceptible to collapse with minimal disturbance. Conversely, two houses situated on the western part of the villages below the aforementioned dwellings appear unaffected, likely due to their construction on sandstone bedrock, in contrast to the loose soil foundation of the damaged dwellings above (Fig.29). Descending towards Tahal Khad from the village, an intact house is positioned adjacent to the severely damaged double-story house, possibly owing to effective water drainage facilitated by an uncemented stone wall constructed beneath it

This slide is categorized as a debris slide with rotational nature and is underlain by Middle Siwalik bedrock. The thickness of the debris material varies and warrants further investigation. Continuous rainfall in the preceding months led to increased moisture content in the debris material, followed by high-intensity rainfall on August 14, 2023, which triggered the slide. The lower part of the slide zones is highly deformed and uneven due to the major movement at this part of the slide which has affected the upper portion of the village and developed scar at the crest of the slide zone (Fig. 30). Detailed investigation of the slide zone is necessary to estimate the depth of the slip surface. Given that the debris material is underlain by bedrock (Middle Siwalik sandstone) along which water flows, facilitating the movement of debris material along the slope. Additionally, the slope of the bedrock is oriented towards the river, compounding the risk.

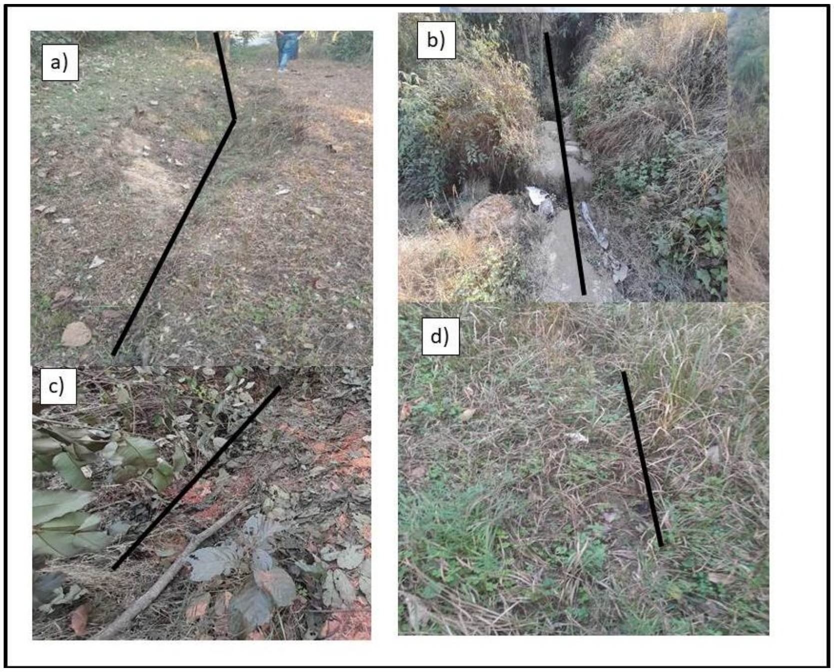

Fig.28 a, c) Shows the development of land fissure and its direction at the summit of the landslide zone Images b) indicated the natural drainage present in the same summit zone by running along the slope direction. d) Again showing the direction of the fissure developed in the upper part of the slide zone.

Fig. 29. Shows damage cause in the middle part of the slide zone to housing and erosion of the retaining walls along the natural drainage b) damage of cemented path c) development of cracks in building d) displacement of pillar and damage caused.

Causes: High intensity rain fall and continues rain fall in the preceding months; debris material above bedrock; blockage of natural drains and toe erosion

Recommendation: This slide requires detailed investigation regarding tectonics, assessing the depth and geometry of the slip surface, as well as evaluating the distribution and erosion status of materials, particularly at the toe area. This comprehensive analysis will necessitate the integration of geophysical, geotechnical, and geological investigations. Additionally, implementing an effective drainage system at the village crest can mitigate the problem. Moreover, it is imperative to construct structures elevated from the bedrock, considering its shallow depth, except for the lower part of the village.

Site 6 (b) Place Name: Lower Ambada

The lower Ambda area is located at coordinates 31º54'34.847''N and 76º21'56.444''E, likely representing the toe region of the scar developed in the Upper Ambada region. The terrain appears rugged and uneven, indicative of significant movement in this location. It is probable that toe erosion occurred, possibly exacerbated by Tahal Khad during the high-intensity rainfall and flooding on August 14th 2023.

Evidence of deformations beneath the earth's surface is apparent, resulting in the disruption of the upper soil layer. Some plants and bushes have been uprooted and inclined downward due to the heavy rainfall and the subsequent movement of water downslope in this area. Large, uneven subsidence of land has occurred in this region, highlighting the necessity for a detailed study to elucidate the factors contributing to these phenomena.

Fig.30. Shows the uneven topography in the lower Ambada (toe region) a) uprooting of tree and bushes b) developed of crevasses and cracks c) uneven topography and d) developed of cracks and movement of landmass downward.

Recommendation:

- ***Toe erosion needs to be protected***
- ***Detailed investigation are required for mapping the whole region in terms of tectonics and depth of slip surface using geophysical, geological and geotechnical investigations***

Site 7. Place Name: Silh

The site is positioned a short distance north of Khundian town, with coordinates of Latitude: 31º54'55.601''N and Longitude: 76º22'27.744''E. It features an extremely steep slope prone to erosion, primarily caused by cloudbursts or flash floods. These natural events have led to road damage and the displacement of one building within the slide zone. The area experiences frequent cloudbursts, which have contributed to the formation of an 80-degree slope through land movement (see Fig.31). Consequently, two houses situated below were demolished. Furthermore, trees were uprooted, and sediment from the slope was carried downstream, accumulating behind the cowshed nearby.

Fig.31 a) shows the upper portion of the slide from where the sliding starts along the road side b) middle part of the slide zones c) indicated the uprooting of tree and extent of flash flood d) the lower part of the slide zone which joins the river downstream.

LANDSLIDE SITES IN BHATIYAT TEHSIL (DISTRICT- CHAMBA)

The Chamba district showcases a varied lithological spectrum extending from the Siwalik foothills to the towering heights of the high Himalayas. Within the Bhatiyat constituency's lower reaches lies the outer Himalayan range, characterized by middle and lower Siwalik formations comprising sandstone, mudstone, and claystone, overlaid by alluvial sediments. This area is undergoing significant geomorphic degradation and remains at an immature developmental stage. The initial village under investigation for landslide occurrences is nestled within the Siwalik range, showcasing extensively weathered rocks and numerous active neotectonic features.

The district's expanse commences at Dramman town in the Kangra district, with the first affected site being Anain, merely 3 km from Dhramman, reachable through a road diversion from Thulel village on the Dramman-Sihunta road. The site's coordinates are 32°13'54.933"N, 78°08'07.904"E. The road leading to Anain village traverses the hanging wall of the Jawalamukhi Thrust and is susceptible to landslide features. The entire region displays pronounced neo-tectonic activity, resulting in heavily contorted topography along the village route. Persistent rainfall during the 2023 monsoon season diminished the frictional strength of predominantly clayey soil debris, culminating in an extreme event on August 14, 2023.

Village Anain

Anain village has witnessed notable land displacement, evident from a scar formation on the hillock behind the houses, resulting in downhill movement (see Fig.32). The landslide exhibits rotational motion, facilitated by a deep slip surface. Implementing mitigation strategies, such as establishing a proper drainage system and diverting water away from the village along the hillock, may mitigate future risks.

The road leading to Anain village from Thulel has encountered significant deformation and neo-tectonic activity. The debris primarily comprises thick layers of clay interspersed with fractured sandstone rocks. This composition renders the soil susceptible to swelling due to solifluction processes, resulting in downhill movement along the slip surface. Given the steep slope gradient and immature topography along the road, such occurrences are inevitable in this tectonically active area (refer to Fig.33). To maintain road functionality, constructing Gabion walls along the affected road sections is advisable. However, conducting thorough investigations is crucial to devise effective mitigation measures for the village.

Fig. 32 Image depicts the scenario of village Anain where there is no land fissure have developed however, a scar has been developed on back of these houses.

Fig. 33 Image depicts the immature topography of the road leading to Anain village.

Causes: High intensity rain fall and improper drainage of the hillock water

Recommendation: To safeguard the lower lands from the impact of continuous rainfall, it is crucial to divert rainwater from the hillock towards the west side. This can be achieved by implementing a robust drainage system at the base of the hillock.

Kamladi Kali Dhar, close to Lahru, Bhatiyat

The slide zone lies just 2.5 km north of Lahru junction, towards Chowari town. It's important to note that this slide predates the monsoon event of 2023; instead, it's attributed to tectonic activity. This tectonic slide forms a thrust zone, trending in the NW-SE direction. The rocks within the slide zone, including phyllites and volcanic material, have been pulverized over time, creating a mixture that moves downslope when combined with water. Erecting a retaining wall from the base in a benching formation upwards may mitigate soil erosion risks and safeguard the road (refer to Fig. 34). Additionally, bio-engineering efforts could help mitigate soil erosion, although the underlying tectonic activity will persist.

Fig.34.Iimage depict s the Kali dhar slide zones with pulverised material of volcanic rock and phyllites. When mixed with water it loses its frictional strength and moved like slurry along slopes. Even the material from hillock moves down. The slide is in the thrust zone and not easy to mitigate the activity however bioengineering measure may reduce the soil erosion.

Recommendation: Bioengineering measures and toe erosion needs to be protected by having bench retaining walls from the river side to protect the road

Brampala

This site is just 100 m north of Kalidhar towards Chowari and has the shales and carbonaceous phyllite which is close to thrust and always remain under stress due to tectonic activity. Excavation along the hillock may create a problem so efforts should be made not to disturb the slide zones.

Fig.35 Image depicts the sheared carbonaceous shale and phyllites at Brahmpala site which indicated that they are under stresses due to their location close to the MBT and Panjal Thrust.

Keru pahad (Tunnu Hatti)

GPS location $32^{0}28'03.478N; 75^{0}54'25.443E$

This site is situated 2-3 km south of Tunu ki hatti, towards the Pathankot side. The geological composition of the area consists of sandy soil interspersed with layers of pebbles and clay (see Fig.36). Pebbles often detach from the main rock and can either roll onto the roadside or potentially collide with passing traffic. The terrain is characterized by immaturity and is currently undergoing natural weathering processes. Increasing the height of the retaining wall can effectively shield the road from impacts caused by loose stones. Additionally, grouting the rock mass can help prevent pebbles from shifting downslope. Enhancing the height of the retaining wall will specifically safeguard areas prone to such incidents.

Fig.36 Image shows the rock type (sandy rock intercalated with pebbles layers. The site is under denudation which resulted weathering of pebbles layer.

Chamba Region

The Chamba region is situated within a broad longitudinal valley, flanked by the Zanskar range to the north and the Dhauladhar range to the south. Known for its seismic activity, it falls within zone V as classified by Kumar and Mahajan (1991). Notable seismic occurrences include earthquakes of magnitudes M = 6.5 in 1945, M = 6.2 in 1947, M = 5.5 in 1950, M = 4.5 in 1995, and M = 4.5 in 2005. Surrounding regions have also witnessed significant earthquakes, such as the Kangra earthquake (M = 8) in 1905; Dharamshala earthquakes (M = 5) in 1978 and (M = 5.7) in 1986; and the Kathua earthquake (M = 5.3) in 1980 (Sharma et al., 2005). Remarkable deformations are observed in the southernmost part of the orogen, as documented by Kumar and Mahajan (2001).

The landscape of Chamba varies from low-lying plains to moderate and higher Himalayan mountain ranges. Positioned between the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT), the Lesser Himalaya is characterized by extensive anticlines and synclines with amplitudes spanning several kilometers. Geological formations in the area comprise the Chamba Formation, Katarigali Formation, Batal Formation, Manjir Formation, Mandi Granites, Bhalai Formation, and alluvium, representing diverse geological epochs (see Fig.39).

Chamba-Bahrmaur Road

The Chamba-Bharmaur route serves as a crucial transportation artery, significantly influencing human activity and economic pursuits. However, the Himalayan road network confronts formidable challenges stemming from landslides, characterized by the downward movement of soil or rock along slopes. These occurrences pose imminent threats to infrastructure, human settlements, and ecological habitats. Varnes (1978) delineated landslide classifications based on movement and material compositions, emphasizing the imperative of assessing landslide hazards along road networks for robust planning and mitigation strategies.

While the entire stretch from Chamba to Bharmaur and Holi is susceptible to landslides, our survey within the Chamba District unveiled various landslide types. We conducted a preliminary investigation aimed at elucidating the underlying causes and devising potential mitigation measures.

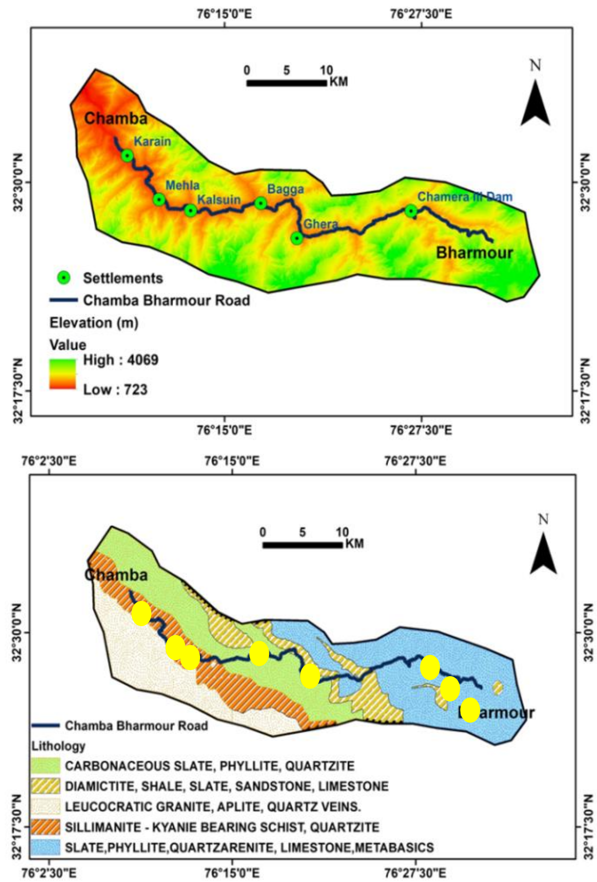

Fig. 39 a) image depicts location major sites mentioned in the letter and its elevation profile b) shows the lithology present along this Chamba-Bharmaur route.

Village Saloon

Although not explicitly referenced in the DDMA letter, our survey, conducted in consultation with local DDMA officials and engineers, extended to sites along the Holi road. The initial site, situated at latitude 32°20'29.796"N and longitude 76°32'11.147"E on the route from Chamba to Holi, warranted attention. Field observations indicated material sliding along the riverbank, attributed to river erosion caused by intense rainfall during the 2023 monsoon season (refer to Fig.40).

Recommendation: The village situated above cannot be protected by designing diagonal walls to act as barrier for water flow along with retaining walls towards hillside to protect the loose deposit from further erosion.

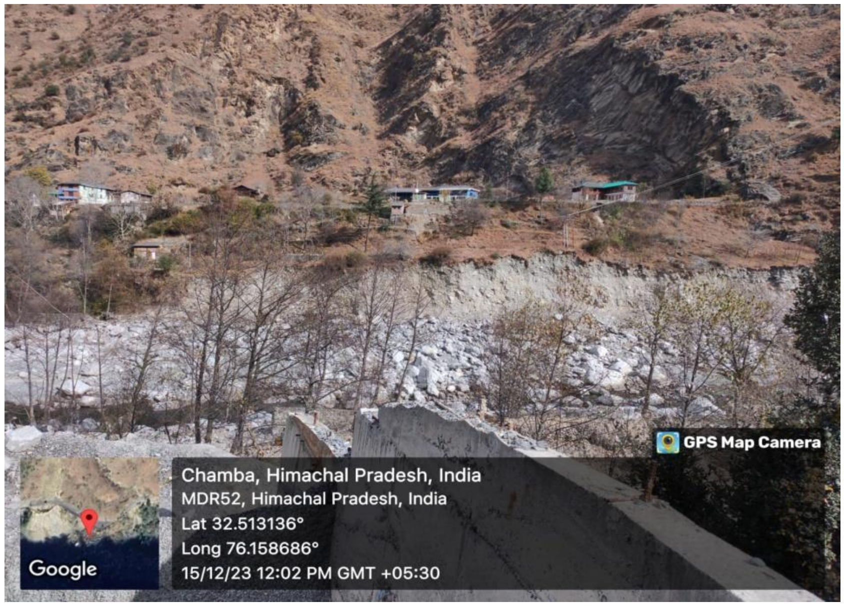

Fig.40 Image depicts river erosion at Village Saloon long Holi road.

The subsequent sites visited included Tiari village (latitude 32°20'20.376"N and longitude 76°32'27.918"E), Jhadouta Ghar (latitude 32°33'85"N and longitude 76°56'92"E), and Kuleth village along the Chamba-Holi road. These areas were impacted by flash floods and intense rainfall during the 2023 monsoon season. To safeguard these sites, it is recommended to construct gabion barrier walls along with retaining walls to prevent slope failure along the hillside. Once again, river erosion resulting from high flood levels was identified as the primary cause of sediment erosion.

Fig. 41 a) Images depicts the erosion of sediments and cutting of hillock on left side of the river Ravi opposite Jhadouta Ghar village toward main road. B) the Village located on the right bank of the river also get affected and needs protection c) river cutting due to river course diversion during high flood level d) Right bank of river indicating erosion of sediments and road subsidence at Kuther. Further, the subsidence of road and erosion of land was due to river cutting and slope angle. The slope angle needs geometrical modification and the hillslope needs to be protected from toe erosion by erecting gabion barrier to protect the hillock from direct touch with Ravi river water structures and erection of concrete from deeper depth at the toe and gabion structure from middle of the slope will protect the slope from further degradation

Causes: River cutting, toe erosion and presence and high level of saturation in the rock of uphill on left bank of the road.

Recommendation:

- ***Gabion water barrier structures need to be used on both sides of the river at theses slide zones for diverting the water flow and decreasing the velocity of water including flood control.***
- ***Gabion wall in benches towards hill side to protect soil erosion and further subsidence of roads due to water flow.***

Village Bagga and Lothal on Chamba- Bharmaur

The Bagga village is just receiving dam water and due to water storage, the hillock towards Bagga village is being affected (Fig.42). Although there are number of concrete structures are in place by the gravitation pressure of the slope material (Highly pulverized metamorphic rocks) and saturation of slope material lead to such failure. NHPC has raised retaining structures just a km before the Bagga village and protected the slopes from hill side. Similarly this slope can also be protected by erecting concrete wall followed by gabion structures by modifying the slopes to protect the slope.

At the same time with the river bed there is a need to raise the concrete wall needs to be raised from deeper depth by inserting pillars using hydraulic pressure within the water body. Constructing retaining wall just from shallow depth will not serve the purposes it had done earlier, because shallow concrete wall got eroded due to water scoring action.

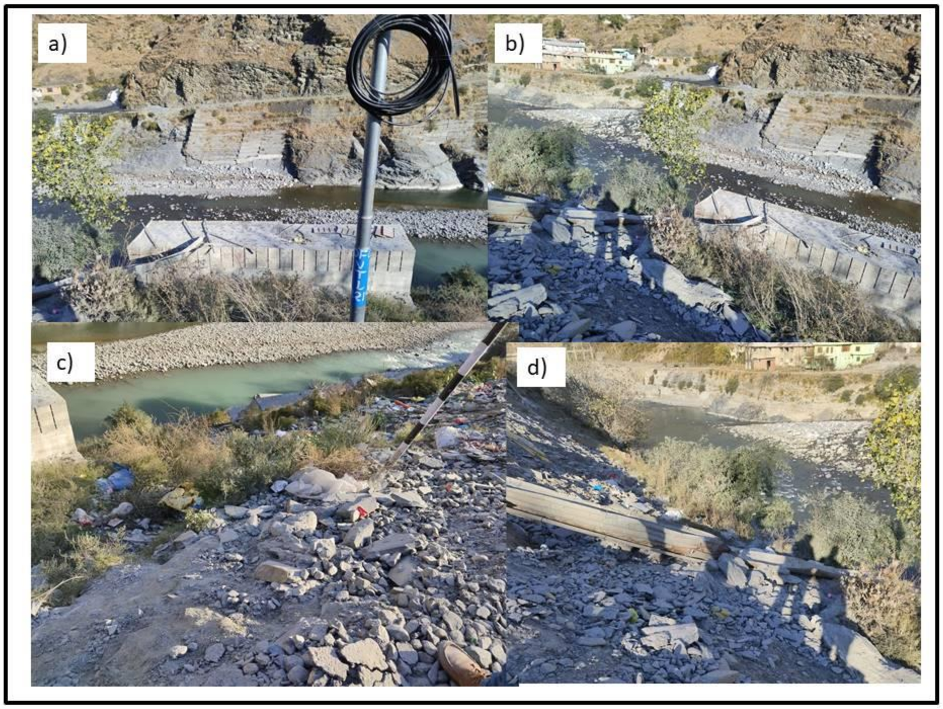

Fig. 42 Image depicts a) damaged retaining wall raised within the water body due to subsidence of the foot of the wall b) Damage to the retaining wall on right bank of the river c and d) area river and road indicating enough space for raising protections walls.

Site Lothal

This site is located a few kilometers beyond Bagga village and is characterized by a tectonic slide, featuring highly pulverized and metamorphosed lesser Himalayan rocks (refer to Fig.43). The main causes of instability observed here are toe erosion and water infiltration within the slide zone. Moist conditions reduce the frictional strength of the slope material to zero. Considering the weight of material from the hill slope, it is advisable to install concrete walls along the uphill side of the road and along the river. However, the concrete wall along the river should extend from a depth to prevent erosion caused by the river water. ***Following the concrete wall, gabion structures are recommended to create a permeable layer, allowing water to drain out and reducing pore pressure. Additionally, dewatering of the slope material is advised for further stabilization.***

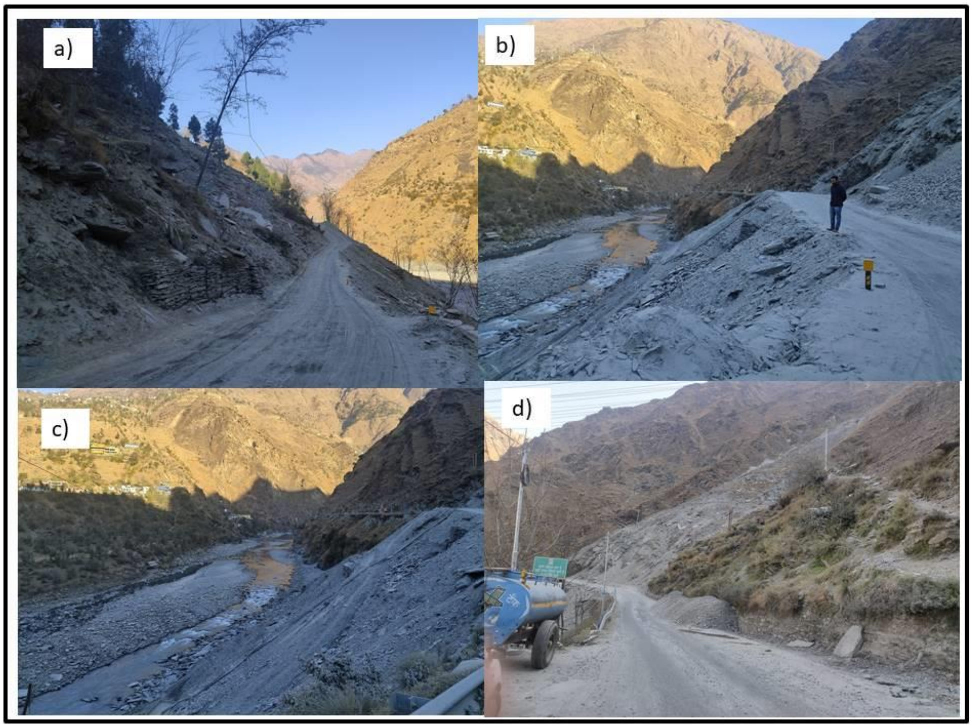

Fig.43: Lothal slide zone where presence of shear zone slope angle and water scoring action leads to toe erosion and further movement of the hill slopes and cause damage to the road.

Chamba-Tisa Road

During our visit to the Tisa area, we observed a variety of lithological formations along the road. Initially, we encountered Sillimanite and kyanite-bearing schist and quartzites, followed by carbonaceous slate and phyllites, along with quartzites. Upon reaching Kalhel village, we encountered Diamictite, shale, slate, sandstone, and limestone rocks. Moving further north, we once again encountered carbonaceous slates, phyllites, and quartzites. Additionally, we observed lenses of calcareous sandstone, shale, and limestone as we ascended near Kalhel village. Numerous shear zones and active thrusts were identified along the Tisa road, playing a significant role in the destabilization of the rock formations (refer to Fig. 44).

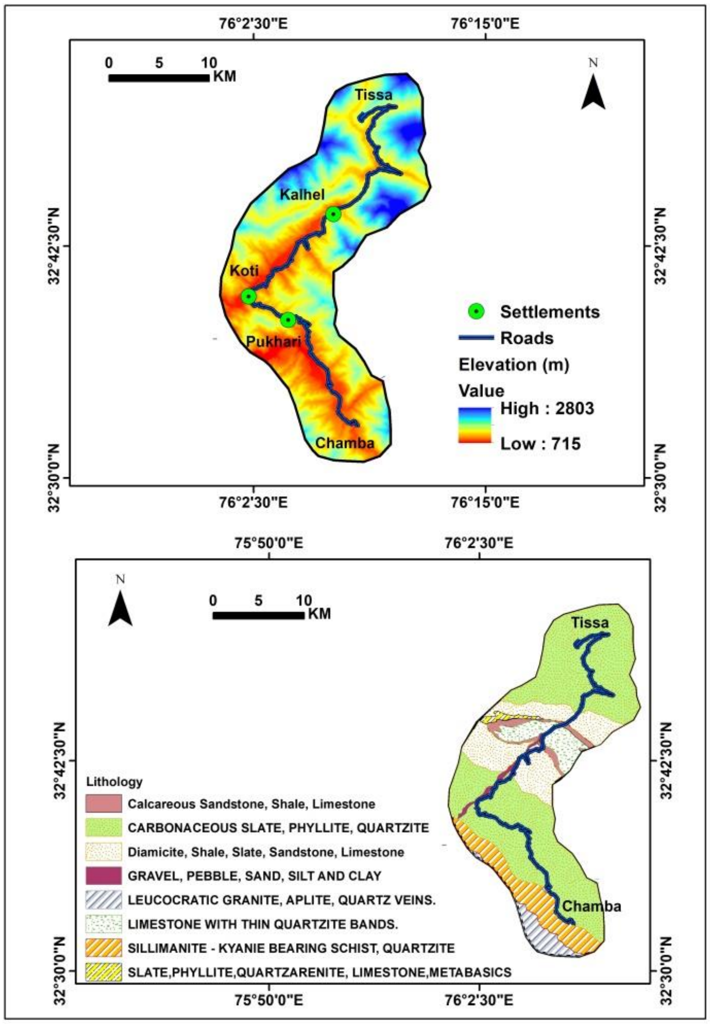

Fig. 44 Shows the a) settlements and elevation along Chamba-Tisa road b) geology along the Chamba-Tisa road

Kalhel (Churah)

This particular site is situated just before the MDR 85 location and is predominantly composed of shale, phyllites, and limestone in a shattered state (refer to Fig.45). Its coordinates are 32°44'24.017"N and 76°07'19.70"E. The rocks exhibit extensive jointing and fracturing, with significant accumulations of alluvial deposits on their surface. These rocks display high levels of weathering and fragmentation, indicating their proximity to tectonic planes similar to the MDR 85 site. The slope angle is remarkably steep, approximately 70 degrees, facilitating the downhill movement of highly pulverized materials during periods of intense rainfall.

Recommendation:

- ***Diversion of water on both sides of the hill slopes to avoid run off from the hillock to enter to the slide mass.***
- ***Shortcreting may bind all the loose jointed material and protect it from moving down slope.***
- ***Construction of concrete structure on hill side followed by gabion structure in benches may modify the slope and protect it from further degradation.***

Fig.45 Image depicts a) highly shattered phyllites rocks with number of joint planes which are subjected to high stress due to presence of tectonic plane in its vicinity b) shows the upper reaches of the MDR 85 sites with very loose material which can move downslopes under high moisture condition due to its low frictional strength c) Phyllites rocks with number of joints and sheared adjacent to the MDR 85 site.

MDR-85(Churah):

This site is situated alongside the road while traveling from Chamba to Tisa, with coordinates of 32°44'24.921"N and 76°07'00.691"E. It forms part of the existing slide zones, where significant material movement occurs during the rainy season, primarily due to the presence of irregular boulders (quartzites) within the sheared zone. These boulders are remnants of glacial deposits resting upon hard rock formations. The removal of material along the hill slopes poses a potential problem, as the debris consists of unstable, irregularly large-sized boulders mixed with loose soil and phyllitic rocks, characterized by very low frictional strength (see Fig. 45 and 46).

During our visit, we provided engineers on duty with suggestions for proper remedial measures. However, to ensure the completeness of this report, we reiterate the recommendations here.

Recommendation:

- ***Avoid removal of material from hill side in case, the material moves down due to rain fall. This will create more problem as the while land mass (loose irregular boulders and gravel with muddy matrix material) is in very unstable state.***
- ***Constructing concrete retaining walls on the leeward side of the road will help to widen the road.***
- ***Geometrical modification of slopes and bioengineering required to be implemented.***
- ***Diverting rain water from the top of the hill slope to protect the slope from runoff water.***

Fig.46: Image depicts a) leeward side of the road where hard rock dipping towards hillock can be seen which can be used to raise the protection and road widening wall b) slope angle and the pulverized material located at MDR 85 site c) the slope angle at the lower part of the slide zone

Pangola Nala

This bridge is located on Chamba-Tisa road after the Churah sites. The coordinates of the sites are $32^0 47'50.20$N and $76^0 9'15.41$E. The rocks are slated and phyllites dipping N70^0 E (Fig.47). The rocks are highly deformed and jointed and with one of the joint direction towards road side which brings the rocks towards the rock. ***There is nothing much to do except short crating or injecting the cementing material inside the fracture/joints to bind the rocks together. Nailing can also be effective.***

Fig.47 Image depicts the phyllites rocks present along Pangola nala and joitn direction which are oriented towards the road side which brought the tackles towards road. Raising protection wall and ejecting cementing material will protect the slide zone.

Junas Ghar (Tarela-Boundary-Mangli Road).

The coordinates of the slide zones are 32°54'48.815" N, 76°08'50.281" E, situated on the northwestern side of Tisa along the Tarela-Boundary Mangli Road. The slope in this area exhibits a 40-45 degree angle and is characterized by high moisture content attributed to leakages in pipes. The slope primarily comprises debris material, including irregular boulders, cobbles, and soil originating from the Lesser Himalayan rocks such as carbonaceous slates, phyllites, and quartzites (Fig.48). The thickness of the debris material appears substantial, necessitating modifications to the slope through benching, while improvements to the drainage system are imperative.

It is cautioned that removing material from the slide toe region along the road could potentially lead to disastrous consequences. Concurrently, observations indicate that the river flowing at the toe region has contributed to toe erosion, warranting modifications to the river course. Priority should be given to protecting against river erosion by installing barriers along the riverbank adjacent to the hillock and erecting retaining walls. Expansion towards the river side is recommended over removal of material from the hillock side

Nevertheless, conducting a detailed investigation and mapping of the bedrock orientation and its depth through both geophysical and geological methods will facilitate the identification of more precise mitigation measures. Further having bioengineering application will allow binding the soil material along the slopes and increasing the resisting power and shearing strength.

Fig.48 a) Shows the damaged part of the road and retaining wall along the Tarela-Boundary Mangli Road slide zones b & d) indicated large chunk of slates and boulders which can be used to diver the river channel and slope angle of the slide zone c) shows the moisture content and irregular stones which have been broken from the in situ rock.

Recommendation:

- ***Draining of water from slope***
- ***Raising gabion structures along the hill side***
- ***Modification of slopes and bioengineering will have long lasting effect.***
- ***Raising retaining wall from river bank by modifying the river courses and by placing big rock slabs towards the hill side to protect toe cutting during flood situation***
- ***This slide needs detailed investigation to understand the depth of the bedrock along the slope for applying remedial measures.***

Salooni Village

This site is located in the southern region of the Chamba-Tissa zone, precisely at coordinates 32°43'16.687" N and 76°02'59.259" E. The predominant rock types in this area include black pyritized shale, carbonaceous shale, minor siltstone bands, and phyllites (see Fig.49). Along the village road below the Guest house, numerous slide zones are observed, primarily consisting of debris material, despite the rock's opposite dip direction. The primary cause of these slides is attributed to the inadequate drainage system and water from the town's sewerage system.

Urbanization in the Himalayan town has led to an increase in the number of sewerage tanks and soak pits. For instance, if each house consumes 500 liters of water daily, this water directly infiltrates the underlying landmass, subsequently moving along the slopes and contour directions. With approximately 50 houses in the region, this amounts to almost 25,000 liters of water daily infiltrating the landmass, surpassing the infiltration from rainfall. Therefore, implementing a proper drainage system in the area is crucial to safeguard all slide zones.

Furthermore, erecting concrete retaining walls from the top part of the slide zones increases the load on the top, facilitating downward movement due to gravitational force. It is advisable to construct the retaining walls from the toe region instead. Protecting landslides in Himalayan terrains should involve constructing retaining walls in a benching pattern. Additionally, reinforced concrete (CC) walls should be erected at the toe region, while gabion walls should be employed in the middle part of the slide zone to ensure proper permeability for water to move out. This approach will help reduce pore pressure in the slide zones and enhance their resistance and shear strength.

Fig.49. The image illustrates the following features: a) The slide zones along the road are predominantly composed of rock fragments, primarily consisting of lesser Himalayan Phyllites and slates b) A substantial retaining wall has been installed at the crest of the slide zones. However, this wall increases the load at the crest, potentially inducing downslope movement of the land mass over time. This is attributed to the expected rise in pore pressure within the land mass c) The designated site for the proposed hospital construction can be observed d) The slope angle at the proposed sites, along with rock fragments and debris material, presents a significant risk to the proposed building, especially during periods of high-intensity rainfall, potentially resulting in disastrous consequences downstream

Upon thorough inspection of the proposed hospital construction site, taking into account various factors such as slope angle, material composition of slide zones, and the observed conditions during the 2023 monsoon season, it is strongly advised against proceeding with the construction at this location. The prevailing conditions, along with the rock type and the impacts of the 2023 monsoon, indicate a heightened risk of potential disasters in the future.

The retaining walls, planned to accommodate the hospital's expansion, are unlikely to endure the long-term challenges posed by the steep slope angle and the structural load of the building once erected. Consequently, selecting an alternative site for the hospital construction is highly recommended to mitigate future disaster risks and ensure the safety and stability of the infrastructure (see Fig.50).

Fig.50. The image depicts the slope angles and reclaimed land intended for the proposed hospital site in Salooni Village. However, it is evident that the heavy concrete wall constructed on the steep slope may not endure over time due to its weight and the nature of the slope material. Moreover, the design of the retaining wall is flawed, as it has the potential to exacerbate pore pressure in the area. This could lead to destabilization, particularly during periods of high-intensity rainfall or continuous rain events. Consequently, it is concluded that the site is unsuitable for accommodating any large structures, including a hospital

Recommendation

- ***Proper sewerage system needs to be in place in village Salooni.***
- ***Drainage needs to be improved all road should have proper drainage system***

- ***Protection walls/ retaining walls should be raised from toe rather than from the crest of the slide zone as the slope of the slide zone is very steep.***

Major causes and mitigation measures required in the Chamba-Holi and Chamba-Tissa Section are as follows.

Common Causes of Landslides in these regions

- Tectonic activity (Earthquake
- Heavy rainfall/ Flash flood
- Soil erosion
- Improper drainage system
- Slope
- Use of blast material beyond specified quantity which opens up the joints in the rock
- Debris material
- Anthropogenic activities: over mining, overgrazing
- Increasing moisture content between the debris material above bedrock due to increasing urbanization, resulting in increasing septic tank and soak pits

Mitigation Measures: Mitigation measures are tailored to address the specific causes of landslides, but there are some common strategies.

- Geometric Modification: Geometric modification involves re-profiling a slope to enhance stability by either
- Lowering the angle of the slope
- Adding infill at the foot of the slope.
- Implementing a proper sewerage system in all mountainous towns to protect them from further destabilization.
- Bioengineering application considering local bushes and small plants to protect soil erosion

Drainage: Implementing a proper drainage system in the region to protect all slopes from increasing pore pressure

- Using chemical agents to reinforce slope material/shortcreting in case of joints and fractures within the rocks
- Installing structures such as piles and retaining walls when it needs to be raised from water body
- Grouting rock joints and fissures
- Nailing of slope material without understanding bedrock profile is not feasible.
- Diverting debris pathways and rerouting surface and underwater drainage
- Measures to manage drainage include preventing water from entering the hillside through open or discontinuity traction crack

- Reducing water pressure near potential breakage surfaces through selective shallow and sub-shallow drainage
- Placing drainage systems to alleviate water pressure in the immediate vicinity of the hillside.
- Reinforcement Measures: Reinforcement measures entail introducing metal elements to increase the shear strength of the rock and reduce stress release during cutting. These measures include metal rock nails or anchors, classified as active anchorage when subjected to pre-tensioning, and passive anchorage, which is not pre-tensioned. Anchorage can also serve as pre-reinforcement elements on a scarp to limit hillside decompression associated with cutting. However, in zones where sloping material is debris or moraine deposits, stabilization using rock nails is not possible unless the depth of rock is known.

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