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GEOLOGICAL SURVEY OF INDIA

हिमाचल प्रदेश के किंनौर जिले में उर्नी भू-स्खलन के आरम्भिक आंकलन का प्रतिवेदन

मद संख्या: एन आर/ पी एच पी/2014/41 /076

(कार्यसत्र : 2014 - 15)

REPORT ON THE PRELIMINARY ASSESSMENT OF LANDSLIDE INCIDENCE AT URNI, DISTRICT- KINNAUR, HIMACHAL PRADESH

Item Code: NR/PHP/2014/041 /076

(Field Season: 2014 -15)

द्वारा

राहुल वाडक्केडत, भूवैज्ञानिक

एवं

ए रमेश कुमार, भूवैज्ञानिक

By

Rahul Vadakkedath, Geologist

and

A Ramesh Kumar, Geologist

अभियान्त्रिक भूविज्ञान प्रभाग

Engineering Geology Division

राज्य इकाई: पंजाब एवं हिमाचल प्रदेश, मिशन-IV उत्तरी क्षेत्र, चंडीगढ़

State Unit: Punjab and Himachal Pradesh, Mission –IV, Northern Region, Chandigarh

2015

REPORT ON THE PRELIMINARY ASSESSMENT OF LANDSLIDE INCIDENCE AT URNI, DISTRICT KINNAUR, HIMACHAL PRADESH

Item Code NR/PHP/2014/041 ITEM NO: 076

(Field Season: 2014-15)

By

Rahul Vadakkedath
and
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हिमाचल प्रदेश के किंनौर जिले में उर्नी भू-स्खलन के आरम्भिक आंकलन का प्रतिवेदन

मद संख्या: एन आर/ पी एच पी/ 2014/041/76

(कार्यसत्र : 2014-15)

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राहुल वाडक्केडत एवं ए रमेश कुमार,

भूवैज्ञानिक

सारांश

आकलन , रिकॉर्ड और भूस्खलन का मूल्यांकन करने के लिए, उर्नी गांव किन्नौर जिले , हिमाचल प्रदेश में, भूस्खलन के प्रारंभिक आकलन 20/04/2015 से 28/04/2015 के मध्य किया गया था । उर्नी भूस्खलन जटिल और सक्रिय है , इसलिये आपदाग्रस्त क्षेत्र की चित्रित और हदबंदी करने के लिए और 1.5 की अस्थिरता हालत की वर्तमान स्थिति का अध्ययन करने के लिए टोटल स्टेशन के साथ मानचित्रण किया गया ।

अध्ययन का क्षेत्र टोपोशीट संख्या 53I/2 में पड़ता है और अध्ययन के क्षेत्र में जेओरी- वनगतू ग्रानइटॉईड परिसर के नेईसेस पाये गये है जो की अनेक चरणों में विकृत हैं । भूस्खलन सतलुज नदी के दाहिने किनारे पर एक मलबे अवरित चट्टानी ढलान में 2014 के मानसून के दौरान शुरू की गई है । जो मलबे सामग्री ग्लेसियो फ्लूवियल मूल के हैं वो राष्ट्रीय हाइवे-22 की तरफ गिर गया है और पूरे सड़क के यातायात को प्रभाबित कर रही है । यातायात को सामने तट में एक और भूस्खलन होने का खतरा सड़क पर अस्थायी पुलों के माध्यम से बाँटा गया है। यह मलबा सतलुज नदी के प्रवाह को सीमित करके एक भूस्खलन झील के बनने के लिए बढ़ावा दे रही है । अस्थायी सामान्य सीमा संतुलन आधारित संख्यात्मक ढलान स्थिरता विश्लेषण , ढलान के गठन के मलबे को सुरक्षा का एक बहुत कम कारक (0.678) देने के साथ एक अत्यधिक अस्थिर श्रेणी मे रखा है । यह संख्यात्मक स्थिरता विश्लेषण जो की ढलान द्रव्यमान के एकरूपता पर और मिट्टी सामग्री की एकजुटता पर निर्भर करता है उसे और अधिक यथा-स्थान जांच की जरूरत है। स्थलाकृति और दरारों का 3-डी उन्मुखीकरण का उपयोग करके जो काईनेमॅटिक ढलान स्थिरता विश्लेषण की गयी है उससे यह प्रकट होता है की ढलान पर चट्टान गिरने की संभावना है जिसका भू-स्खलन के साथ उपचार करना ज़रूरी है ।

जांच के दौरान स्लाइड के संभावित प्रेरणा का कारकों का आकलन किया गया है तथा आगे और गिरावट से बचने के लिए उपयुक्त उपचारात्मक उपायों पे काम कर रहे हैं।

REPORT ON THE PRELIMINARY ASSESSMENT OF LANDSLIDE INCIDENCE AT URNI, DISTRICT KINNAUR, HIMACHAL PRADESH

Item Code NR/PHP/2014/041/076

(Field Season: 2014-15)

By

Rahul Vadakkedath and A. Ramesh Kumar,
Geologists

ABSTRACT

In order to, record and evaluate the landslide at Urni village, Kinnaur district, Himachal Pradesh; preliminary studies of the landslide were carried out between 20/04/2015 to 28/04/2015. As the Urni landslide is complex and active, geological mapping was carried out on 1:2500 scale with the help of total station to delineate and demarcate the distressed zone and to study the present state of the instability condition covering 1.5 sq. km.

The study area falls in Toposheet no 53I/2 and exposes gneisses of the Jeori- Wangtu gneissic complex which have undergone poly phase deformation. The landslide has been initiated during the monsoon of 2014 in a debris covered rocky slope on the right bank of Sutlej River. The debri material, of glacio-fluvial origin has slide down to the NH-22 thus severely affecting the traffic. The traffic was diverted through temporary bridges on another landslide prone road on the opposite bank. The debris had also restricted the flow of the Sutlej River thus converting it to a landslide lake. The tentative General Limit Equilibrium based numerical slope stability analysis revealed that the slope forming debri are highly unstable with a very low factor of safety (0.678). The numerical stability analysis which depends on the homogeneity of the slope mass and precise values of cohesion of the soil materials needs more in-situ investigations. The kinematic slope stability analysis by using 3-D orientations of the discontinuities and topography revealed the possibility of rockfalls in the slope which should also be treated along with the landslide.

During the investigation, probable causative factors of the slide have been assessed and appropriate remedial measures are worked out to avoid further deterioration of the existing slide.

REPORT ON THE PRELIMINARY ASSESSMENT OF LANDSLIDE INCIDENCE AT URNI, DISTRICT KINNAUR, HIMACHAL PRADESH

1. INTRODUCTION:

Preliminary assessment on landslide incidence has been carried out at Urni village, District Kinnaur, Himachal Pradesh based on a request from the Special Secretary, Government of Himachal Pradesh vide Lr. No. Rev (DMC)(F)11-09/2013 dated 12th November, 2014. Initially, reconnaissance of the distressed area had been taken up during the period between 20/01/2015 and 22/03/2015 by S/Shri. Rahul Vadakkedath and Shri A Ramesh Kumar, Kundan Rangari and Ravi Shanker Chaubey, Geologists GSI, SU: P & H.P, Chandigarh. It was observed that the slide has a complex nature. Therefore detailed survey with total station was found mandatory. Accordingly, a request had been made to the State department, Govt of H.P to provide a surveyor with total station vide Lr. No 396/32/GSI/EG/Urni/LS/2015 dated 12/01/2015. The State Govt was kind enough to provide the same for a limited period, with available limited resources, detailed landslide investigation had been carried out between 20/04/2015 to 28/04/2015 by S/Shri Rahul Vadakkedath and A Ramesh Kumar, Geologists, GSI SU: P & H.P, Chandigarh. S/Shri Manoj Kumar, Surveyor, HPPCL and Shri Joginder Singh, Patel engineering Pvt Ltd accompanied the GSI team during the landslide investigation.

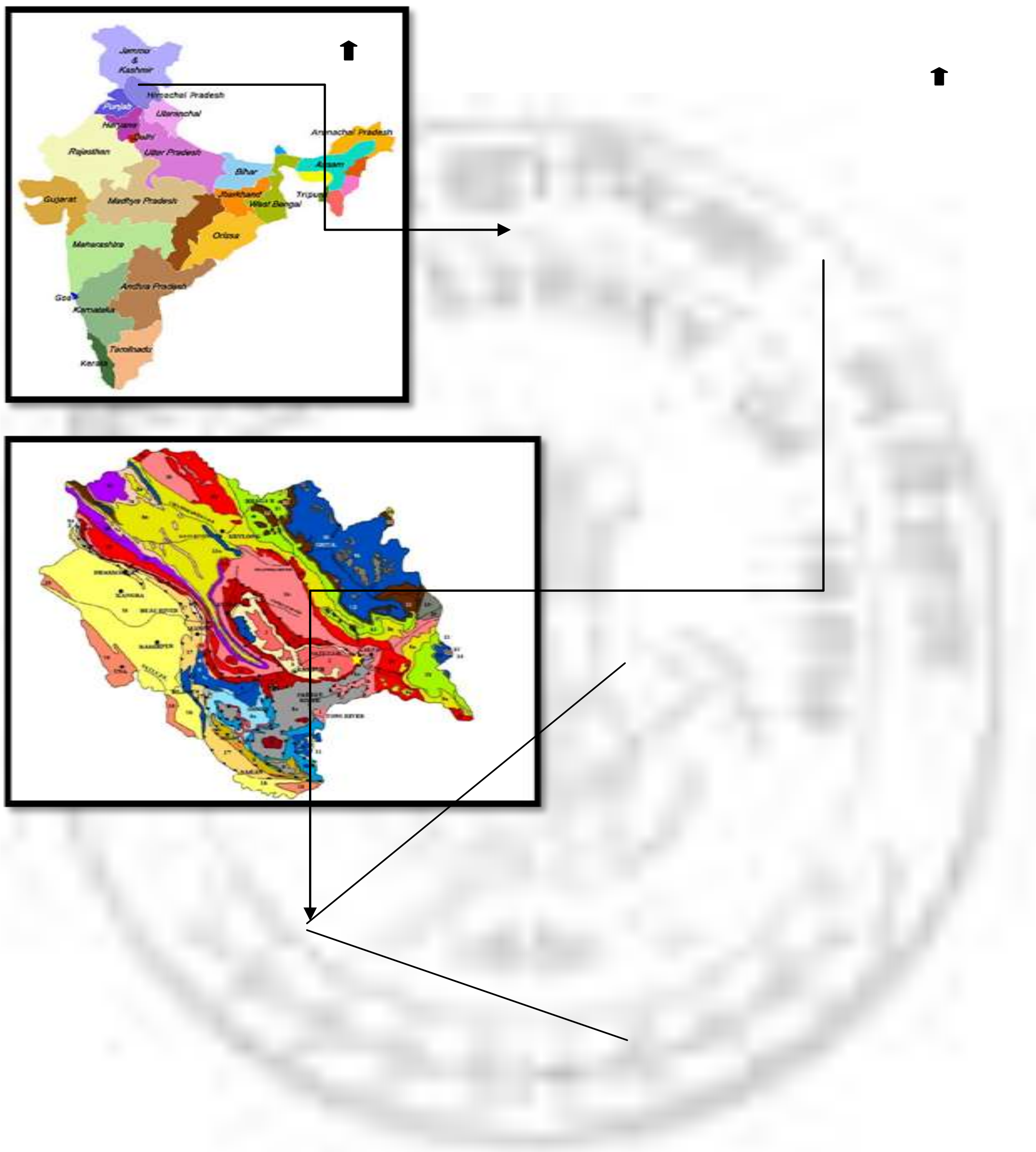
1.1 OBJECTIVE:

To assess, record and evaluate the landslide at Urni, Kinnaur district, Himachal Pradesh, prepare a geological map on 1:2500 scale using total station, to assess the probable causative factors for the landslide, and to suggest appropriate remedial measures to avoid further deterioration of the existing slide.

1.2 LOCATION AND ACCESSIBILITY:

The Study area falls under the Survey of India toposheet no 53I/2 (latitude N 31° 31´ 03.8´´: longitude E78° 07´ 51.6´´) **(Plate-1)**

Plate 1 Location map of Urni landslide



Nearest town is Tapri which is 3km SW of the study area. It can be approached from Chandigarh by NH-22. Shimla, the State Headquarters, having the nearest railway station and airport is 194 km SW of Tapri and can be approached via NH-22. Reckong Peo is the District Headquarters located 30 km NE of the study area.

1.3 PHYSIOGRAPHY AND DRAINAGE:

The area of investigation forms a part of the Great Himalayan Range showing young topography with steep escarpments, cliffs and gorges. The elevation of the area varies from 1760m at Tapri and 2230 near Urni village. The northern part of the area is drained by southerly flowing Raurakhad, Runangkhad and Rohikhad streams. All these streams join the Sutlej River flowing in WSW direction. The southern part of the area is drained by northerly flowing Baspa River which joins the Sutlej River near Karchham. The rivers show dendritic type of drainage pattern.

1.4 CLIMATE:

Due to its high altitude, the study area experiences with long winter from October to April and moderate snowfall between December and March. During winter, the temperatures plunge as low as -1 to 2^{o}. From June to September, the area experiences summer and spring. Rainfall is scanty as the area falls in rain shadow zone.

1.5 FLORA AND FAUNA:

The flora comprises thick forest of pine, fir, spruce and birch. The higher reaches (>3800m) are devoid of trees and supported mainly with small bushes and medicinal plants such as dhoop (Jurinea alonds) are quite common. Leopards, wild goat, bear, wild cat represent the fauna in the area. (Dorka and Gupta 1994)

1.6 PREVIOUS WORK:

Mc Mahon (1886), Dey and Chakraborty (1973), Jangi and Gaur (1975) and Bassi (1988) have carried out geological mapping in Jeori -Wangtu-Karchham area. Singh and Jain (1992) while carrying out transact mapping in the Jeori-Karchham area reported four generations of folding. Dorka and Gupta (1994), carried out study of granites and pegmatites and investigated potentials for tin and tungsten. Dorka and Prasher (2000) carried out investigations for tungsten and silver in the eastern part of the study area. GSI had carried out geotechnical assessment of landslide at Reckong Peo, Kinnaur district, H.P. during 28th Nov to 4th December 2010 where the subsidence in a 650m wide zone was studied near Govt degree college, Reckong Peo.

1.7 PRESENT WORK:

The present work deals with the delineation of the distressed zone and also to study the instability condition by mapping with total station in 1:2500 scale, identifying the chief causative factors for the landslide, applying numerical and kinematic slope stability analysis to the slide to derive the factor of safety and mode of failure of the slide and to recommend suitable control and corrective measures to avoid further deterioration of the existing slide at Urni.

1.8 ACKNOWLEDGEMENT:

The authors express their sincere thanks and gratitude to Dr. K Jayabalan, Director, EG division, SU: P & H.P for critically reviewing the report, guiding the authors by giving effective suggestions and ideas during the work. The authors render their sincere thanks to the District administrative officers, Kinnaur, surveyors and staffs for providing necessary logistics support during the landslide investigation.. The authors extend their gratitude to Shri Ravi Shanker Chaubey and Kundan Rangari, Geologists, GSI SU: P & H.P for their help and cooperation during the initial part of field work. Last but not the least; the authors are indebted to the

2. REGIONAL GEOLOGY:

The study area lies on the eastern part of the Jeori-Wangtu Gneissic Complex. The Wangtu Granitoid acts as a basement rock in the area. Bhargava and Ameta (1987) and Bassi (1988) reported that, the Manikaran Formation of Rampur Group lies over the Jeori-Wangtu Gneissic complex along an unconformity. The Manikaran Formation is thrusted over by the Jutogh Group and the Jutogh Group is thrusted over by the Vaikrita Group. (B.S Dorka et al-2000). The tentative stratigraphic succession of the area of field study is as follows.

Table 1 Stratigraphic succession of the area

AGE	GROUP	FORMATION	LITHOLOGY
Lower Paleozoic		Rakcham Granitoid	Biotite granite with leucocratic and pegmatitic differentiates
Middle Proterozoic	Jutogh Group	D-Formation	Quartzite, Quartz mica schist, porphyroblastic gneiss
		C-Formation	Dark Grey garnetiferous mica schist and quartzite with thin bands of mineralized calc silicates and amphibolite.
Early Proterozoic	Vaikrita Group	Kharo Formation	Psammatic gneiss, Porphyroblastic gneiss,

			kyanite- sillimanite schist and quartzite
	Rampur Group	Manikaran Formation	Creamy white well bedded quartzite and sericite quartzite
Early Proterozoic	Jeori Wangtu Granitoid Complex		Porphyroblastic Gneiss with thin bands of schist, quartzite, amphibolite and calc-silicate bodies intruded by pegmatite and aplite

(Source: B.S Dorka et al- 2000)

SITE GEOLOGY:

The study area is bounded by MCT (Main Central Thrust) in the south and Indus Tsangpo Suture Zone in the north. The lithounit exposed in the study area comprises of augen / porphyroblastic gneiss with K and Na Feldspars in association with biotite, muscovite and quartz. **(Fig-1).** The bedrock is overlain by thick glacio-fluvial deposits with silt sized sediments and many erratic boulders. The rock has well developed foliation trending N75°W- S75°E and dipping 30° towards NE direction which is against the valley slope. Also, the rock shows three sets of prominent joints, the characteristics of which are enumerated in Table-2. The interplay of these joint sets forms wedge failures, observed along the road section. Valley dipping joint J_2 with intersection of J_1 and J_3 joint sets leads to the slope failure. Field data reveals that, the area had undergone poly phase deformations vise fold, faults, shears, etc. as evidenced by the development of augen structures in the gneisses, stretching and realignment of mineral grains, boudins, striations, slickensides, etc. **(Fig-2,3**). Further, a N-S trending fault has also been reported near Kilba (B.S Dorka et al- 1997).

The Urni landslide is on the right bank of Sutlej River which is flowing towards the WSW direction. The slide exhibits a moderate slope of 40°-45° (**Plate 2).** Whereas, the left bank of the Sutlej River exhibits a steep rocky knob, the right bank exposes thick overburden comprising of debris.

Plate 2 Slope map of Urni area showing the location of Urni landslide

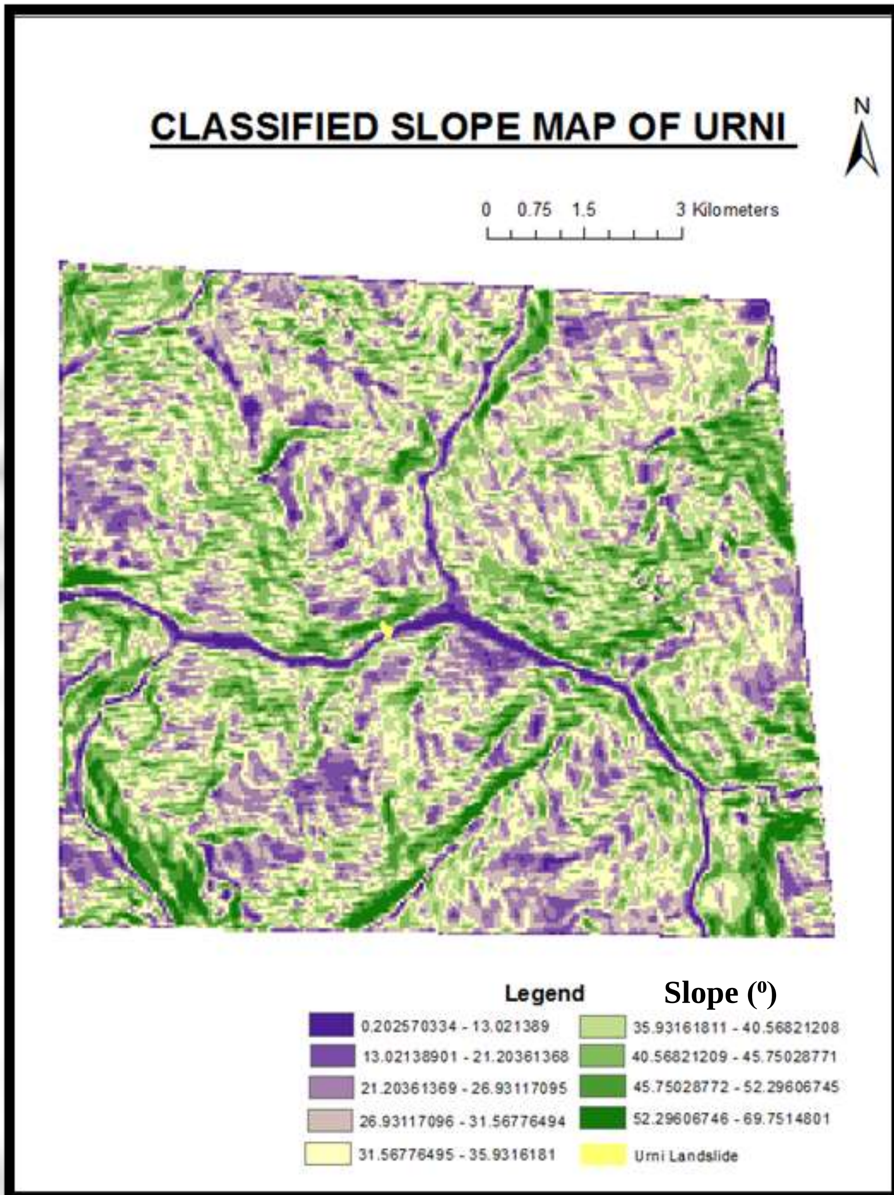
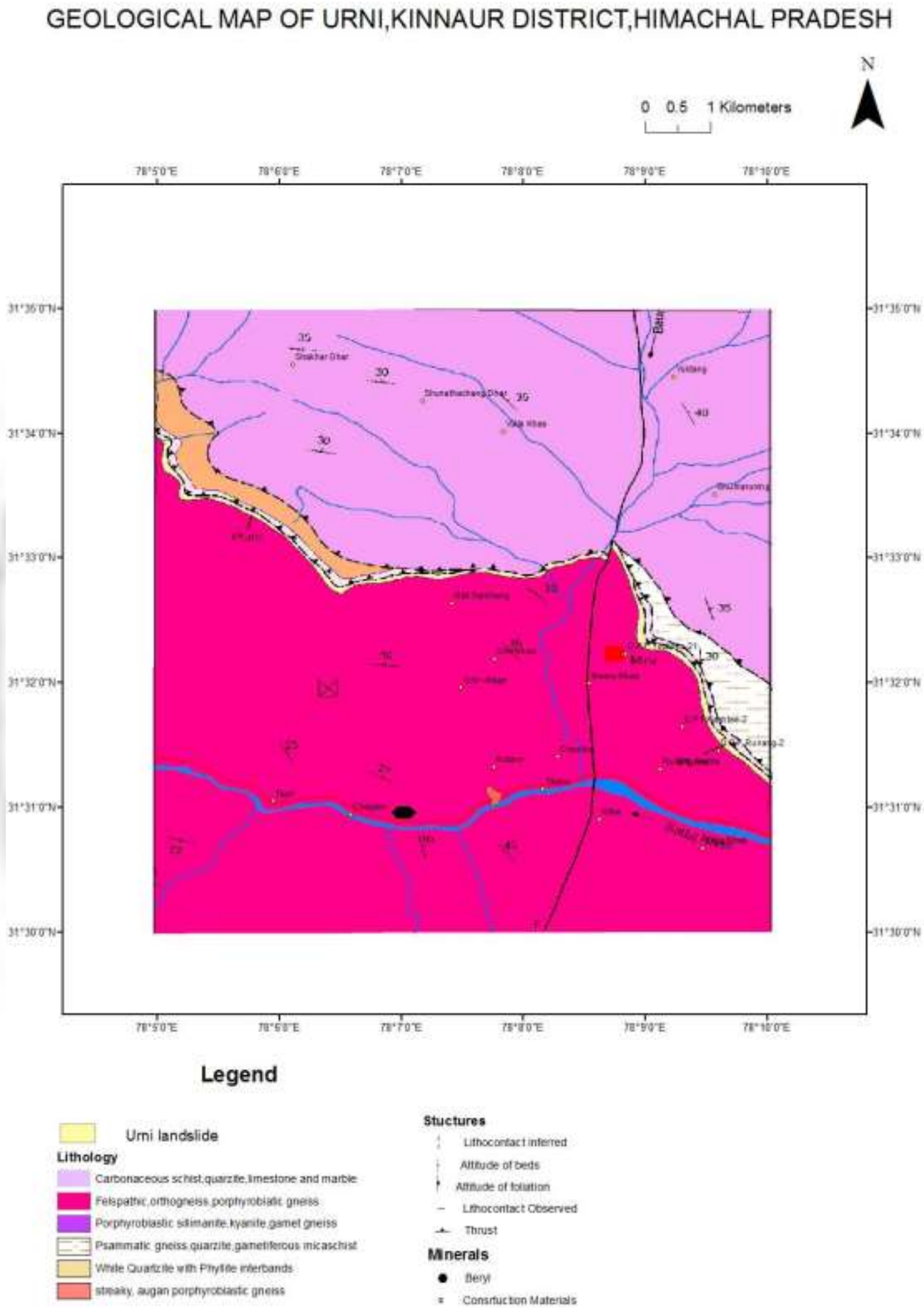


Plate 3 Geological map of the study area



source: portal.gsi.gov.in

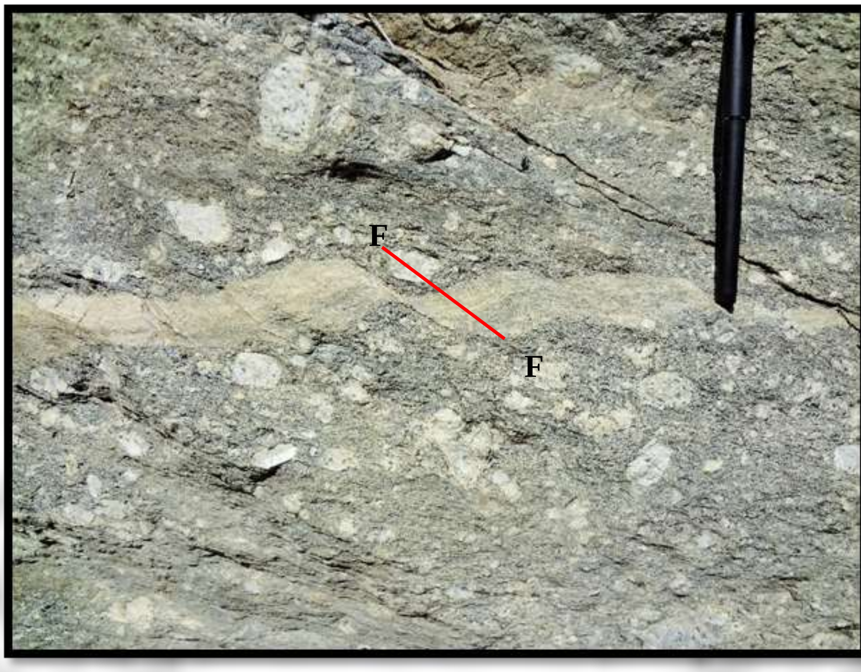


Fig 1 Rock showing feldspar crystals along with boudins and micro fault.

Fig 2 Rootless folds and displacements found in rock exposures.

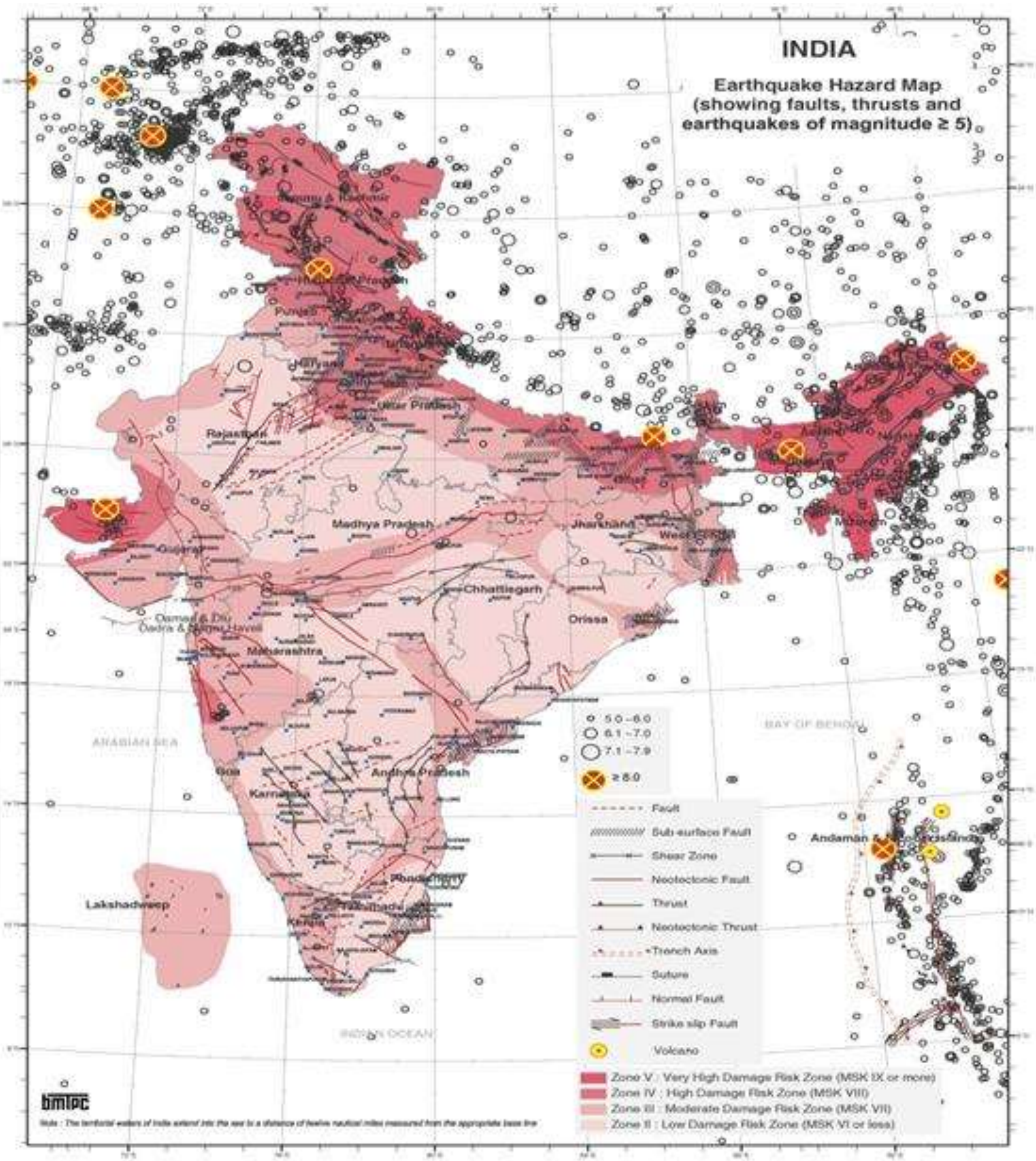
Fig 3 Sheared rock with development of augen along the shear plane observed.

3. SEISMOTECTONICS AND SEISMICITY:

The study area is located in the Higher Himalayas between the Main Central Thrust and the Indus-Tsangpo Suture Zone (ITSZ), and falls in zone IV of the seismic zoning map of India. The role of active tectonics is supported by the presence of low enthalpy hot water springs at two locations (N31°31’ 02”, E 78° 06’ 13”) and (N31° 31’ 2.3”, E78° 06’ 20.9”) near the Tapri village. Important seismic events that has happened near the study area is as follows.

- 1905Kangra earthquake (Magnitude 8+)
- 1908 Kullu earthquake(Magnitude 6.0)
- 1945 & 1947 Chamba earthquake (Magnitude 6.5 & 6.6)
- 1975 Kinnaur earthquake (Magnitude 6.8)
- 1991 Uttarkashi earthquake (Magnitude 6.6) **(Source: www.imd.gov.in)**

Plate 4 Seismotectonic atlas of India, Source: bmptc atlas



BMTPC : Vulnerability Atlas - 2nd Edition; Peer Group, MoH&UPA; Map is Based on digitised data of SOI, GOI; Seismic Zones of India Map IS:1893 – 2002, BIS, GOI; Seismotectonic Atlas of India and its Environs, GSI, GOI

4. GEOTECHNICAL EVALUATION:

1. The landslide, which is defined by a rotational failure, has its crown near Urni village where the glacio-fluvial debris material is resting over the bedrock on the hill slope (**Fig-4**). The slide debris comprises of fine grained silt, soil and precarious boulders of up to $5m^3$. The debris dumped on the course of the Sutlej River has choked the river flow creating conditions conducive for the formation of a landslide lake (**Fig-6**).

2. All the traffic through the NH-22 is being detoured using the temporary road constructed in the opposite bank or via Urni village which is also a landslide prone zone.

3. Archival satellite imageries show that the slide was initiated around 6/5/2014 with its main scarp exposed at an elevation of ±2005m above msl. The present position of the main scarp is at EL ± 2168 m above msl. The huge quantity of debris and lack of toe support resulted in the rapid expansion of the existing slide. The slide seems to be still active.

4. The slide can be classified as a major complex slide, wherein two major scarp faces have been developed with slide scarp rising up to 30m high. The thickness of debris in the scarps indicates that the average debris thickness in the distressed zone will be close to 25-30m. The upper part of the slide, above the crown has benches made for the orchards and are still intact. The middle part of the slide has become completely dislodged due to movement along the slope and the toe of the side has the bedrock exposed due to mass wasting. Many large boulders are exposed in the scarps as well as the crown. (**Fig-7).** The toe of the slide has many boulders and loose debris on a 45-50° slope which continues to slide down the slope to get deposited in the debris cone in the river. The left flank of the landslide has comparatively less sediment cover than the right bank. This is inferred due to the presence of bedrock fringing the left flank of the slide.

Fig 4 A panoramic view of the Urni landslide

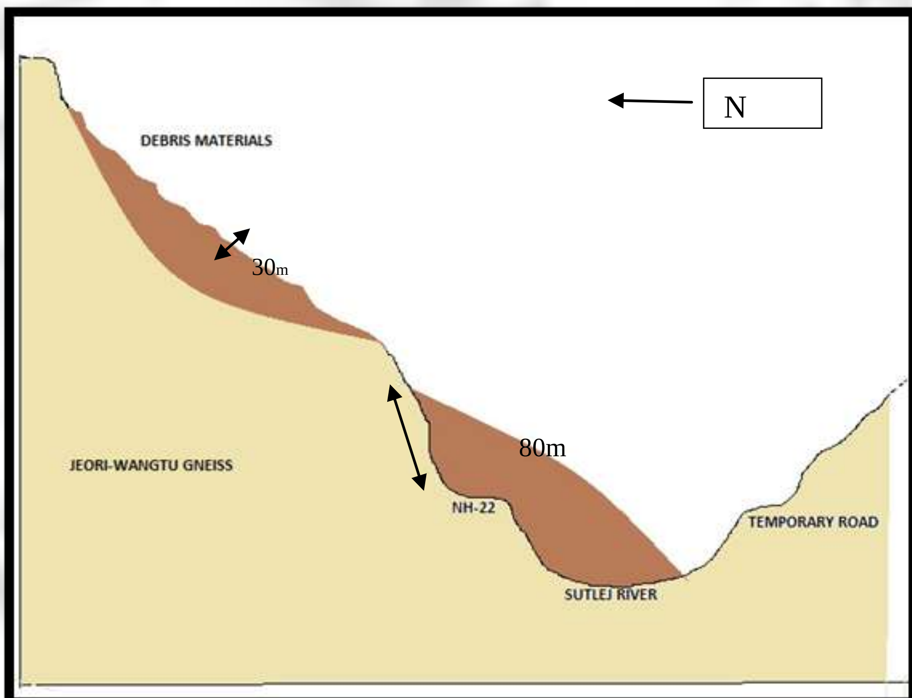


Fig 5 Tentative section of Urni landslide w.r t A-A' in Fig: (Not to scale)

Fig 6 Debris accumulation on NH-22 and part of river Sutlej forming a landslide lake

Fig 7 Secondary scarp with huge overburden thickness

Fig 8 spring near the slide area at El ±2195.4 msl

5. KINEMATIC STABILITY ANALYSIS:

One of the major factors governing the stability of rocky slopes is the directional anisotropy of planar discontinuities in the rock vise Faults, Joints, foliations etc and its geometrical relation with the topography. (Ghosh et al 2010; Romana 1985). This in turn defines the mode of rock sloe failure (plane, wedge or topple) The NH-22 passing below the slide area was observed to be prone to rock falls and therefore the stability of the rocky slope was analyzed using the failure criteria proposed by Hook and Bray (1981) regarding planar and wedge failures. Joint data from various locations has been plotted and analyzed using an arbitrary value (30^o) for friction angle of the rock. (Dunan C Wyllie, Christopher W Mah -2004)

The analysis prove that the road is also prone to rock falls as the intersection between J_3 and J_2 joints and the topographical slope forms a wedge which slopes towards the road **(Fig 9&10)**

Table 2 Average estimates of orientations and conditions of major structural discontinuities

Sl No.	Structure	Strike direction	Dip (°)	Characteristics
1.	Foliation	N285º	30º NE	Defined by the parallel alignment of minerals.
2.	Joint-1	N310°-330°	38°-45° NE	Tight joint, spacing 5-10m, continuity 10-20m, smooth planar, dry. Parallel to foliation.
3.	Joint-2	N85°-95°	45°-60°SE	Prominent in the left flank of the slide with spacing 1-2m, continuity 10-15m, tight, smooth planar, dry.
4.	Joint-3	N340°-355°	70°-85°SW	Tight Joint spacing 1-3m slickenside present. smooth, lineation having pitch of 26°
5.	Shear-1	N275°-N290°	25°-35° NE	Maximum thickness of 4m, continuity >20m
5.	Shear-2	N340°- N345°	80°-85° SW	Parallel to joint-3, continuity >20m

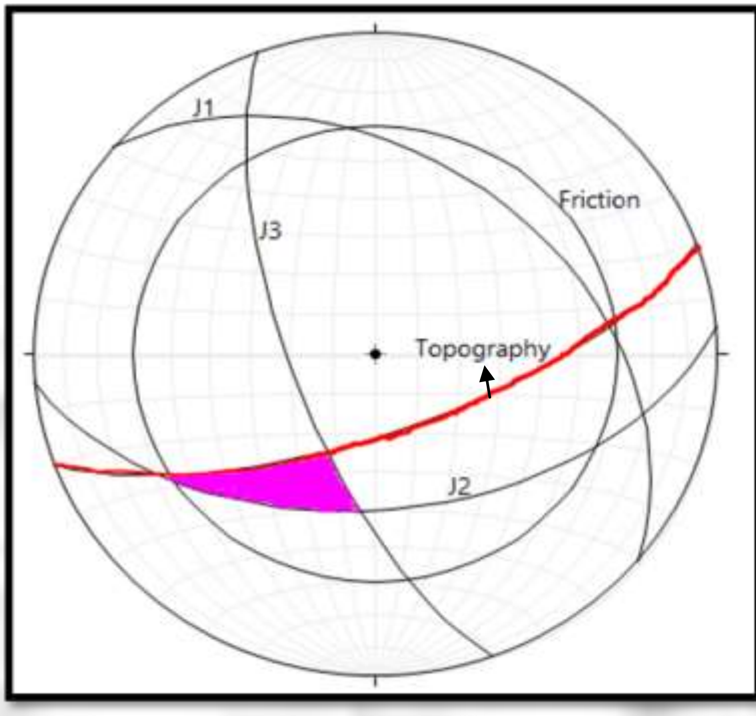


Fig 9 Stereo plot showing possible wedge formation in the left flank of the slide

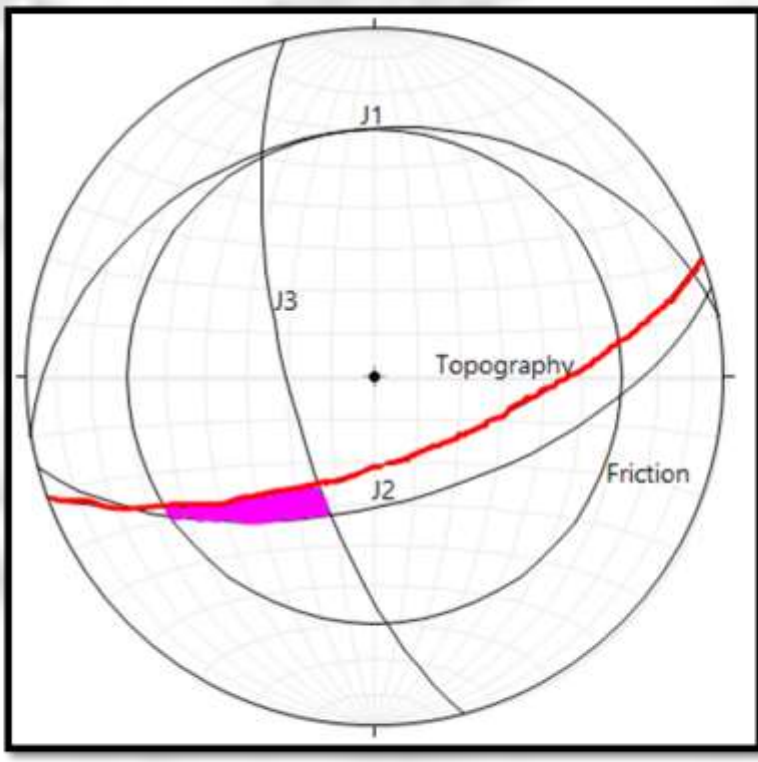


Fig 10 Stereo plot showing possible wedge formation in the right flank of the slide

6. TENTATIVE LIMIT EQUILIBRIUM ANALYSIS OF SLOPE STABILITY AT URNI LANDSLIDE:

The limit equilibrium methods used in this study evaluates the stability of the debris mass under the influence of gravity. The method compares the driving and resisting forces of the debris mass to derive a factor of safety (*F*) which is defined as the ratio of shear strength to the shear stress. If the value of *F* is less than 1, the slope is unstable. For this numerical analysis, SLOPE/W extension of GeoStudio software of the GEO-SLOPE international was used.

Morgestern and Price (1965) method of slope stability based on General Limit Equilibrium theory has been applied to calculate the factor of safety (*F*) by taking arbitrary values for cohesion and friction of the materials under dry conditions due to non-availability of laboratory and instrument data.

The analysis revealed that the debris materials on the slope have a very low factor of safety of 0.678. This may further decrease upon saturation of the materials. The details of the numerical stability analysis has been enumerated in Annexure-1

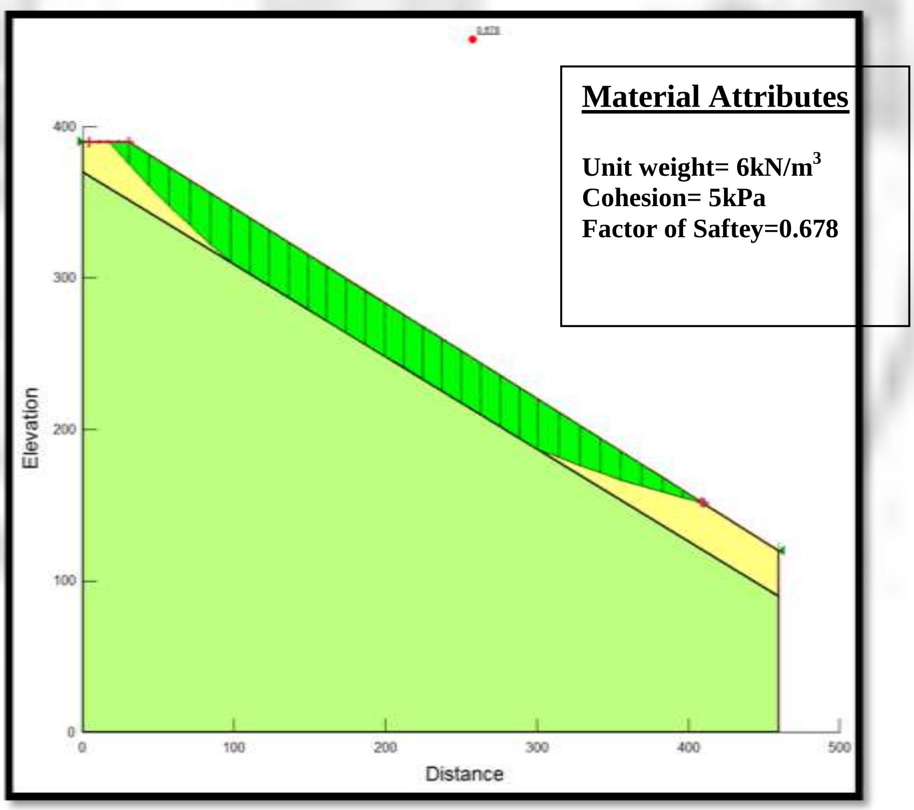


Fig 11 Result of general limit equilibrium analysis of slope stability

Table 3 RMR of the rock exposure at various locations on NH-22

LOC	UCS		RQD (%) =(115-3.3*JV)		Discontinuity condition		Discontinuity spacing(m)		Seepage		RMR Basic
	MPa	Rating	Value	Rating	Type	Rating	Value	Rating	Type	Rating	
1	100-250	12	88.6	17	Very rough and unweathered wall rock. Tight and no separation	30	0.6-2	15	Dry	15	89
2	100-250	12	88.6	17	Rough and slightly weathered, wall rock. Separation <1mm	25	0.6-2	15	Dry	15	89
3	100-250	12	75.4	17	Rough and slightly weathered wall rock. Separation <1mm	25	0.06-0.2	8	Dry	15	77
4	100-250	12	62.2	13	Slicken side. 1-5mm thick gouge filled with clay	10	0.06-0.2	8	Dry	15	58
5	100-250	12	62.2	13	Slicken side, 1-5mm thick gouge filled with clay	10	0.06-0.2	8	Dry	15	58
6	100-250	12	55	13	Slicken side, 1-5mm thick gouge filled with clay	10	0.06-0.2	8	Dry	15	58
7	100-250	12	55.6	13	Slicken side, 1-5mm thick gouge filled with clay	10	0.06-0.2	8	Dry	15	58
8	100-250	12	62.2	13	Slicken side, 1-5mm thick gouge filled with clay	10	0.06-0.2	8	Dry	15	58
9	100-250	12	95.2	20	Very rough and unweathered, wallrock. Tight and no separation	30	0.6-2	8	Dry	15	85

Field data reveals that the average RMR value of the exposed rock mass would be around 70 which puts it in Fair to Good category.

7. CAUSATIVE FACTORS FOR THE LANDSLIDE:

ANTHROPOGENIC FACTORS:

- Concrete water tanks and drainage pipes are laid on the orchards at different locations. The water derived for irrigation and natural drainage seep through the soil and as a result the existing slide debris become oversaturated which leads to the slide.
- The water, may seep through the debris materials and reach up to the bed rock where there is the interface between the rock and overburden leading to reduced frictional resistance between them causing its downward movement.
- The presence of natural spring below the scarp faces proves that the presence of water in the debris can be a major driving force for the slide.
- Blocking and choking of the existing drainages and diverting the stream water to agricultural land for irrigation may also leads to slide.
- Presence of large precarious boulders at higher elevations increases the down force of the material. The huge thickness of overburden also compliments to the movement of the materials downslope.

8. REMEDIAL MEASURES:

- Drainages in the uphill slope of the slide area should be channelized and diverted away from the slide area to prevent water percolation. The drainages should be properly maintained.
- Precarious boulders above the crest and on the slide should be removed.
- The entire slide affected slope should be modified by creating proper benches and V shaped lined drain with a longitudinal drainage grade and with suitable catch basins to carry the water down the slope.
- The debris materials in the crown portion of the scarp faces (**Fig-7**) may be removed and the slopes should be made gentler by creating benches.
- Pier supported cantilevered walls, 10m in length with weep holes **Plate-5** may be provided at various intervals as mentioned in the map.
- Intermittent RCC walls of minimum 1m thickness fringed by 2 m thick gabions, both of which is reinforced with steel rods drilled to the bedrock may be provided near the toe of the slide. **Plate-6.**

- Suitable irrigation practices like drip irrigation should be practiced in and around the slide affected area to reduce the influx of water.
- Loose scaling and shotcreting has to be done for the hanging blocks of rock in the vulnerable areas along the road cut near the slide.
- Concrete pillars of standard size and shape at selected locations may be erected to monitor the movement of the slide.
- Since the slide is of a complex nature and located above the strategic NH-22, a detailed site specific investigation involving drilling and laboratory testing of materials to estimate the bedrock depth and soil properties should be carried out to recommend a permanent solution to control the slide.

9. REFERENCES

- B.S Dorka, S. Prasher (2000) Investigation of tungsten and silver mineralization in the eastern part of Jeori-Wangtu Gneissic Complex.
- Dunan C Wyllie, Christopher W Mah (2004) Rock slope engineering No 81, 82
- Saibal Ghosh, Anjan Bora (2012) Geotechnical investigations of Lanta Khola and Mayang Chu landslides on North Sikkim Highway, North District, Sikkim
- F.V. De Blassio, (2011) Introduction to the physics of landslides/ lecture notes on the dynamics of mass wasting.

Plate 5 Pier supported Cantilever wall

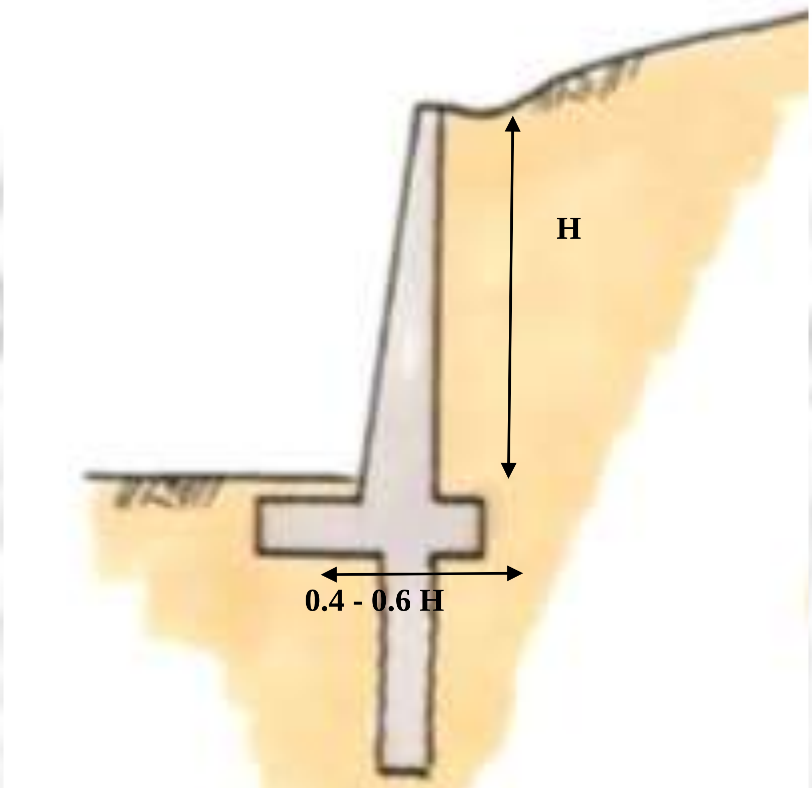
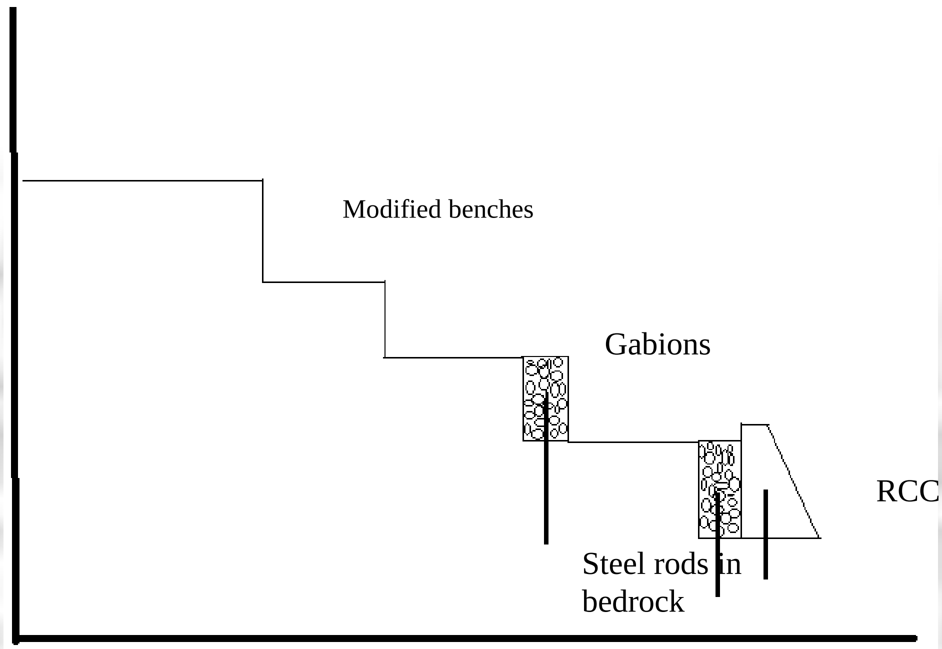


Plate 6 Retaining wall design

Side view



Plan view

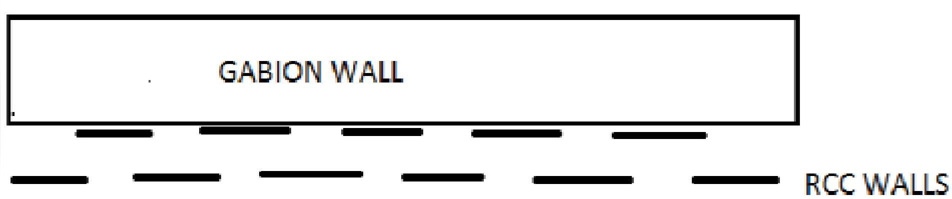


Plate 7 Detailed geological map

ANNEXURE-1 Slope stability analysis- Dry conditions

File Information

- File Version: 8.14
- Revision Number: 4
- Date: 15-Jun-15
- Time: 3:22:54 PM
- Tool Version: 8.14.1.10087
- File Name: urni trial.gsz
- Directory: C:\Users\Lenovo\Desktop\
- Last Solved Date: 15-Jun-15
- Last Solved Time: 3:22:59 PM

Project Settings

- Length (L) Units: Meters
- Time (t) Units: Seconds
- Force (F) Units: Kilonewtons
- Pressure (p) Units: kPa
- Strength Units: kPa
- Unit Weight of Water: 9.807 kN/m³
- View: 2D
- Element Thickness: 1

Analysis Settings

SLOPE/W Analysis

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions Source: (none)
- Slip Surface
  - Direction of movement: Left to Right
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Resisting Side Maximum Convex Angle: 1 °
  - Driving Side Maximum Convex Angle: 5 °
  - Optimize Critical Slip Surface Location: No
  - Tension Crack
    - Tension Crack Option: (none)
- F of S Distribution
  - F of S Calculation Option: Constant
- Advanced

Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 m
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

Debris

Model: Mohr-Coulomb
Unit Weight: 6 kN/m³
Cohesion': 5 kPa
Phi': 20 °
Phi-B: 0 °

jeori wangtu gneiss

Model: Bedrock (Impenetrable)

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (4.2, 390) m
Left-Zone Right Coordinate: (30, 390) m
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (408.55345, 152.30365) m
Right-Zone Right Coordinate: (410, 151.39535) m
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (0, 390) m
Right Coordinate: (460, 120) m

Points

	X (m)	Y (m)
Point 1	0	390
Point 2	30	390
Point 3	460	120
Point 4	460	90
Point 5	0	370
Point 6	460	0
Point 7	0	0

Regions

	Material	Points	Area (m²)
Region 1	Debris	1,2,3,4,5	15,550
Region 2	jeori wangtu gneiss	5,4,6,7	1.058e+005

Current Slip Surface

Slip Surface: 72
F of S: 0.678
Volume: 10,997.796 m³
Weight: 65,986.777 kN
Resisting Moment: 17,455,929 kN-m
Activating Moment: 25,730,583 kN-m
Resisting Force: 19,685.616 kN
Activating Force: 29,013.643 kN
F of S Rank: 1
Exit: (410, 151.39535) m
Entry: (17.1, 390) m
Radius: 760.47271 m
Center: (589.82902, 890.30013) m

Slip Slices

	X (m)	Y (m)	PWP (kPa)	Base Normal Stress (kPa)	Frictional Strength (kPa)	Cohesive Strength (kPa)
Slice 1	23.55	382.80292	0	21.626227	7.8713029	5
Slice 2	36.771839	368.42932	0	58.636183	21.341825	5
Slice 3	50.315518	354.43486	0	78.004833	28.391437	5
Slice 4	63.859196	341.13115	0	94.989371	34.573304	5
Slice 5	77.402875	328.46902	0	110.10111	40.073528	5
Slice 6	90.946553	316.40596	0	123.73342	45.035281	5
Slice 7	104.06642	306.65522	0	154.15843	56.10908	5
Slice 8	116.76246	298.9272	0	153.44118	55.848023	5
Slice 9	129.45851	291.19917	0	152.84794	55.632102	5
Slice 10	142.15456	283.47114	0	152.37437	55.459736	5
Slice 11	154.85061	275.74311	0	152.01498	55.328927	5
Slice 12	167.54665	268.01508	0	151.76317	55.237276	5
Slice 13	180.2427	260.28705	0	151.61129	55.181996	5
Slice 14	192.93875	252.55902	0	151.55065	55.159927	5
Slice 15	205.6348	244.83099	0	151.57159	55.167549	5
Slice 16	218.33084	237.10296	0	151.66348	55.200991	5
Slice 17	231.02689	229.37494	0	151.81476	55.256054	5
Slice 18	243.72294	221.64691	0	152.01307	55.328231	5
Slice 19	256.41899	213.91888	0	152.24522	55.412728	5
Slice 20	269.11504	206.19085	0	152.49735	55.504496	5
Slice 21	281.81108	198.46282	0	152.75496	55.598259	5
Slice 22	294.50713	190.73479	0	153.00303	55.688549	5
Slice 23	307.67671	184.14515	0	177.17112	64.485014	5
Slice 24	321.31981	178.845	0	161.08079	58.628612	5
Slice 25	334.96292	173.84385	0	141.84539	51.627499	5

Slice 26	348.60602	169.13546	0	119.76423	43.590613	5
Slice 27	362.24913	164.71414	0	95.265554	34.673826	5
Slice 28	375.89224	160.57465	0	68.872338	25.067481	5
Slice 29	389.53534	156.71224	0	41.155228	14.979278	5
Slice 30	403.17845	153.12254	0	12.679173	4.6148417	5