



**Report on Site-Specific Assessment of the Mehla Landslide on
Chamba-Bharmaur National Highway (NH-154A), Chamba
District, Himachal Pradesh**

(Field Season: 2021-2022)

Prepared by:

Dr. Harish Bahuguna, Director, GSI, SU:JK, Jammu

Shri Prashant Tukaram Ilamkar, Director, GSI, SU:PHHP, Chandigarh

Shri M.Chasie, Sr. Geologist, GSI, CHQ, Kolkata

Shri Shib Kanta Das, Survey Officer, GSI, CHQ, Kolkata

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Background

In pursuance to the request of the Honorable Governor of Himachal Pradesh and in compliance to the instructions of the Director General, Geological Survey of India (GSI), the Deputy Director General, NM-IVA, CHQ, Kolkata constituted a team of experts (vide Office Order No. 05/DDG/MIVA/HP_Landslides/2022, dated: 02.02.2022) for carrying out geoscientific appraisal of the Mehla landslide on Chamba-Bharmaur National Highway (NH-154A) and suggest appropriate engineering solutions for implementation by the Govt. of Himachal Pradesh. Reportedly, the Chamba-Bharmaur sector of NH-154A is under road widening for upgradation from single lane to two lane road, and the stretch of road adjacent to the Mehla Bridge has been subjected to blasting and excavation for road widening.

Complying to the above mentioned office order, the constituted GSI team visited the site as per the given details:

- i. Shri M. Chasie, Sr. Geologist and Shri S.K. Das, Survey Officer carried out geological mapping from 26.02.2022 to 03.03.2022
- ii. Dr. Harish Bahuguna, Director, GSI, Jammu and Shri P.T. Ilamkar, Director, GSI Chandigarh visited the site from 03-03-2022 to 04-03-2022 and reviewed the geological map and other details to provide engineering solutions.

The GSI team was accompanied by Shri Vipul Punj, Assistant Engineer, PWD (NH), Govt. of Himachal Pradesh who provided a detailed account of the activities being carried out for road widening in the area, the sequence of events at the site with respect to slide initiation, road closure and reopening after concerted efforts, etc. During the period, the following work components were carried out for a detailed appraisal of the Mehla landslide.

- a. Generation of a very-high resolution digital terrain model (DTM) using 3D Terrestrial Laser Scanner, required for understanding the geomorphology of the landslide and for preparation of topographical base-map.
- b. Delineation and mapping of the landslide boundaries, tension cracks, type of slope forming material, hydrology, estimation of overburden thickness, etc., for a comprehensive understanding and characterization of the landslide.
- c. Preparation of a detailed geological map and collection of structural data for kinematic analysis.
- d. Formulation of appropriate mitigation measures/engineering solutions for the landslide.

On completion, the GSI team led by Dr. Harish Bahuguna, Director also had a meeting on 04.03.2022 with Shri D.C. Rana, the District Collector of Chamba and apprised him about the fieldwork carried out by GSI.

Regional Geology of the Area

The Mehla landslide (Lat. 32°29'8.221"N and Long. 76°10'39.803"E) on Chamba-Bharmaur National Highway (NH-154A) in Himachal Pradesh falls in the Survey of India (SOI) Toposheet no. 52D/3 and is situated on the right bank slope of Ravi River (Fig 1). Physiographically, the area presents highly dissected, pronounced relief with high ridges and deep gorges. The altitude of the area ranges from 1003 m (river level) to 1094 m (max. limit of landslide scarp).

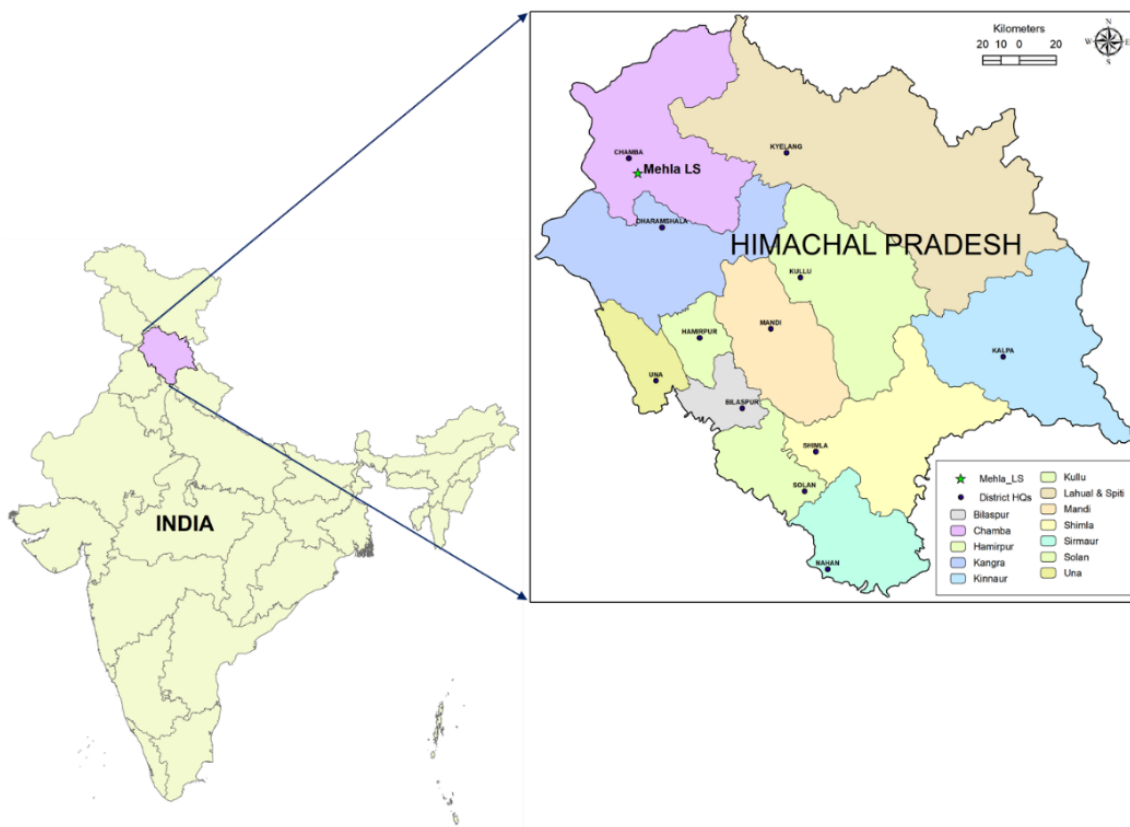


Fig 1. Location of Mehla landslide, Chamba district, Himachal Pradesh.

Geologically the area exposes the sillimanite-kyanite bearing schist and quartzites of Morang Formation (Vaikrita Group of Proterozoic age) on the right bank slope of Ravi while towards the left bank slopes the leucocratic granite, aplite and quartz veins (Dalhousie/Dhauladhar Granitoid of Palaeozoic age) are exposed. The regional geology map of Mehla area as described above is presented in Fig 2 (Source: Bhukosh, Geological Survey of India).

Historically, the state of Himachal Pradesh has experienced large to mild earthquakes, the biggest being the Kangra Earthquake of 1905. As per the Seismic Zonation Map of India (BIS; IS: 1893, Part-I, 2016), Mehla landslide comes under Seismic Zone V- a zone of very high damage risk (liable to shaking intensity of MSK- IX or greater).

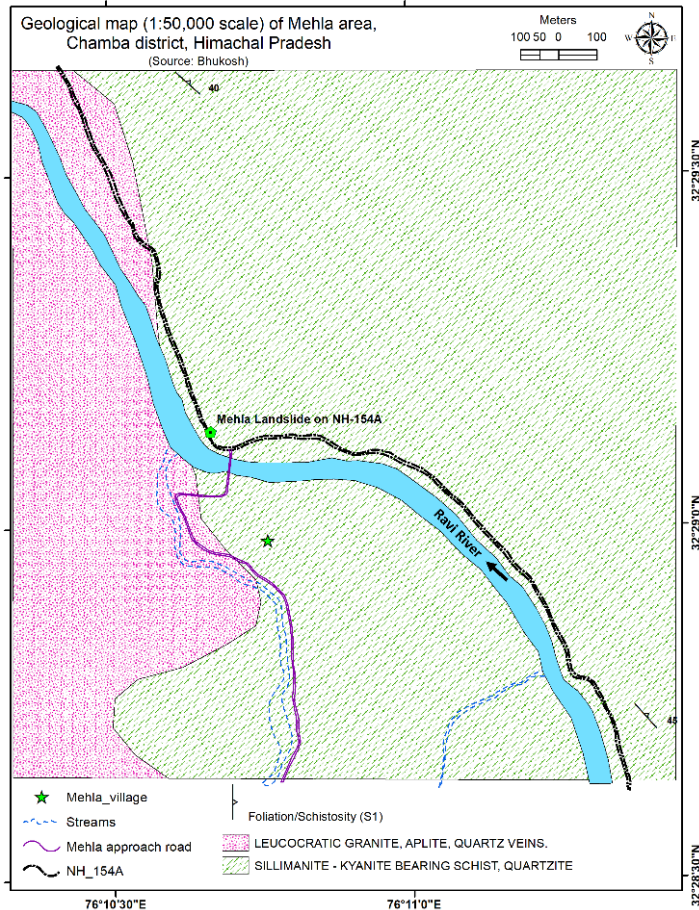


Fig 2. Regional geology around Mehla Landslide (Source: Bhukosh, GSI).

Landslide Susceptibility of the Area

Landslide susceptibility mapping of the entire Ravi River basin for an area of 3,710 sq. km was carried out by GSI between 1993 and 1994, and 2002 and 2006 under five field season programmes. An important outcome/observation made from the study for toposheet 52D/3 is that the high susceptible zones in the area are restricted to the river valleys, largely occurring along Chamba-Bharmaur road, where the hill slopes are disturbed and there exists a greater influence of anthropogenic activities or river undercutting. Consultation of the above mentioned landslide susceptibility map has shown that the Mehla landslide is located over moderate to low susceptibility zone (Fig 3). This clearly indicates a sudden deterioration of the

hill slope brought about by anthropogenic interferences through road widening activities in recent times that is responsible for the initiation of Mehla landslide.

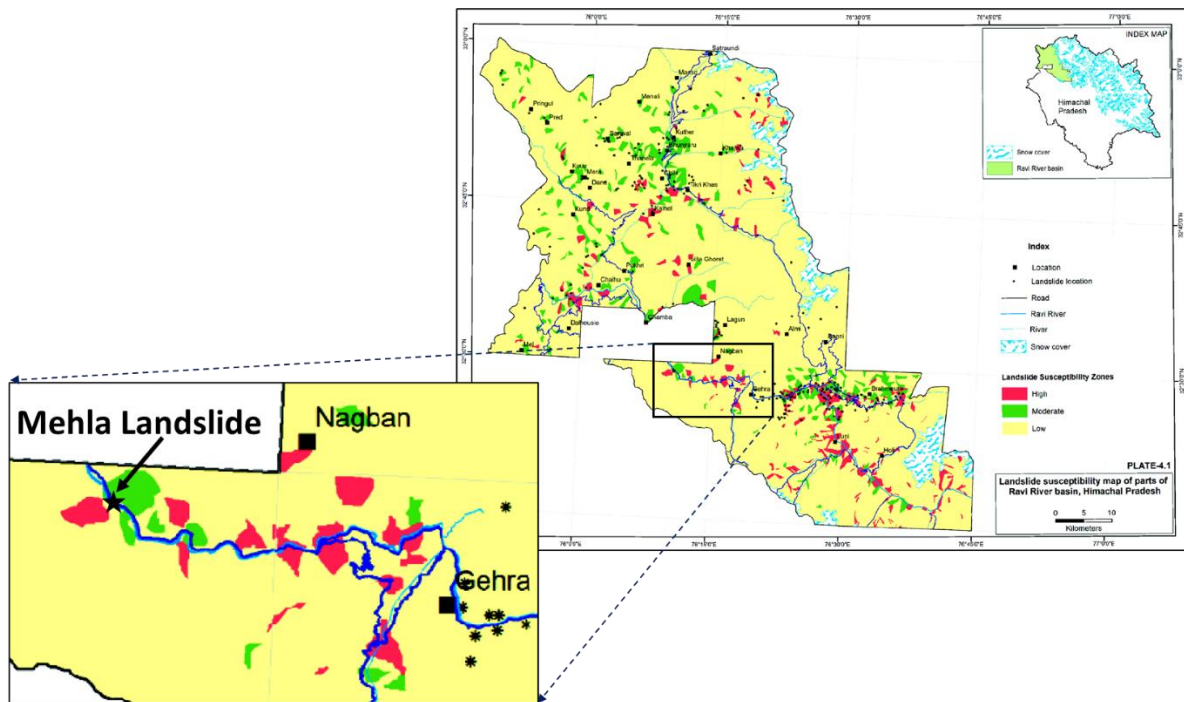


Fig 3. Overlay of Mehla landslide on the Landslide susceptibility map of Ravi River basin, Himachal Pradesh (GSI, 2016).

Temporal Evolution of the Mehla Landslide

The landslide inventory prepared by GSI during the Landslide susceptibility mapping of the entire Ravi River basin does not indicate the occurrence/presence of an earlier landslide at the present-day location of Mehla landslide. Consultation of multi-temporal Google Earth imageries for the area also corroborates this observation. Photo 4A (Imagery date: 06.10.2018) indicates a normal, stable slope at the present-day location of Mehla landslide. While Photo 4B (Imagery date: 27.05.2021) shows shadow areas for the immediate upslope of the road and therefore cannot be commented, however a slight hillward curvature of the road and the appearance of soil dump/muck by the river bank (downslope of the road) has been observed which indicates slope excavation for road widening and subsequent downslope dumping of the excavated material since the early months of 2021. The latest available data (Imagery date: 06.11.2021) indicates presence of a cut-slope scarp upslope of the road and a slight increase in the volume of soil dump/muck on the downslope of road (Photo 5A). In Photo 5B, the trace of the present-day landslide scarp is overlain on the available latest Google Earth imagery for comparative visualization.



Photo 4. Temporal Google Earth images for the Mehla landslide; (A) Normal slope conditions prior to 06.10.2018, (B) Slight hillward curvature of the road and sudden appearance of soil dump/muck downslope of road.

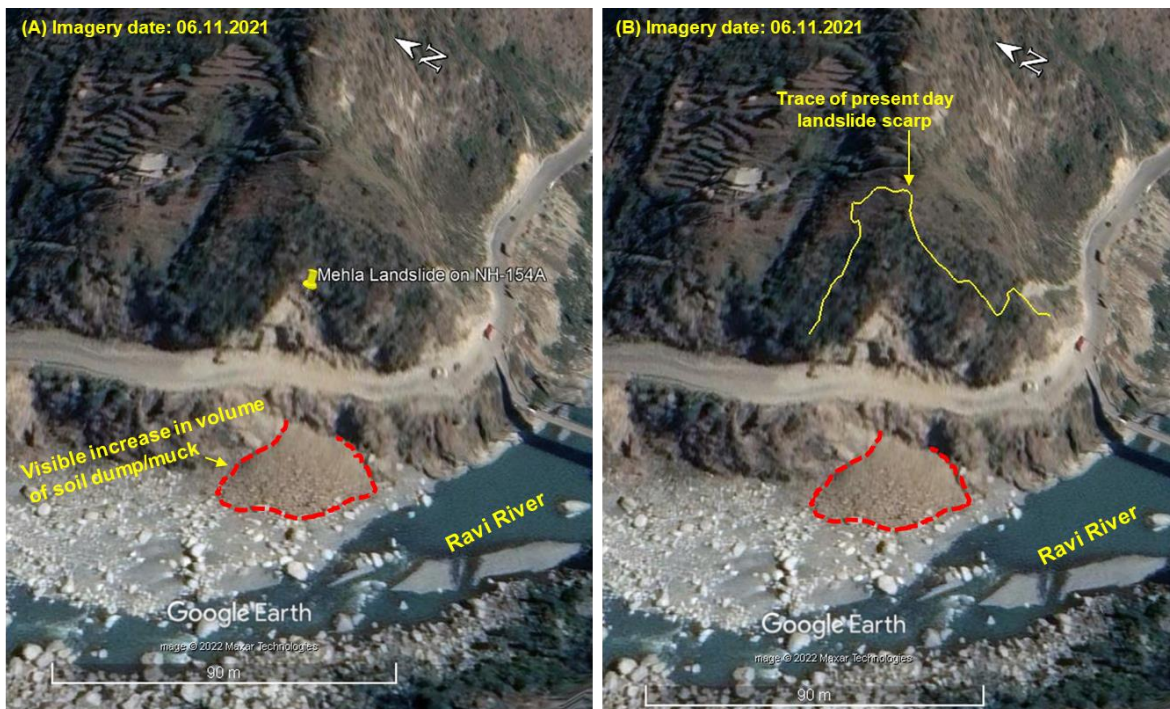


Photo 5. Available latest Google Earth imagery; (A) A small but pronounced cut-slope scarp with visible increase in the volume of soil dump/muck, (B) Overlay of present-day landslide scarp.

Information gathered from the concerned state authorities has indicated that the stretch of Chamba-Bharmaur road adjacent to the Mehla Bridge has been subjected to blasting and

excavation for road widening. The last phase of blasting at this site was reportedly carried out during November, 2021. However, following a spell of incessant rains during the 3rd week of January 2022, intermittent sliding of rock mass from the steep excavated slope started posing danger to the commuters. This was followed by the development of cracks and ground fissures at the crown of the landslide and the same was noticed by the locals and state authorities on 24-01-2022. Following increased activity of the sliding rock mass (at Km. 120/800 to 121/000) and keeping in view the safety of the commuters, the road was closed on 26-01-2022 which could only be reopened at 2:00 pm on 01-02-2022 under continuous vigilant check of traffic police. During the period of road closure, short term remedial measures like light charge blasting and manual scaling of the overhanging strata, construction of kutchra/earthen drain at the crown slope, clearing of the slide debris on road, etc., were reportedly carried out to minimize the eminent danger to commuters and make the route traffic worthy.

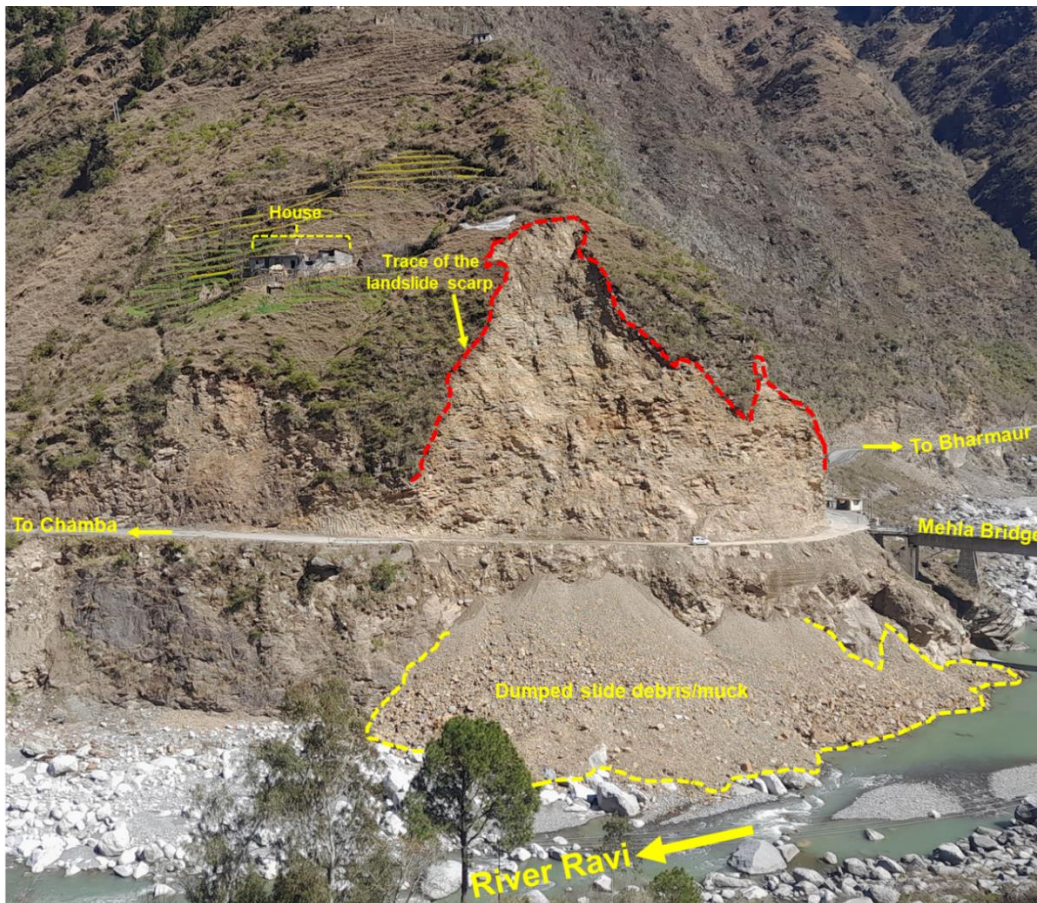


Photo 6. Perspective view of the present day Mehla landslide, as seen from the left bank slope of River Ravi.

Geological Mapping

Site-specific detailed geological mapping on 1:1000 scale with contour interval of 1 m was carried out for an area covering 25,159 m² around the landslide affected zone. The geological mapping has covered the flanks on either side of the landslide scarp, the head and crown portion, the stretch of National Highway and the toe part at the level of Ravi River.

Geological Observations and Rockmass Characterization

The following geological observations with respect to the landslide were made during the field investigation:

1. The dimensions of the Mehla landslide measures 76 m length (includes the zone of depletion and zone of accumulation) and 70 m width. The landslide-affected slope at present possesses a generalized slope angle of 69° at the center (Profile CD, Plate III), a steeper 75°-77° towards the right flank and similar steep angled slopes (69°-77°) towards the left flank as well. The slope angle at the immediate crown area is at 38°. Owing to the very steep slope, the landslide can only be accessed either at the road level or at the crown slope.
2. The slide debris on road has been cleared and dumped on the downslope of road (Photo 6).
3. The landslide scarp is irregular in shape (Photo 6). Five (5) linear cracks oriented NNW-SSE have been mapped at the downstream (right) flank of the slide (Photo 7). The width of the delineated cracks measure 6 cm to 28 cm with visible depth of 0.8-1 m at the time of study (Photo 8). The longest delineated crack measures 11.2 m and all the cracks have been appropriately represented in the detailed geological map (Plate I). However, no tension cracks or ground fissures were noticed at the crown or upstream (left) flank of the landslide.
4. The lithology encountered at the road level is the dark grey to grey coloured, hard and massive quartzites (Photo 9A & B). Hillward dipping of the bedrock (bedding) with general NW-SE trend and moderates dips (30°-38°) towards NE (N50° to N60°) has been recorded. At about 38-40 m high above the road level, alternating bands of slightly deteriorated rock mass (more weathered) have been observed. From the strike continuity (towards Bharmaur-end) it has been observed that the alternating bands are the thinly bedded, lighter colored schistose quartzite (Photo 10A). In general the bedrock at the landslide zone comprises hard and massive quartzites interbedded with lighter colored schistose quartzites.

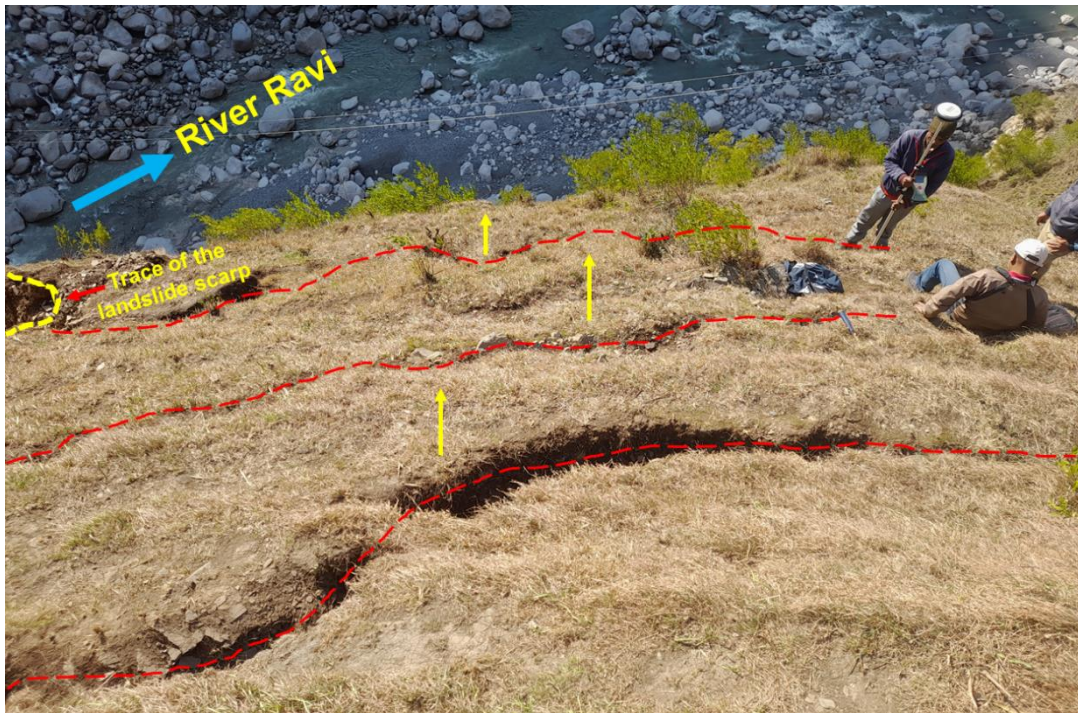


Photo 7. Downslope view of the right flank slope of the landslide, trace of some delineated linear cracks shown in red dashed lines. Yellow arrows indicate the direction of movement.



Photo 8. Representative photographs on the crack opening width and depth delineated at the right flank of the landslide.



Photo 9. The hillward dipping dark grey to grey, hard and massive quartzites exposed at the level of NH-154A.



Photo 10. (A) The thinly bedded, lighter colored schistose quartzites seen at the higher slopes, (B) Blast induced fractures in the rock mass.

5. The rocks in the area are traversed by three joint sets, the most prominent being J1 . The other two less-prominent joint sets are J2 & J3. These joint sets are in addition to the bedding-parallel joint (S1) which is hillward dipping. Towards the Chamba-end of the mapped area away from the right flank of the slide, J1 and J3 are found to be the important discontinuity planes, while at the center and towards the left flank of the slide (Mehla bridge-end), J1 and J2 are the important discontinuity planes dissecting the rock. Blast induced fractures have also been observed as shown in Fig 10B. The details of joint planes as recorded at the site are presented below in Table 1.

Table 1: Details of joint sets at Mehla landslide.

Type of discontinuity	Dip amount	Dip direction	Persistence	Weathering	Roughness	Separation (Aperture)	Infilling	Spacing
Prominent Joint (J1)	52°-56°	N200° to N192°	1-10 m	Slightly weathered	Rough	1-5 mm	None	0.3-8 m
Joint (J2)	65°-67°	N255°	0.5-3 m	Slightly weathered	Rough	1-5 mm	None	0.2-2 m
Joint (J3)	65°-66°	N280°	0.5-3 m	Slightly weathered	Rough	1-5 mm	None	0.1-1 m

6. Estimation of the insitu UCS of rock mass through the use of Rock Schmidt Hammer (N Type) has indicated a value ranging from 193 MPa to 227 MPa. The rebound number has been primarily obtained for the J1 and J2 planes at the accessible road level only. Following the ASTM D 5873 standard test method for determination of rock hardness by Rebound Hammer Method (Proceq SA, 2017), the average of 10 readings at a site has been adopted as presented in Table 2. For conversion of the obtained rebound value to UCS, the Kilic and Teymen (2008) equation ($UCS = 0.0137 N^{2.2721}$) has been used.
7. Determination of the approximate range of UCS for the rockmass exposed at the NH road level following the Deere-Miller approach (1966) was also carried out (Table 3) for cross-referencing as well as comparative studies with the values obtained using the Rock Schmidt Hammer.

Table 2. Rock Schmidt Hammer (N-Type) rebound values obtained at the NH road level

No. of impact	Location: Near Mehla bridge-end	Location: At the central portion of the landslide	Location: Towards Chamba-end
1	57	64	73
2	69	67	69.5
3	74	66	74
4	71.5	64	77
5	73	75	63.5
6	74.5	69.5	78.5
7	68	51.5	77.5
8	65.5	72.5	67
9	57	69	72
10	62	71	70.5
Average rebound value (rounded)	68	67	72
Converted UCS (in MPa)	199.69	193.08	227.38

Table 3. Strength of rock at the NH road level by Manual Index [IS: 11315 (part 5)- 1987]

Location	Rock type	Field identification	Grade	Description	Approx. range of UCS (in MPa)
Near Mehla bridge-end	Quartzite	Specimen requires many blows of geological hammer to fracture it	R5	Very strong rock	100-200
At the central portion of the landslide	Quartzite	Specimen requires many blows of geological hammer to fracture it	R5	Very strong rock	100-200
Towards Chamba-end	Quartzite	Specimen requires many blows of geological hammer to fracture it	R5	Very strong rock	100-200

8. Rockmass characterization through estimation of RMR (Bieniawski, 1989) at the road level has brought out presence of a fair rockmass (Class III). However the rockmass at the higher reaches (towards the main scarp) is assessed to be poor rockmass (Class IV). The estimation of RMR values for the three different parts of the slide at the road level are tabulated and presented in Table 4.

Table 4. Determination of RMR (Bieniawski, 1989).

Location	Strength of intact rock material (UCS)		Spacing of discontinuities		Volumetric joint count (Jv)		RQD		Groundwater condition		Condition of discontinuities		RMR _{basic}	Rating adjustment	RMR class
	MPa	Rating	Value	Rating	Value	%	Rating	Type	Rating	Type	Rating	Value	Fair		
Towards Mehla bridge-end	200	12	200-600 mm	10	14	69	13	Dry	15	Persistence 2-5 m, aperture 1-5 mm, no infilling, rough surface, slightly weathered	19	69	-25	44 (III, Fair rock)	
At the central portion of landslide	193	12	200-600 mm	10	14	69	13	Dry	15	Persistence 2-8 m, aperture 1-5 mm, no infilling, rough surface, slightly weathered	19	69	-25	44 (III, Fair rock)	
Towards Chamband	227	12	200-600 mm	10	13	72	13	Dry	15	Persistence 1-10 m, aperture 1-5 mm, no infilling, rough surface, slightly weathered	19	69	-25	44 (III, Fair rock)	

9. The friction angle of the rockmass was determined following the Residual Tilt Test of Barton and Choubey (1977). The empirical relation between residual friction (Φ_r) and basic friction (Φ_b) is as follows:

$$\Phi_r = (\Phi_b - 20^\circ) + 20 (r/R)$$

where,

r is the Schmidt rebound on weathered surface, and

R is the Schmidt rebound on unweathered surface.

10. The basic friction angle (Φ_b) determined at site are tabulated in Table 5. Following the empirical formula stated above, the residual friction angle for the rockmass is estimated at 32° and is used in the kinematic analysis of rock discontinuity planes.

Table 5. Determination of basic friction angle at site.

Sl.No	Estimated tilt angle	Average (Φ_b)	r/R
1 st set of test specimens/jointed rock blocks	34	32.6	68/70
	30		
	33		
	33		
	33		
2 nd set of test specimens/jointed rock blocks	33	33.2	67/70
	34		
	32		
	36		
	31		
	34		

3 rd set of test specimens/jointed rock blocks	34	32.8	68/70
	30		
	33		
	33		

11. Kinematic analysis of the recorded structural planes following Markland’s test (1972) was carried out which indicates the presence of both vulnerable wedge and planar failures. For the central portion of the landslide, wedge failure at the intersection of J1-J2 planes and planar failure along J2 plane are the vulnerable failure modes (Fig 11). For the slope towards Chamba-end, wedge failure at the intersection of J1-J3 planes and planar failure along J3 plane are the vulnerable failure modes (Fig 12 & Photo 13).
12. Observation of the failed rock mass dumped as slide debris/muck on the downslope of road shows that the largest failed rock boulder measures 1-1.5 m³ while the rest comprises small rock fragments and indicates the size of wedges formed due to the intersection of the joint planes.

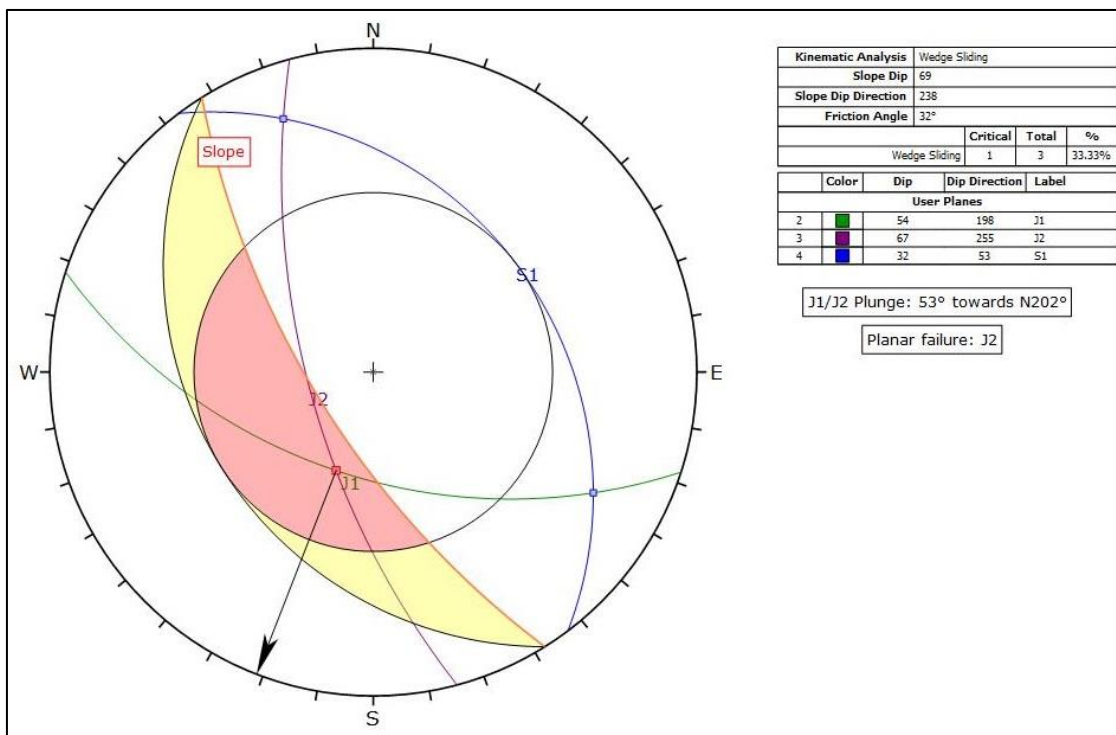


Fig 11. Kinematic admissibility of the structural data collected at the central portion of Mehla landslide.

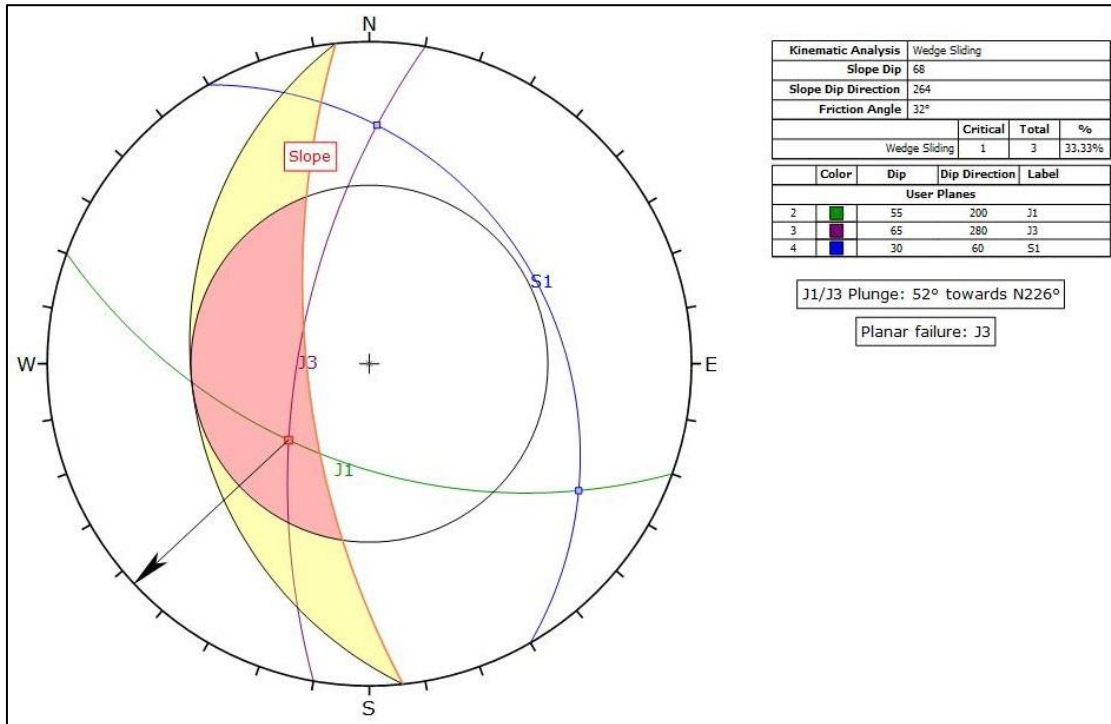


Fig 12. Kinematic analysis of the structural data collected for the slope towards Chamba-end.

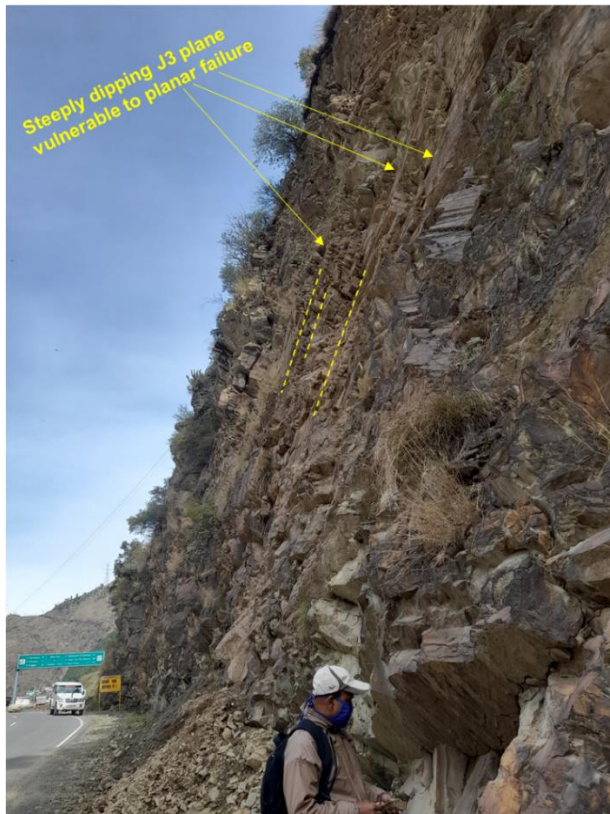


Photo 13. The vulnerable planar failure along J3 plane as seen on the slope towards Chamba-end.



Photo 14. Trace of the prominent J1 plane indicated in yellow dashed lines.

13. Rock exposures are found all around the landslide except for a small patch of variably thin (0.5-2 m) colluvial soil towards the right flank slopes and further away from the direct influence of the slide zone (Photo 15A).

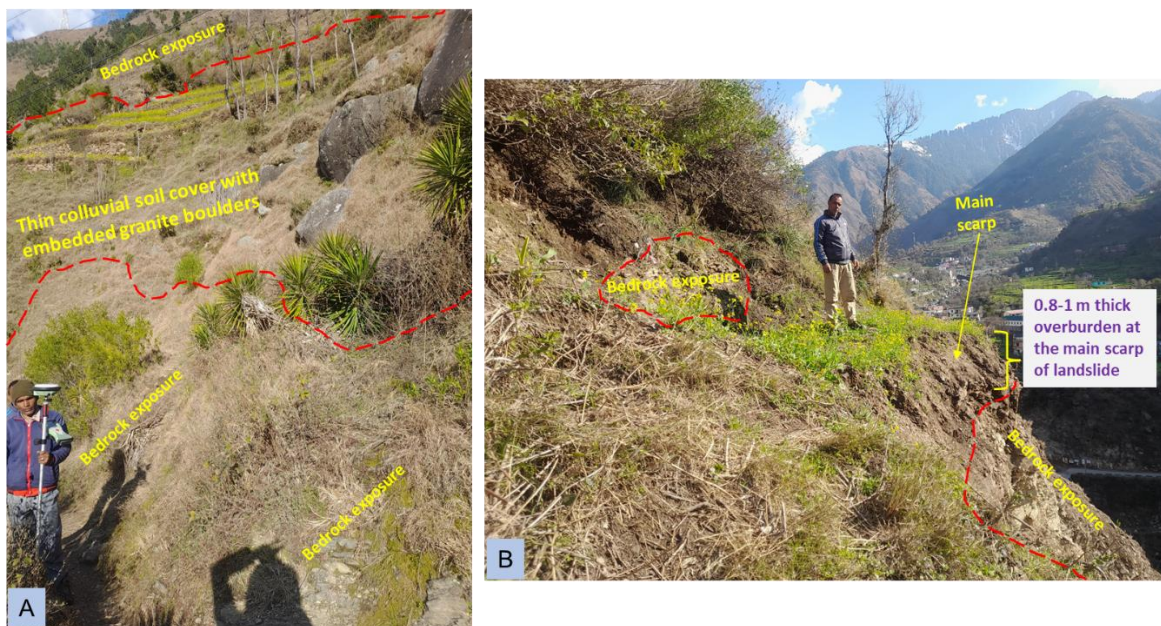


Photo 15. The variably thin overburden cover towards the right flank slope and the main scarp.

14. Based on the information gathered from the road maintaining authorities pertaining to the sequence of events at the site and field observations made with respect to the structural disposition of rocks, rockmass condition, the existing slope morphometry and the landslide

attributes, the Mehla landslide can be classified a rock slide (and rock fall) that had been induced due to recent road widening activities. Removal of the toe of slope through excavation and/or blasting for road widening and consequent formation of overhanging slopes during the initial stages coupled with the presumed development of pore pressure along the vulnerable wedges and joint planes following the incessant rains led to free fall of the poor rockmass under gravity and development of tension cracks over the comparatively better/more competent rocks.

Elements at risk

The elements facing the direct impact of the landslide include the 120-125 m stretch of the National Highway and the commuters/traffic along the road. Other infrastructural elements, if any, located nearby the landslide are one 11 KV transmission pole located at about 14 m upslope (NE direction) from the landslide main scarp and a residential house (Photo 6) located atleast 32 m away from the downstream flank of the landslide (NNW direction). Further, in the space between the right flank of the landslide and the residential house exists a minor depression leading to a change in the slope aspect (Photo 6 & Fig 16) which is crucial when viewed from the ability/potential of the slopes for crack propagation and slide enlarging/widening activity.

Geological Assessment

The morphological details of the landslide vis-à-vis the stability appraisal of the elements at risk and the expected activity of the landslide are outlined below:

- a. Part of the irregular-shaped main scarp of the landslide exposes a thin cover of colluvial soil (0.8-1 m) underlain by the variably weathered schistose quartzites (Photo 15B). Due to the existing very steep slope (69°) at the main scarp of the landslide which is highly detrimental to the slope stability, intermittent failure of the exposed slope mass from the higher reaches of the landslide (towards the main scarp) cannot be ruled out.
- b. At the immediate crown of the landslide, a steep natural slope exists which gradually increases in gradient towards the hilltop leaving absolutely no space for a meaningful/sustainable slope moderation. No tension cracks or ground fissures were recorded at the crown of the landslide which may be encouraging from the slide retrogression point of view. An unlined-drain (kutchu/earthen) is also seen constructed to follow the trace of a foot track at the crown.

- c. The upstream flank of the Mehla rockslide exposes in-situ bedrock with no records of tension cracks or ground fissures. Further, the continuity of the upstream flank is limited by the spur line beyond which a change in the slope aspect occurs and therefore no possibility of widening/enlarging of the landslide is apprehended.
- d. Five linear cracks oriented NNW-SSE and transverse to the slide have been mapped at the downstream flank of the landslide. However, at about 9 m north to this downstream flank, a depression occurs beyond which the slope aspect changes (Fig 16) and thereby restricts the ability/potential of the 5 delineated cracks to propagate further north. Since the lone residential house in the vicinity of the landslide is located further away to the north of this depression (Fig 16), enlargement of the landslide till the location of this house in the event of reactivation thereby endangering the house and its occupants can be ruled out under the existing geological and geohydrological conditions.

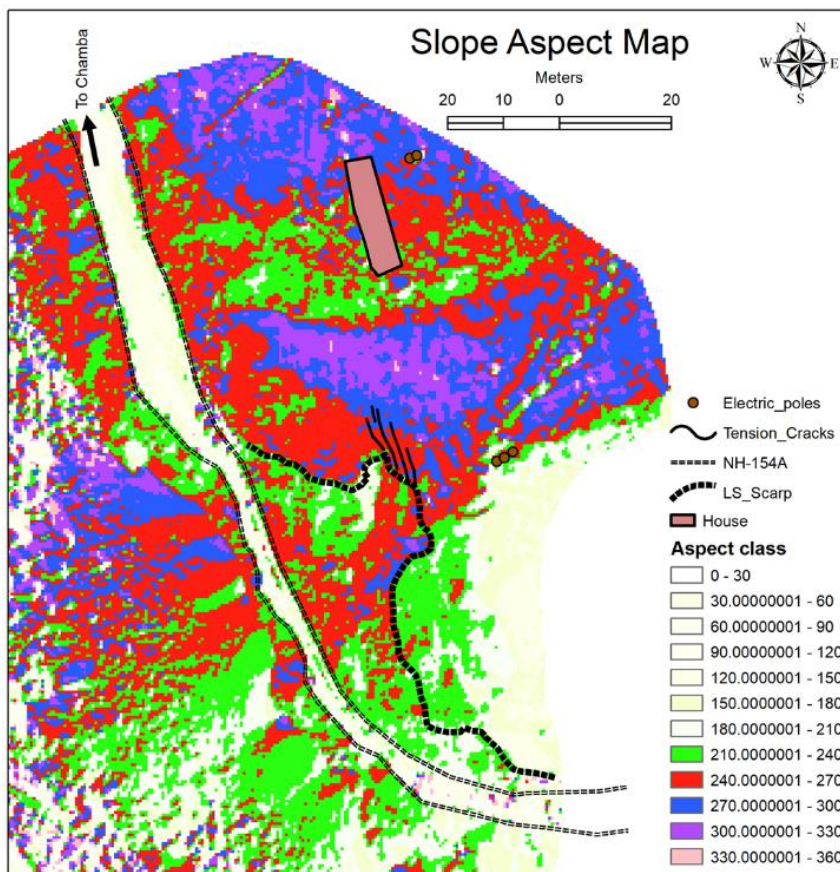


Fig 16. Slope aspect map of Mehla landslide area. Note the change in aspect from the right flank to the residential house.

- e. The portion of the slide from the NH road bench up to the main scarp forms the zone of depletion while the portion of the slope from and including the NH road bench down to the Ravi River bed forms the zone of accumulation for the landslide.

- f. Kinematic analysis of the discontinuity planes indicate the presence of vulnerable wedges and planar failures that gets daylighted solely due to the excavated steep slope (68°-69°). In other words, the steep plunge of wedges and steep dips of discontinuity planes at the site would not have been vulnerable under natural slope conditions which explains the lack of any landslide records at this site during the consultation of earlier landslide inventories available with GSI or from the available temporal Google Earth imageries.
- g. The contributory factors in the initiation of the Mehla rockslide includes the inherent poor rockmass conditions and the daylighting of planes and wedges formed by the intersection of joints as a result of the excavated steep slope. However, the causative factors remains the blasting and cutting at the toe of slope for road widening giving rise to an unfavorable steep slope (with initial overhang conditions).
- h. The reported spell of incessant rains during the 3rd week of January 2022 acted as the triggering factor in the failure of the rockmass standing on the excavated steep slope.

Recommended Mitigation Measures

In view of the geological constraints at the site which leaves very little or no scope for grading the slope and development of adequate intervening benches and closure of the road/NH during the period of such grading, following mitigation measures are suggested which can be executed rapidly and with the locally available resources.

- a. Manual scaling of the loose overburden and detached rock mass from the upslope.
- b. Lining of the drain at the head region of the slide so that any surficial water is guided and drained away from the affected stretch of the slope.
- c. Spot rock anchors length 6-8 m, ϕ 32/36 mm @ 3m staggered spacing and a suitably designed concrete cladding for a stretch of 5-6 m above the level of NH be provided to support the lower part of the affected slope.
- d. A suitably designed rock shelter, preferably of RCC, with a half tunnel profile may be provided as a passive measure so that the sliding of rock mass, if any, does not hit any person or vehicle passing through this affected stretch.
- e. The columns for the slab of this shelter can be raised from the river edge where the in-situ rock is exposed.

Plate I: Detailed Geological Map of Mehla Landslide on Chamba-Bharmaur National Highway (NH-154A)

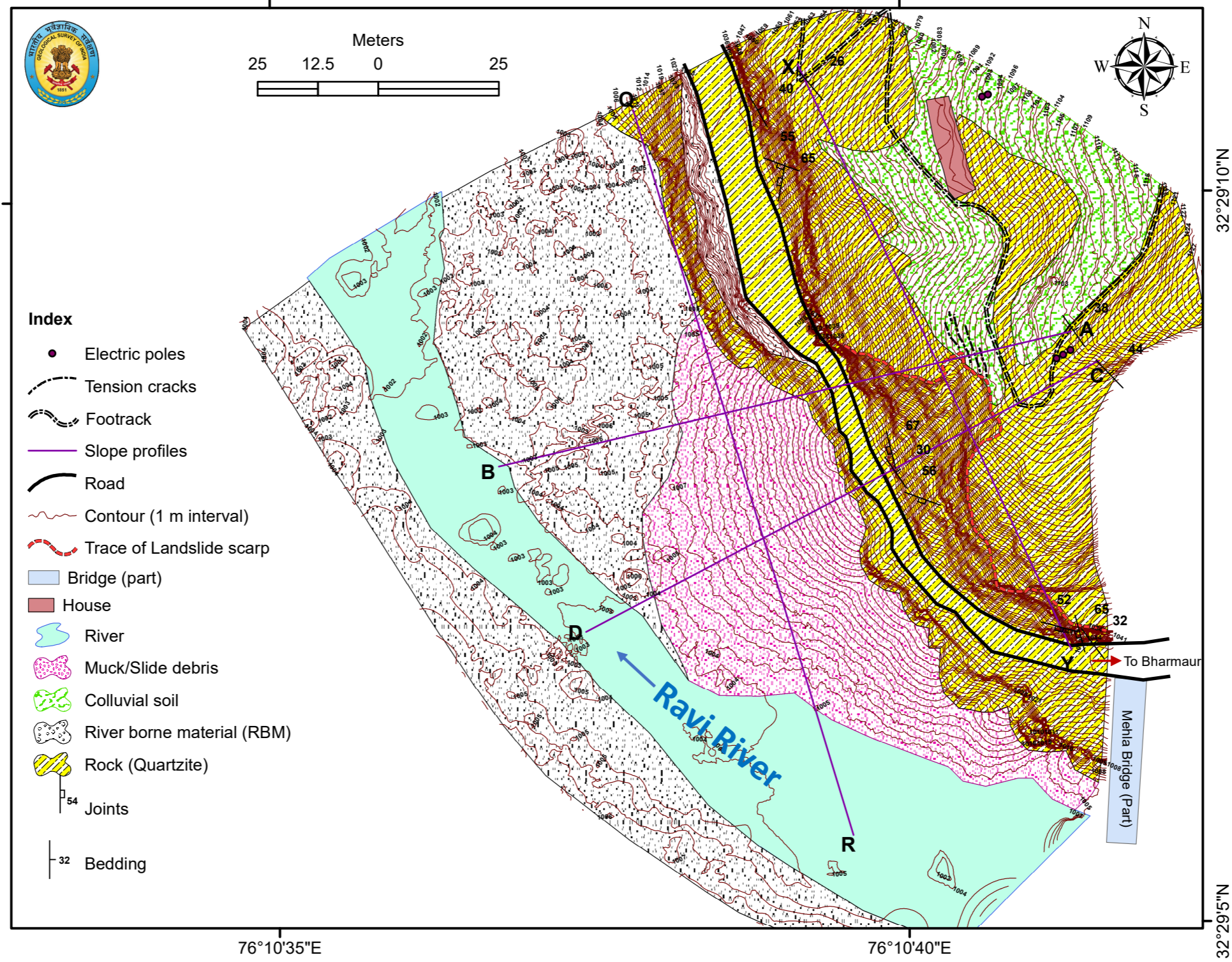
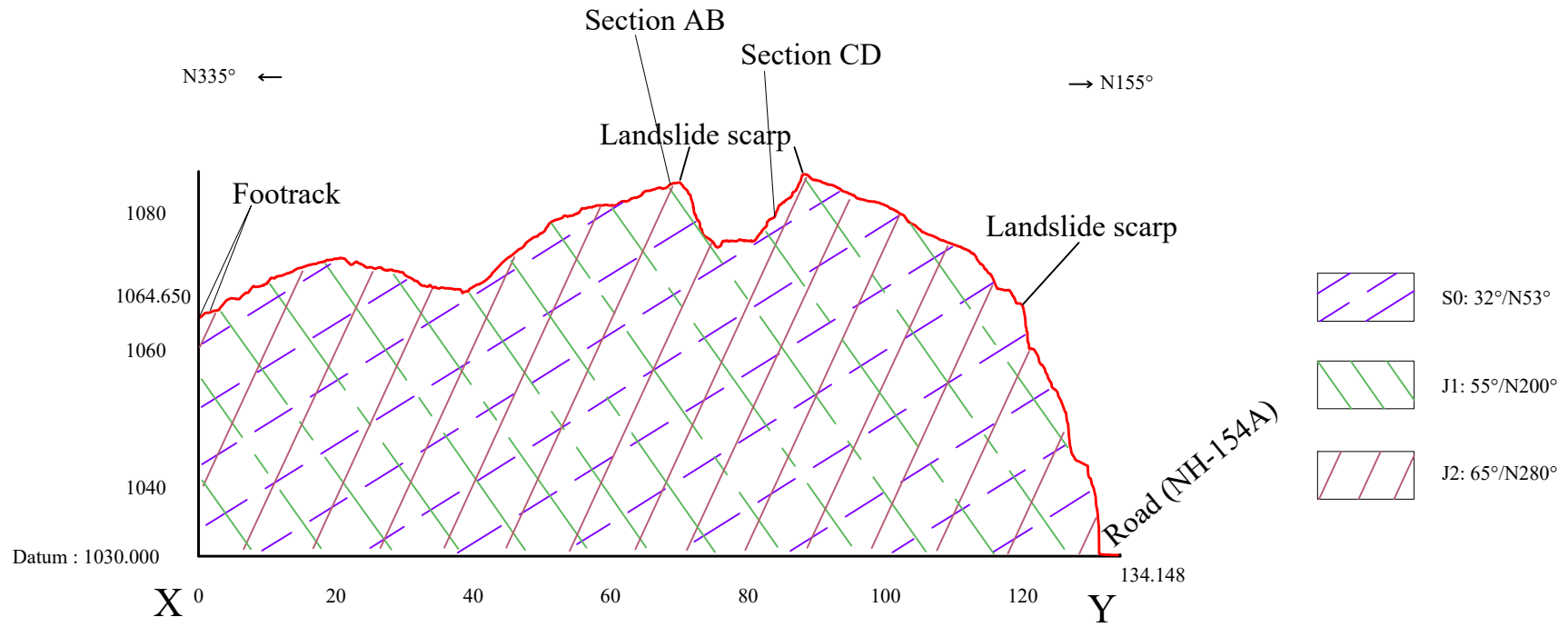
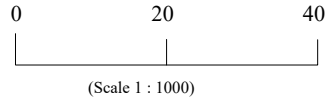


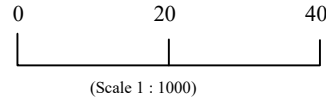
Plate II: Geological cross section along X-Y line at Mehla Landslide on Chamba-Bharmaur National Highway (NH-154A)



Note:
 a) Spacing of discontinuity planes is schematic
 b) Apparent dips plotted

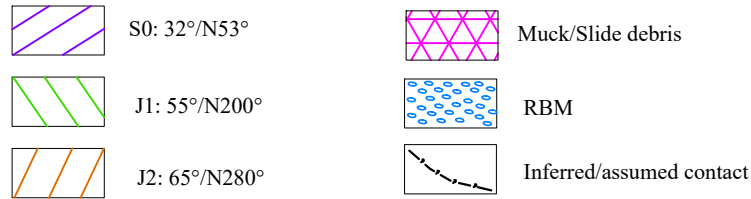
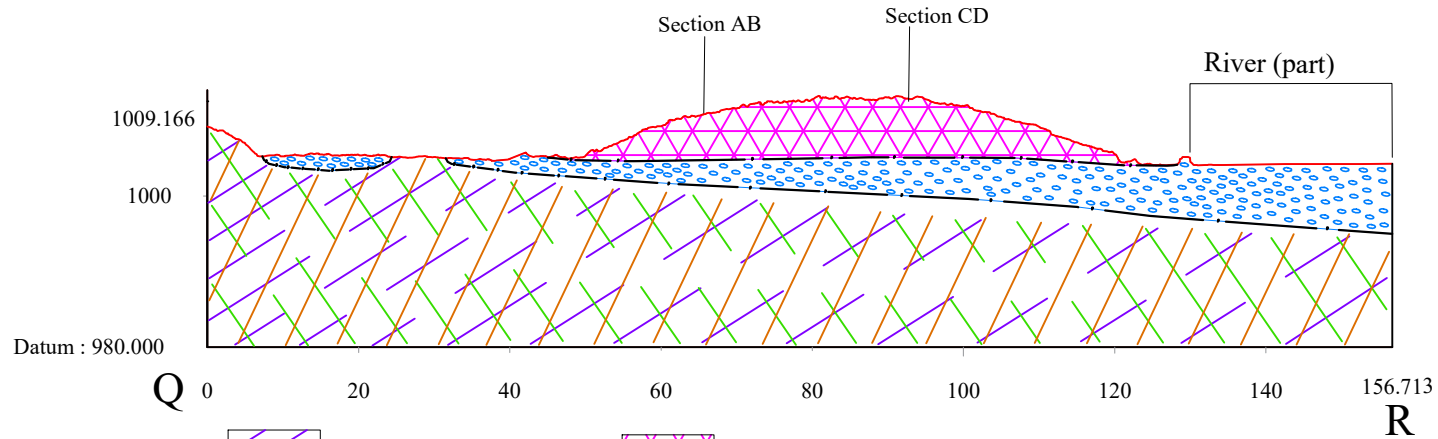
Geological Survey of India (FS: 2021-2022)	
Surveyed by:	Shri S.K.Das, Survey Officer
Prepared by:	Shri M.Chasie, Sr. Geologist
Checked by:	Dr. Harish Bahuguna, Director
	Shri P.T.Ilamkar, Director

Plate III: Geological cross section along Q-R line at Mehla Landslide on Chamba-Bharmaur National Highway (NH-154A)



N343° ←

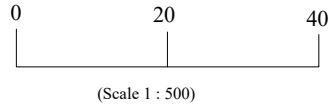
→ N163°



Note:
 a) Spacing of discontinuity planes is schematic
 b) Apparent dips plotted
 c) Thickness of overburden is assumed.

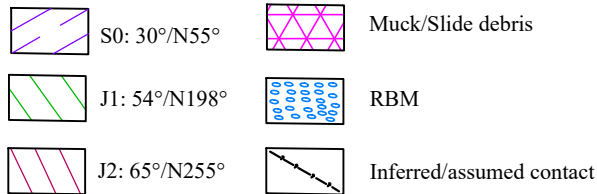
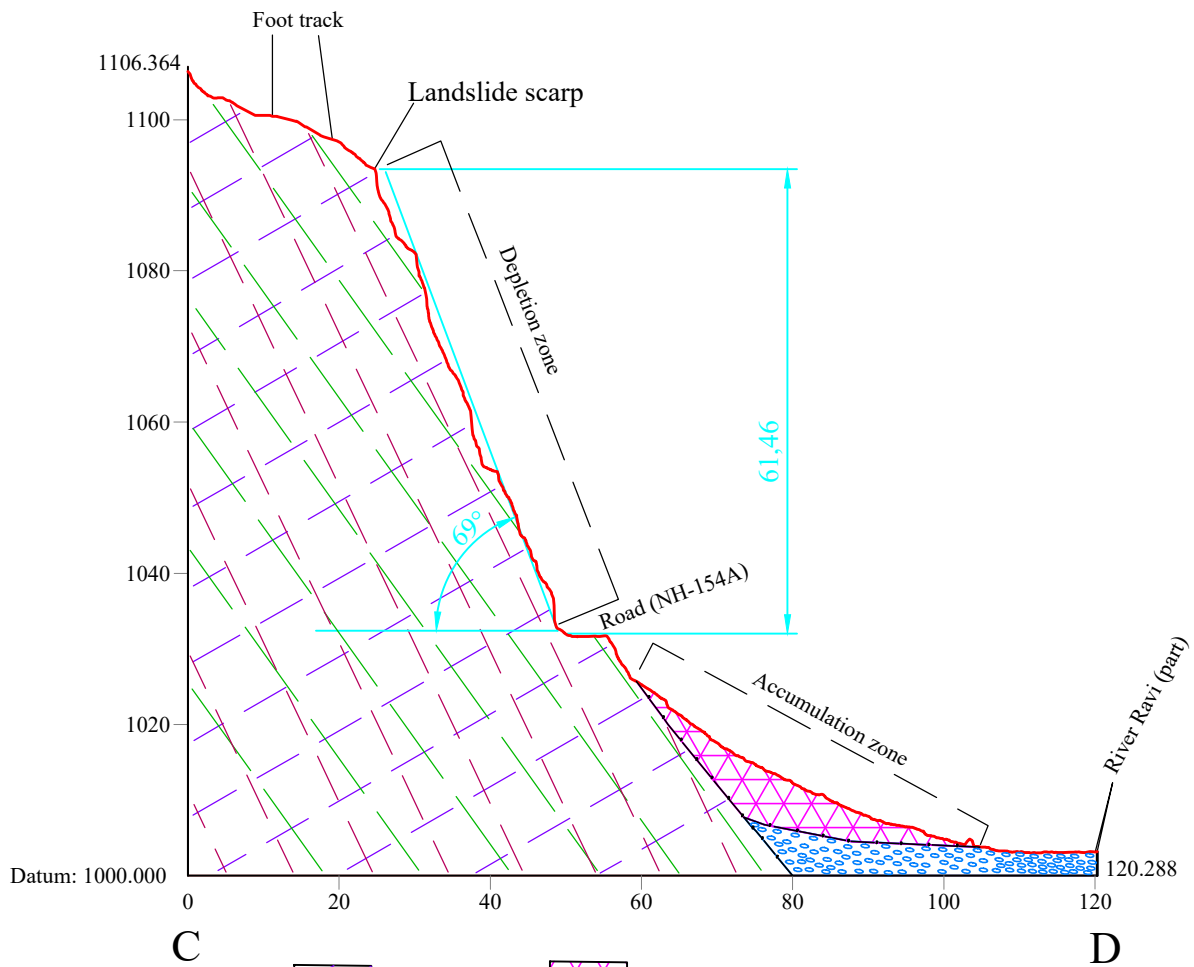
Geological Survey of India (FS: 2021-2022)	
Surveyed by:	Shri S.K.Das, Survey Officer
Prepared by:	Shri M.Chasia, Sr. Geologist
Checked by:	Dr. Harish Bahuguna, Director
	Shri P.T.Ilamkar, Director

Plate V: Geological section along C-D slope profile at Mehla Landslide on Chamba-Bharmaur National Highway (NH-154A)



N62° ←

→ N242°



Note:
 a) Spacing of discontinuity planes is schematic
 b) Apparent dips plotted
 c) Thickness of overburden is assumed.

Geological Survey of India (FS: 2021-2022)	
Surveyed by:	Shri S.K.Das, Survey Officer
Prepared by:	Shri M.Chasie, Sr. Geologist
Checked by:	Dr. Harish Bahuguna, Director Shri P.T.Ilamkar, Director