REPORT ON GEOLOGICAL ASSESSMENT OF KOTRUPI LANDSLIDE, MANDI - JOGINDERNAGAR - PATHANKOT NATIONAL HIGHWAY (N.H.-154), TEHSIL PADHAR, DISTRICT MANDI, HIMACHAL PRADESH

(Field Season: 2017-18)
(Item No.: M4/EGG/C/NR/SU: PHP/2017/11904**)**

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1. INTRODUCTION:

1.1 The Backdrop:

The network of roads including the national and state highways plays a vital role in socio-economic development and promotes the economy, more prominently in case of a mountainous region. In Himalayan region, characterized by extremely steep and rugged slopes, landslides are a major hazard (Anbarasu, K.et. al., 2010). Many of such incidences take place along hill roads, which constitute major link of communication in this terrain. Major roads in the Himalayas are frequently blocked due to heavy landslides and remain closed for long periods of time. (Sharma, S.P., et. al., 2010). Every year during the monsoon period (between July and September), the Himalayan state of Himachal Pradesh witnesses a number of slope failures, especially along the road networks, which causes loss to life, property and exchequer.

In the early hours of 13/08/2017 (at around 00.15hrs.), a calamitous landslide occurred at Mandi - Jogindernagar - Pathankot National Highway (N.H.-154), near Kotrupi Village, Tehsil Padhar, District Mandi, Himachal Pradesh. Reportedly, a total of about 46+ passengers of Himachal Road Transport Corporation (HRTC) Buses [40+ of Chamba - Manali and 6 passengers of Manali - Katra Buses respectively], have lost their lives. In addition, a few vendors and pedestrians also lost their lives. One pocket of Kotrupi village that was nestled up-slope (reportedly six houses and their cattle shades) on hill side got completely razed off in the incidence, with no loss to life as the residents here had left the

settlement sometime before in anticipation of possible slope failure. Although no loss to life took place in main Kotrupi village on valley side of right fringe of slide, two houses and a few agricultural field were partly damaged due to slide debris. In addition, ±350m length of road stretch, a bridge (±25 to ±30m in length), a few bikes and vegetable vehicles (as per local residents) also got engulfed in slide debris. Nonetheless, no loss to life and property was recorded to Badond village nestled on valley side of left fringe of slide zone due to the presence of a ridge line that in fact, acted as a protective measure and didn't allow the debris to slip down till village.

1.2 Kotrupi Landslide Studies:

For the preliminary assessment of Kotrupi landslide, a team of Geologists were deployed, as a quick response to disaster mitigation. S/Shri Atul Kohli, Sr. Geologist and Ravi Shankar Chaubey, Geologist, Engineering Geology Division, GSI (NR), Chandigarh reconnoitered the site and carried out preliminary studies of the slide on the day of disaster i.e. 13/08/2017 itself. During the reconnaissance, preliminary field data was collected in the standard format and was submitted to GSI (CHQ) through proper channel, for uploading on GSI Portal for public viewing and for the use of stake holders (Appendix-1). In addition, a short note on the disastrous Kotrupi landslide along with comments of Supervisory Officer was submitted to the concerned authorities on 14/08/2017 (Annexure-I of Appendix-2). The concerns about detailed studies and formulation of better remedial measures were expressed by the Government of Himachal Pradesh and it was requested to GSI to take up the detailed studies of this slide.

Subsequently, visualizing the criticality, magnitude of slide, loss of lives and property due to this calamitous slide, another team comprising S/Shri D. P. Dangwal, Sr. Geologist, Parveen Kumar, Sr. Geologist and Venu Gopala krishna B., Geologist, Engineering Geology Division, GSI (NR), Chandigarh was deputed for detailed geological and geotechnical evaluation of the slide. The detailed geological assessment and mapping was initiated by the field officers. During their field trip, Chief Secretary, Government of Himachal Pradesh, who was also on a visit at the Kotrupi slide site, also expressed the need to identify such potential/ probable slide zones, in order to avoid huge loss to life and property in future.

Nonetheless, due to problems in the survey equipment arranged by Himachal Pradesh Public Works Department (HPPWD: National Highways Division, Joginder Nagar, District Mandi) authorities, geological mapping could not be initiated. It was, therefore, decided that detailed geological and geotechnical investigations including detailed geological mapping would be resumed, once detailed contour plan of the slide area is prepared. Geological mapping and geotechnical evaluation of Kotrupi landslide was initiated during 2nd fortnight of November-2017, after the contour plan was made available to GSI. Based on the geological mapping and geotechnical evaluation carried out by the authors of this report in the period from 14/11/2017 to 08/12/2017, a note was submitted (Appendix-2).

On 15/11/2017, Mr. Sanjiv Kumar, Director, Engineering Geology Division, GSI, Chandigarh also visited the site and examined parts of right fringe and middle portion of slide area followed by submission of an inspection note (Annexure-II of Appendix-2).In the field, S/Shri Anil Sangrai, Executive Engineer and R. K. Gupta, Jr. Engineer, HPPWD (N.H. Div.), Joginder Nagar, District Mandi, have also joined the GSI team. Several issues regarding the detailed geological and geotechnical evaluation, sample collection and estimation of geotechnical parameters were discussed. Moreover, joint technical discussions were carried out on the topographical map prepared by M/s ONN Survey Consultants, Dharamshala, District Kangra, H.P. - the agency hired by HPPWD authorities. During the course of present investigation, technical discussions on relevant issues were discussed with Mr. Anil Sangrai, Executive Engineer, Mr. Suman Kumar Saundal, S.D.O. and Mr. R. K. Gupta, Jr. Engineer, H.P.P.W.D. (N. H. Div.), Joginder Nagar.Towards the end of the field work, Dr. G. C. Kandpal, Dy. Director General and Mr. Sanjiv Kumar, Director, S.U.: P., H. and H.P., GSI (NR), Chandigarh, visited the Kotrupi Slide and had technical discussions with the authors of this report regarding the work carried out and provided various useful inputs followed by submission of a Note incorporating his observations and suggestions (Appendis-3). Later, after this field trip, one more field trip was carried out during 13/02/2018 to 20/02/2018 and suitable modifications in the map were attended including modification in outline of the slide using Total Station. Further, towards the end of this second field trip, Mr. Kumar, Director again visited the site and reviewed the work, followed by submission of another inspection note (Appendix-4).

1.3 Location and Accessibility:

The Kotrupi Landslide is located in the vicinity of Kotrupi village along Mandi - Joginder Nagar - Pathankot National Highway (NH-154) (Fig.-1, 2).

Fig.-1: Location Map of Kotrupi Landslide, Kotrupi, NH-154, Tehsil Padhar, District Mandi, H.P. (*Source: Google Earth*).

Fig.-2: Distal view of Kotrupi Landslide, Kotrupi, NH-154, (Date of Landslide Incidence: 13/08/2017).

The slide is located at a distance of about 4 and 21kms from Padhar and Joginder Nagar Tehsils of Mandi district (Himachal Pradesh) on either side respectively. The study area falls in the Survey of India Toposheet No. 53A/13 [Geographical Coordinates: Latitude: N31º54'37.60", Longitude: E76º53"26.30"]. The area is approachable by all weather roads and can be accessed from Chandigarh and Shimla via Chandigarh - Mandi - Manali NH-21 up to Mandi and subsequently following the NH-154 (Via Padhar) and Shimla - Bilaspur - Mandi - Padhar respectively. The nearest railway station is Joginder Nagar on narrow gauge railway line (Joginder Nagar - Pathankot of Northern Railways).

1.4 Climate and Rainfall:

The climate of the district is sub-tropical in the valleys and tends to be temperate near the hilltops. In the higher region, the climate remains cold throughout the year. The winter starts from the middle of November and continues till the middle of March. Thereafter, the mercury continues to rise till the onset of the monsoon, which starts from the last week of June to early July and continues till the middle of September. During October and November, the nights are pleasant, whereas the days are a little bit hot. Average minimum and maximum temperature in the district varies from 3ºC to 35ºC. The district receives precipitation in the form of rainfall, mainly during the monsoon period from July to September. The average annual rainfall in the district is about 1331.50mm. Annual average rainfall from place to place in the district is highly variable and ranges from 700 to more than 2000mm at Joginder Nagar. During winters snowfall often occurs down to elevation of 1300m above MSL (CGWB, 2013).

1.5 Objective and Scope of the Present Work:

The main objectives of the present work are geological and geotechnical assessment of Kotrupi landslide in order to impart suggestions and remedial measures, if any. The work attended to is enumerated below:

1) Detailed geological mapping of Kotrupi landslide using Total Station.
2) Observed geological sections with Total Station.
3) Collection of soil samples for determination of geotechnical parameter estimation.
4) Geological and geotechnical assessment based on field and laboratory data.

5) Recommendations for further investigations, if any.
6) Formulation of appropriate suggestions/ remedial measures, with a view to reduce the risk to life and property.

1.6 Acknowledgement:

The authors extend their sincere thanks to Mr. S. N. Chandel, Additional Director General (ADG) & Head of Department (HoD), GSI (Northern Region), Lucknow for approval of the report. The authors also extend their thanks to Mrs. Varsha A. Aglawe, Dy. Director General & Regional Mission Head - IV, GSI (NR), Dr. G. C. Kandpal, Dy. Director General, Stat: Unit: Punjab, Haryana and Himachal Pradesh, GSI (NR), Chandigarh, for their valuable suggestions during field visits and report writing. The investigations were carried out under the overall guidance and supervision of Mr. Sanjiv Kumar, Director, Engineering Geology Division, S.U.: P., H. and H.P., GSI (NR), Chandigarh. The guidance and encouragement given by the Director during the course of field work and also during writing of report are thankfully acknowledged. Sh Sanjiv Kumar, Director was deeply involved in the assignment as clear from his regular inspection notes. It is pertinent to mention here that geological section of the slide was prepared by the Director, E G Division. The authors are thankful to the officials of Himachal Pradesh Public Works Department (HPPWD), Government of Himachal Pradesh. The authors thankfully acknowledge the assistance/support given by the engineers and surveyor during the course of investigations and digitization of the geological maps and sections.

2. REGIONAL GEOMOPHOLOGY, REGIONAL GEOLOGY AND SEISMICITY:

2.1 Regional Geomorphology:

The area forms part of drainage basin of the river Beas following northwesterly course from Neola in the south to its exit at Sidhpur in the west. It is joined by a number of tributaries. Amongst them the Uhl river follows the Kullu Thrust Plane and drains the eastern part of the area. Southeasterly flowing Rana *Khad*, Arnodi *Khad* and Luni *Khad* are other minor tributaries of the Beas river. The major drainage pattern dominantly reflects trellis type with the dendritic drainage in the upper order streams. Physiographically, the area falls in the Lesser Himalayan Zone occupied by the Dhauladhar range in the northeastern part. The

topography is rugged, displaying high ridges and deep valleys. The ridges trend NW-SE in the northern part which gradually acquire NNW-SSE trend in the southern part and follow the regional strike. The minimum elevation (700m) at Sidhpur and maximum elevation (3488m) at Jangal Tilla on Damwangahr dhar in lie in the western and northeastern margin respectively.

2.2 Regional Geology:

Geologically, the area is occupied by the rocks of Palaeo-proterozoic to Holocene age. The Palaeo-proterozoic rocks are represented by the Kullu, Vaikrita, Sunder Nagar Groups, the Meso-proterozoic comprises Shali Group and Neo-proterozoic includes the Manjir, Katarigali and Guma Formations. The Palaeogene and Neogene are constituted of the Sirmaur and Siwalik Groups respectively. Newer alluvium group of the Holocene age represents the Quarternaries.

2.3 Seismicity:

Earthquakes, quite devastating and sudden in nature, are one of the most common types of disasters in Himalayan terrain. Himachal Himalayas lying in the sensitive Himalayan belt, near the juncture of two active tectonic plates, the region is prone to severeseismic activity. The movement of large blocks along the thrust planes resulting in the release of stored energy is the basic cause of earthquakes in this region. As per seismic zoning map of India (BIS, 2002), the project area falls within Zone V. A shallow earthquake of magnitude 4.0 has been reported in past, in Deol/ Thalot area in the vicinity of the study area (i.e. Kotrupi landslide area).

3. SITE CHARACTERIZATION:

3.1 Physiography of the slide area:

The Kotrupi village is located on southerly slopes of a NE-SW trending ridge in Lesser Himalaya. The slope is moderately to steeply inclined with occasional breaks-in-slope. The slope is moderately to highly dissected as evidenced by minor streamlets on either side of the slope. The slope failure affected slope is having its broad orientation N200ºdirection and having an inclination of ~45º-50º.A total of about ±175m length of road passes through the

failure affected zone. On either side of the failure affected slope, natural seasonal *nala* depressions are there (Fig.-3).

Fig.-3: Updated/ Post-2017 incidence satellite view of Kotrupi Landslide [Part of NH-154 can be seen repaired] [*Source: Google Earth*].

3.2 Site Geology:

Geologically, the area comprises of rocks belonging to Shali Group and Dharamshala Group/ Dagshai Formation and Quaternary deposits. The Shali Group rocks consist mainlyofphyllite, slate, and phyllitic quartzitein the slide area. Pyllitic quarzite is dominating in the upper part of the slide. The Dharamshala Group/ Dagshai Formation comprises of red shale and siltstone, which is separated from the Shali Group along the Shali Thrust (Source: Geoinformatics Division, GSI, Chandigarh). Due to intense thrusting, the rock is sheared and crushed in a zone of about 50-80m thick (visible in the area and is mapped). An appreciable stretch adjoining to the main Kotrupi landslide area is characterized by the presence of Quaternary deposits (older terrace material) and overburden on right and left fringes of the slide respectively. Terrace material in the area is also having calcareous cementation which is inferred to be due to leaching of carbonate material from in-situ rock (Shali Group).

3.3 Weathering and accumulation:

In-situ soil with rock detritus are the materials observed over the bedrock and are occurring as capping material above the in-situ rocks in the sub-vertical scar portion. Calcareous cementation has been observed in the colluvium material which is inferred to be due to leaching from the carbonate rocks present in the area. The rocks exposed in sub-vertical scar and in parts of right fringe of the slide are highly weathered. An appreciable stretch adjoining the road is characterized by the presence of colluvium and terrace material. As a consequence of 13/08/2017 landslide incidence, enormous volume of debris was generated within the slide area. The slide debris comprises rock blocks of various lithology (viz. phyllite, phyllitic quartzite, shale, limestone and sandstone) andcolluvium material (both coarse as well as finer fractions).

4. GEOLOGICAL MAPPING OF KOTRUPI LANDSLIDE:

The detailed geological mapping of the Kotrupi landslide and part of its adjoining area has been carried out on 1:1000 scale, covering an area of about 0.17sq. km. using Total Station (Make: Topcon, Model: GPT 7500). In geological mapping, following themes have been covered: a) Topography, b) Landslide features and surface materials, c) Hydro-geological conditions, d) Land-use and Land-cover and e) Civil Structures. An account of the mapped portions is given below:

4.1: Topography:

In the map, the topography is represented by means of contours having 1m interval. The crown of the landslide is at an elevation of ±1620m. The height of the main landslide is roughly ±230m while the width of the slide ±210m (maximum). The length of the slide from the crown to toe is ±300m though for identifying exact position of toe drilling will be required). Run out area of the slide is ±650m.

4.2: Landslide features and Surface material:

Within the main slide zone, strip of colluvium material is seen in top part (crown) of the landslide. Above the crown, very steep natural slope is there which is further followed by

gentler slope and flattish land (Saraj Bagda village area) in Kotrupi landslide hill slope. The orientation of slope is broadly 50º /N224º. Below the crown portion, moderately to highly weathered and highly jointed rock-mass, particularly slates, is exposed (Fig.-4).

Broadly four sets of joints are seen here in weathered slates as: J_1 (S_o): 34º /N060º, J_2: 74º /N186º, J_3: 52º /N246º, J_4: 86º /N320º(Fig.- 4).The joints are relatively closed spaced with clay infillings occasionally seen in the joint apertures/ openings. The joints are having minor openings (closed to ~2 to 3mm), as seen in the middle portion of sub-vertical scar.

Fig.-4: Closer view of weathered and jointed slates exposed in sub-vertical scar.

Similarly, rock exposures of red Shale with siltstone were seen on the right fringe of the slide. The rock is splintery in nature with ~1 to 4mm opening at places. The rock is highly jointed with broadly four sets of joints as: J_1 (S_o): 46º /N048º, J_2: 42º /N220º, J_3: 82º /N314º, J_4: 72º /Northerly (Random)(Fig.-5).At the lower/ bottom part of the sub-vertical scar, piles of slide debris (particularly fine grained scree with rock chips/ chunks) are seen accumulated and, therefore, full view of sub-vertical scar is not visible (Fig.-6).

Fig.-5: Closer view of weathered red shale with siltstone exposed on right bank of Kotrupi landslide.

Fig.-6: Piles of slide debris (particularly fine grained scree with rock chips/ chunks), accumulated below the sub-vertical scar.

Concentration of rock blocks/ fragments are seen fromEl ±1370m to El ±1405m characterized by the presence of relatively larger size blocks (±1m to ±3m or so). The rock blocks within debris include those of phyllite, phyllitic quartzite, limestone and slate. In the valley side flow path, however, mostly slide debris are present and include fine to coarse

grained slide debris, rock chips and chunks of about few centimeters to a few relatively bigger rock blocks as stated above (Fig.-7).

Part of slide debris, however, old slide debris comprising thick colluviums material, compacted debris of old slides (reportedly occurred in August 1977 and August 1997 at the same site, as per the local residents of nearby villages) and relatively recent slope wash material.

Fig.-7: Part of the main debris of slide zone with assorted rock blocks/ fragments.

A number of cracks were recorded on the right flank of the slide (NE side). Active failure in the slide was observed on the right side crown of the slide during the course of geological investigation during November 2017 (NW side of slide). From the geological mapping and assessment done so far, it is inferred that there is good probability of extension of slide particularly on the NE side.

4.3: Hydro-geological conditions:

A number of water springs have been observed in the slide zone mainly in carbonaceous slate (in thrust zone) (Fig.-8). Oozing of water has been observed in the in the red shale exposed on the right flank of the slide. The discharge of water in the springs in the slide

zone has decreased considerably since 13/08/17 (the date on which the disastrous landslide took place).

Fig.-8: Springs and water oozing out in parts of sub-vertical scar area (the wet portions visible in the photograph).

Traverse was taken above the crown of slide (though in reach of ±60m above the slide traverse was not undertaken due to steepness of the slope) to examine the possible source of water in the slide zone. No possible source of water could be demarcated in a zone of about ±200m (elevation from crown of the slide) above the slide.

4.4: Land cover and Land use:

Pockets of trees depicting the density of vegetation observed in adjoining areas of the slide/ slide fringes were plotted appropriately on the map (Fig.-9). Similarly, agriculture terraces, wherever present in the adjacent areas of the slide/ slide fringes were plotted. This was done to have an idea of land cover and land use practices within slide area and to analyse their possible affect, if any, on slope failure/ slope instability.

Fig.-9: Pocket of trees in part of right fringe of the slide

4.5: Civil Structures:

Of the civil structures present in the landslide area, mention may be made of section of Mandi - Joginder Nagar - Pathankot National Highway - 154, and part of Kotrupi - Chukku village road, in addition tohouses of the villages viz. Kotrupi (Right fringe: next to road on valley side), Badond (Left fringe: on valley side), Jaged (mid-slope on right fringe natural slope) and Saraj Bagda (On natural slope above Kotrupi landslide crown). All these features, including a few other feature(s) viz. water tank, one of the destroyed HRTC bus etc. were mapped and plotted appropriately. The length of the highway passing through slide zone is ±175m (Fig.-2).

5. IDENTIFICATION OF MODE OF FAILURE:

Considering the site conditions, field traverses, topographic and geological mapping, slide morphology and configuration, field based geological and geotechnical evaluation of slide area, slope forming material indicated that,the slide (±300m x ±210m) is a complex slope failure, involving both rock as well as overburden material. Water seepage played a critical role in triggering the landslide as it has lubricated the old slide debris as well as highly sheared/ crumpled rock mass. Water seepage was observed at least at half a dozen spots

within slide area (mainly in parts of sub-vertical scar and right fringe portions) (Fig.-8). The rock mass exposed is crushed and of low competency due to the effect of thrust.

5.1 Slide type:

Based on field studies, the Kotrupi landslide can be categorised as *Rock cum debris slide*, involving slide debris (fine to coarse fractions of soils and debris), rock chunks and rock blocks of varying dimensions.

5.2: Mode of failure and Causative/ Slide plane:

As far as mode of failure of Kotrupi landslide is concerned, based on visual estimation the mechanism can be termed as deep rotational (>5m) and, therefore, the slide can be categorized as Slip Circle/ Rotational failure. The toe of the failure plane of the slide is on hill side of the road.

5.3: Causative factors:

1) Highly crushed and sheared rock due to the effect of thrust (Shali thrust).
2) Moderately to steeply inclined hill slope.
3) Pore water pressure development due to ingress of water in old slide debris (As stated above, reportedly the slide has also experienced two more reported slide incidences at the same spot).
4) Poor surface drainage conditions.
5) Rainfall: External factors like seismicity and rainfall may initiate slope movements and are accordingly called as triggering factors (Anbalagan et. al., 2008). Seismicity of the area is already discussed above. Rainfall data of nearest rain gauge stations, if any, could not become available to the authors in spite of verbal requests made to HPPWD authorities during the course of the work.

As per discussion with District Administration Officials and local people residing in adjoining/ nearby areas, although there was no heavy downpour spell reportedly took place before 2-3 days of the incidence, persistent rainfall was reported last few days. However, overall monthly rainfall data for entire Mandi District for previous half decade i.e. for year

2013 to 2015 (Appendix-5) indicates, that maximum monthly rainfall in the district took place in July and August months of the year 2017 (July: 467.8; August: 430.7), the later being the month in which the present incidence of Kotrupi landslide took place (on 13/08/2017*). Still rainfall is an external and regional factor and varies in space and time and the aforesaid maximum monthly rainfall data for entire Mandi district may not be directly attributed to Kotrupi landslide.The slide may be combination of various causes as stated under this sub-head.*

6. SAMPLE COLLECTION AND SLOPE STABILITY ASSESSMENT:

With a view to understand the behavior of slope forming material and its role in Kotrupi landslide, t was decided to collect samples of slope forming material. Soil samples were collected (Fig.-10) from selected locations within Kotrupi landslide area (Plate-1).It was attempted to collect representative samples from failed and natural slope. The coordinates (latitude and longitude) were collected using GPS, and later converted to UTM system (Northing-Easting) to plot the sample location on the Geological map of the slide.

Fig.-10: Sample collection in steel pipes from parts of slide and adjoining area

As there are no standard guidelines/ methodology/ code is available for sample collection, the samples were collected by following procedure:

Step-1: Identification of suitable/ required spot for sample collection.

Step-2: Clearing the surface suitably.

Step-3: Inserting metal pipe tube to get undisturbed sample within it.

Step-4: Proper packing of sample with mild hammering.

Step-5: Sealing both ends of metal pipes properly with molten wax.

Step-6: After drying up molten wax, covering both ends of pipe with news paper and tightening with thread.

Step-7: Sealing both ends with packing tape perfectly.

Step-8: Naming the sample pipe with required code name/ number.

The authors opined that by following the procedure, the Natural Moisture of the sample does not get lost for a certain time span and also there remain no gap within sample tube as well. The samples were collected for determination of geotechnical parameters enumerated in Table-1.

Table-1: Geotechnical parameters to be estimated for samples collected in field

Sl. No.	**Geotechnical Parameters**	**Remarks**
1)	Cohesion (C)	Results of geotechnical parameters are enumerated in Annexure-V
2)	Angle of Internal Friction (ϕ)	
3)	Dry Density	
4)	Natural Moisture Content (NMC)	
5)	Optimum Moisture Content (OMC)	
6)	Void ratio at OMC	
7)	Specific Gravity	
8)	Liquid Limit (LL) and Plastic Limit (PL)	
9)	Grain Size Analysis	

[*Note*: *Parameters to be estimated as per Point No. 14, Page-5 of SOP-Landslide Investigations (Non-NLSM), downloaded from GSI Website*].

A total of **18 Nos. samples** were collected from all **9locations (Total = 2 x 9 = 18 samples)**. At any particular location, 1 sample each was collected in steel pipe (1.5ft length and 2.5" diameter) and 1 in poly bag respectively. All the samples are submitted (through proper channel) to Geotechnical Laboratory, GSI (NR), Lucknow, for estimation of geotechnical parameters. Further, as per suggestions by the Dy. Director General, S.U.: P., H. and H.P. during his visit to the site, **4 samples from 2 more locations** were collected during updation of Geological map (in the 2nd phase of field work: 13/02/2018 to 20/02/2018). In all, samples were collected **from 11 locations** in Kotrupi landslide area

(*Total 22 samples from 11 locations, i.e. 2 samples from 1 location, one each in steel pipe and poly bag respectively as stated above*). The sample locations are enlisted in Table-2 and depicted in the detailed geological map (Plate-1).

Among the Samples enlisted in Table-2, Sample Nos. S-1, S-2, S-2A and S-3 were collected from parts of right fringe of the slide area (selected locations above and below the existing road level). Sample Nos. S-4 and S-5 were collected from middle portion of the slide area (selected locations above the existing road level). Sample Nos. S-6, S-7 and S-8 were collected from parts of the left fringe of the slide area (selected locations above and below the existing road level). Sample Nos. S-9 and S-10 were collected from slide area (above existing road level).

Table-2: Soil samples collected from Kotrupi Landslide Area

Sample No.	Geographic Coordinates (Degree/Minute/Second)				(Degree/Decimal)	Northing Easting (UTM)	Remark
S-1	N	31º	54’	09.23”	31.96923	3532579.89N	
	E	76 º	51’	14.14”	76.85389	0678822.65E	
S-2	N	31º	54’	43.55”	31.91200	3532240.37N	
	E	76º	53’	24.22”	76.88992	678697.93E	
S-2A	N	31º	54’	39.94”	31.91109	3532137.36N	
	E	76 º	53’	18.97”	76.88861	678575.71E	
S-3	N	31º	54’	39.11”	31.91040	3532110.06N	
	E	76º	53’	16.14”	76.88900	678501.35E	
S-4	N	31º	54’	47.50”	31.01319	3532375.59N	
	E	76º	53’	30.30”	76.89170	678864.02E	
S-5	N	31º	54’	42.29”	31.91174	3532212.44N	
	E	76º	53’	25.19”	76.89033	678736.99E	
S-6	N	31º	54’	43.90”	31.91122	3532156.86N	
	E	76º	53’	30.50”	76.89163	678860.70E	
S-7	N	31º	54’	41.00”	31.91129	3532163.50N	
	E	76º	53’	27.80”	76.89105	678805.74E	
S-8	N	31º	54’	37.40”	31.91011	3532028.61N	
	E	76º	53’	20.52”	76.88896	678611.02E	
S-9	N	31º	54’	46.88”	31.91302	3532355.22N	

	E	76º	53’	28.59”	76.89127	678823.43E	
S-10	N	31º	54’	48.48”	31.91347	3532405.54N	
	E	76º	53’	29.52”	76.89153	678847.15E	

The results of geotechnical parameters received from Geotechnical Laboratory (Appendix-6) are enumerated in Table-3.

6.1 Grain Size Analysis:

Grain size analysis of the samples was done by Sieve Analysis Method. Sieves with 4.76mm, 2.36mm, 1.18mm, 0.60mm, 0.30mm, 0.15mm and 0.075mm openings (U.S. Standards) were used for this purpose. The respective ASTM (American Society for Testing and Materials) Standard Nos. for these U.S. Standards are Sieve Nos. 4, 8, 16, 30, 50, 100 and 200 respectively.

Table-3: Results of Geotechnical Parameters of Soil samples

Sample Nos.	**Atterberg Limits**			**Density Test**						**DST**	
	SL	**PL**	**LL**	**DD (gm/ cc)**	**WD (gm/ cc)**	**SG(G_s or G)**	**MC / NMC (%)**	**VR**	**P (n)**	**C (Kg/C m^2)**	**Φ (°)**
S-1	27.21	28.61	37.08	1.14	--	2.49	9.35	1.18	*0.46*^	0.17	47°
S-2	16.30	18.71	21.72	1.74	--	2.61	10.30	0.50	*0.67*^	0.19	40°
S-2A	18.16	20.45	23.16	1.31	--	2.54	6.52	0.94	*0.51*^	0.09	48°
S-3	Non-Plastic			1.47	--	2.62	10.50	0.78	*0.56*^	--	--
S-4	Non-Plastic			1.51	--	2.70	5.26	0.79	*0.56*^	--	--
S-5	Non-Plastic			1.48	--	2.71	5.18	0.83	*0.55*^	--	--
S-6	Non-Plastic			1.49	--	2.65	4.26	0.78	*0.56*^	--	--
S-7	Non-Plastic			1.37	--	2.54	6.19	0.85	*0.54*^	--	--
S-8	9.98	10.51	13.07	1.71	--	2.75	7.42	0.61	*0.62*^	0.18	44°
S-9	Non-Plastic			1.43	1.41	2.70	1.57	*0.92*^	0.48	--	--
S-10	Non-Plastic			1.43	1.39	2.67	3.10	*0.92*^	0.48	--	--

***Abbreviations**: **LL**: Liquid Limit; **PL**: Plastic Limit; **SL**: Shrinkage Limit; **DD**: Dry Density; **WD**: Wet Density; **SG**: Specific Gravity; **MC / NMC**: Moisture Content/ Natural Moisture Content; **VR**: Void Ratio; **P**: Porosity; **DST**: Direct Shear Test; **C**: Cohesion; Φ: Angle of Internal Friction (^: Emperically derived at HQ, from values/ data available from GT Lab., GSI, Lucknow)*

Sample Nos.	**GRAIN SIZE ANALYSIS**						
	Sieve opening mm (%finer)						
	4.76	**2.36**	**1.18**	**0.60**	**0.30**	**0.15**	**0.075**
S-1	87.41	81.59	77.45	74.77	72.18	69.20	67.08
S-2	93.14	90.26	88.61	86.40	84.11	74.82	59.89
S-2A	93.20	91.26	88.98	86.46	82.26	71.88	51.54

S-3	89.11	74.31	66.72	61.64	56.93	50.97	46.86
S-4	77.60	55.37	40.94	30.24	23.43	17.89	16.23
S-5	80.35	60.33	42.82	30.56	20.32	15.92	12.43
S-6	78.80	58.77	46.30	37.69	31.12	25.31	22.97
S-7	77.79	67.95	56.20	43.69	28.42	19.59	14.15
S-8	89.74	78.81	64.53	48.24	31.37	23.12	18.07
S-9	65.73	51.87	37.55	28.21	21.47	17.19	14.65
S-10	63.14	50.21	38.90	31.14	24.76	19.78	16.10

The fraction retained as Weight %age of Soil taken for each of the 11 samples (S-1, S-2, S-2A, S-3, S-4, S-5, S-6, S-7, S-8, S-9 and S-10) is enumerated in Sample-wise row in Table-3. For example, in case of Sample No. S-6, the values of fraction retained as Weight %age of Soil taken are 78.80 (Sieve: 4.75mm), 58.77 (Sieve: 2.36mm), 46.30 (Sieve: 1.18mm), 37.69 (Sieve: 0.60mm), 31.12 (Sieve: 0.30mm), 25.31 (Sieve: 0.15mm) and 22.97 (Sieve: 0.075mm) respectively. This way we can see that the values of fraction retained as Weight %age of soil taken are in decreasing order for individual samples.

As per Unified Soil Classification System (USCS: Appendix-7)all the samples listed in Table-3 can be categorized as ***Fine Grained Soil*** as >50% of the soil samples pass through 0.075mm (No. 200) Sieve. Further, as per USCS, all fine grained soils are Silts and Clays, but those with Liquid Limit (LL) < 50 are categorized as Lean Clay/ Silt/ Organic Clay or Silt.

6.2 Atterbergs Limits:

If the clay is initially fairly dry, it is likely to be hard have the properties of a solid. If its water content is increased, it will start to soften and enter a stage termed semi-solid. With continuing increase in water content, it will further soften and eventually become truly plastic. In its plastic state, clay can be deformed or molded without cracking or breaking and without undergoing volume change. With further increases in water content, the soil will eventually become soft enough to be more liquid than solid. The water content that mark the boundaries between these stages are termed the Shrinkage Limit (SL), the Plastic Limit (PL) and the Liquid Limit (LL). (Wesley, L.D., 2010) (Fig.-11).

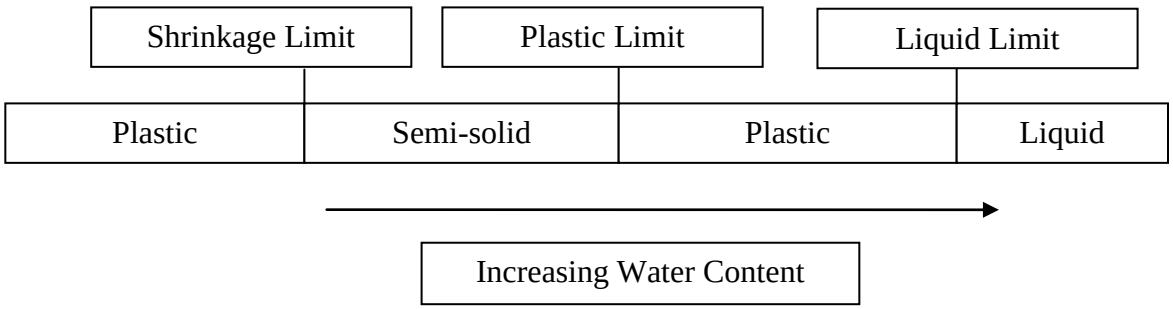

Fig. -11: Solid, Plastic and Liquid Stages of a soil and the boundaries between them (Wesley, L.D., 2010).

The distinction between cohesive and non-cohesive soils is important to an understanding of how a soil may or may not deform under stress. The amount of water in the soil controls deformation behavior for that soil. This behavior is called 'Soil Consistency'. The soil may respond to stress in a non-plastic, plastic or viscous manner. A cohesive soil will change from a non-plastic to a plastic to a viscous state as water content increases. Non-cohesive soils are non-plastic for almost all ranges of water content. High water content can cause a non-cohesive soil to deform as a viscous fluid.

Consistency for a particular soil is defined by the water content present when it changes its response to stress (Atterbergs Limits, as stated above). Between 0% water content and PL and between PL and LL, the soil behaves as non-plastic and plastic material respectively. The range of water content is termed as the Plasticity Index or PI and is calculated using Eq. (1).

$$PI = LL - PL \quad \text{Eq. (1)}$$

The LL, PL and PI values together called as "Atterberg Limits". Above the LL, the soil behaves as a liquid or viscous material (Jonson and DeGraff, 1988). Greater the PI, greater the plasticity of the soil (Ranjan and Rao, 2005).

In fact, if addition of water is continued, the thickness of the water film on a particle increases. Increasing the thickness of water films permits the particles to slide past one another more easily. The behavior of the soil, therefore, is related to the amount of water in the system.

From Table-3, we can see that the values of Shrinkage Limit (SL), Plastic Limit (PL) and Liquid Limit (LL) are available for Sample Numbers S-1, S-2, S-2A and S-8. From the Table-3, we can see that the SL, PL and LL values of a particular sample out of aforesaid four samples, are increasing gradually (say for e.g., for Sample No. S-2A, the values of SL, PL and LL are 18.16, 20.45 and 23.16). In other words, we can say that on increase of water content, the concerned soil is passing thorough Soil, Plastic and Liquid stages and these limits are defining the boundaries between these stages for concerned soils, as indicated in Fig.-11.

'Atterbergs Limits' are a measure of the water content range over which the soil is plastic (Plasticity: of cohesive soils may be defined as their capability to undergo changes of shape without rupture or a change in volume). A soil is considered Non-Plastic when Liquid Limit or Plastic Limit cannot be determined and denoted by NP. Clay Soils having high Plasticity Index with High Liquid Limit, is called Highly Plastic Clays; sometimes called Fat Clays. Those having lean values are called Lean Clays.

6.3 Density:

In case of Dry Density (DD), the overall values vary from 1.14g/cc to 1.74g/cc. (Table-3), for the samples collected from selected portions of slide area. The values reflect that there is not much of difference in field dry densities of the soil samples collected from entire slide zone. The values of Wet Density (WD), received for two samples i.e. S-9 (1.41 gm/cc) and S-10 (1.39gm/cc) are not only close to each other but also close to their respective dry densities i.e. 1.43 each for both samples.

6.4 Specific Gravity:

Specific Gravity (SG) is a dimensionless quantity (not expressed in units) and is defined as the ratio of the weight of a given volume of solids to the weight of an equivalent volume of water at 4°C. From Table-3, it can be seen that the SG's values of the soil samples are varying from 2.49 to 2.75, reflecting not much of difference in its values for samples collected from slide area. From the values of Specific Gravity, Unit Weight of Solids/ Material (γ) can be calculated using Eq. (2) (Ranjan and Rao, 2005).

γ = Specific Gravity (G_s) x Unit Weight of Water at 4°C……Eq. (2)

As Unit Weight of Water at 4°C is 1g/cc, the γvalues for Samples enumerated in Table-3 can be obtained [empirically using Eq. (2)] and are same as Specific Gravity i.e. : S-1(2.49), S-2(2.61), S-2A(2.54), S-3(2.62), S-4(2.70), S-5(2.71), S-6(2.65), S-7(2.54), S-8(2.75), S-9(2.70), S-10(2.67).

6.5 Moisture Content/ Natural Moisture Content:

From Table-3, it can be seen that the post-slide values of Moisture Content (MC)/ Natural Moisture Content (NMC) vary in general from 1.57 to 10.50 and, therefore, no regular trend/ coherence is shown by the samples, which ultimately is reflecting the varying conditions of moisture content in soil, prevailing at the time of collection of soil samples.

6.6 Void Ratio and Permeability:

Void ratio (e) of soil is defined as the ratio of the volume of voids to the total volume of the soil. It is, in general, used in parallel with Soil's porosity (n), and can be empirically defined as per Equation No. (3).

Void ratio (e) = Porosity (n) / [1- Porosity (n)]……Eq. (3)

By placing values of Porosity (n) of Sample Nos. S-9 and S-10 (received from GT Lab., GSI, Lucknow) in Eq. (3), values of Void ratio (e) are obtained as 1.92 for these two samples.Overall, we can see that the values of Void ratio (e) are varying from 0.50 (Sample No. S-2) to 1.18 (Sample No. S-1) (Table-3).

As stated above, Void ratio is used in parallel with Soil's porosity (n) which is, again, the ratio of the volume of voids to the total volume of the soil, and can be empirically defined as per Equation No. (4).

Porosity (n) = Void ratio (e) / [1+Void ratio (e)].……Eq. (4)

Again, by placing values of Void ratio (e) of Sample Nos. S-1, S-2, S-2A, S-3, S-4, S-5, S-6, S-7 and S-8 (received from GT Lab., GSI, Lucknow) in Eq. (2), values of Porosity (n) are obtained as 0.46, 0.67, 0.51, 0.56, 0.56, 0.55, 0.56, 0.54 and 0.62 respectively for these 9 samples (Table-3). Overall, we can see that the values of Porosity (n) are varying from 0.46 (Sample No. S-1) to 0.67 (Sample No. S-2) (Table-3).

6.7 Shear Strength Parameters:

Soil strength of soil may be defined as the resistance to shearing stresses and a consequent tendency for shear deformation. It is expressed by two parameters viz. Cohesion (C) and Agnle of Internal Friction (**Φ**). Cohesion (C) may be defined as tendency of constituent particles to stick together by virtue of molecular and electrostatic forces of particles. Similarly, Angle of Internal Friction (**Φ**) may be defined as the innate resistance offered as a result of interactions between individual particles constituting the plane of separation.

6.7.1 Slope Stability Analysis:

To assess the stability of slope, C and Φ plays an important role. The purpose of slope stability assessment/ analysis is basically to assess the status of the hill slope so that relevant slope stabilization measures can be planned with a view to reduce the risk. In the present case, almost whole slope has been failed and debris are accumulated within main slide zone (above road level) and in flow path area (below road level on valley side). In addition, a colluvium strip is resting in upper part, as seen exposed in the crown portion.

The soil samples collected in field as discussed above, are submitted to Geotechnical Laboratory, GSI (NR), Lucknow, for estimation of geotechnical parameters (Table-1, 2, 3; Annexure-6). Nevertheless, the values of shear strength parameters (C and Φ) could not be obtained for all the samples collected from slide area. Moreover, Φ values obtained for Sample Nos. S-1, S-2, S-2A and S-8 are on much higher side i.e. 47°, 40°, 48° and 44° (Table-3) and, therefore, stability analysis for calculation of Factor of Safety (FOS, or 'F') cannot be done as it may not reflect judicious values of Factor of Safety.

***Note**: In addition to above, one separate set of samples was also collected from above 11 locations (Total 22 samples from 11 locations) in Kotrupi landslide area during the course of field work. This set was handed over to concerned HPPWD authorities for testing in their laboratory or any other relevant/ certified laboratory. Till the finalization of this report, the results of geotechnical parameters of this set of samples could not become available to GSI. Therefore, further attempt to calculate the actual FOS value could not be done.*

7. RISK PERCEPTION:

As stated above, the Kotrupi landslide incidence of 13/08/2017 caused huge life loss to passengers of two HRTC Buses and reportedly to a few local vendors as stated above. Moreover, the up slope settlement of Kotrupi village was completely razed off and the lower settlement was partly affected. In addition, part of National Highway stretch passing through the slide area was damaged due to slide debris.

Some important points regarding risk perception of Kotrupi landslide are enumerated as hereunder:

1) Tension/ Ground cracks were observed on natural slope adjoining to right fringe of the slide (creep movement, as also evidenced by tilting of trees). In case of any major slide/ slip event, problem can be there to Jaged village downslope and to the highway.
2) Although no retrogressive movement of crown of the slide was observed on uphill side, loose rock fragments were observed falling intermittently during the course of field work.
3) Part of highway that is repaired and at present in working condition, is laid on slide debris only any differential movement within slide debris or slip/flow of existing debris present on hill side can create problems to the vehicular traffic and commuters.
4) At present the slide debris next to road on valley side are accumulated in the form of debris, which is further flattened by HPPWDto a platform. These debris are still loose and can slip/ slide down especially during incessant rainfall spells.
5) As the four laning of Mandi - Pathankot NH-154 is proposed, this site i.e. Kotrupi landslide area should be taken care off while planning.

8. CONCLUSION AND SUGGESTIONS TO REDUCE THE RISK:

The present investigation were taken up with a view to carry out geological mapping and geological and geotechnical assessment of the slide area. Mr. Sanjiv Kumar, Director, Engineering Geology Division, GSI, Chandigarh regularly examined the slide with the field officers and provided useful inputs (Annexure-II of Appendix-2; Appendix-4).Subsequently, during field work, the topographic map was improved upon and geological mapping of Kotrupi landslide was carried out. Further, extensive field traverses were carried out within slide complex and adjacent areas with a view to understand slide mechanism, role of various geo-factors, elements at risk and risk perception and planning for collection of samples for estimation of geotechnical parameters which are expected to help during slope stability assessment/ analysis with a view to further plan for suitable remedial measures for the slide area.

Following remedial measures based on the present investigation are enumerated below:

1) Filling up of ground/ tension cracks within slide area.
2) Provision of protection measure, next to road level on valley side, for immediate protection to Kotrupi village.
3) Protective measures/ crate walls on hill side of road to avoid slipping of debris towards hill side unlined drain/ road.
4) Lining of unlined drain on hill side.
5) Biotechnical slope stabilization measures (Geo-juite, species whose roots are able to bind the soil) within the landslide area, after proper identification of suitable places.
6) Provision of proper surface drainage for channelization of surface water. An artificial *nala* towards left fringe of the slide has been developed by HPPWD in slide area. Nonetheless, seepage was observed during field work at a few places in main sub-vertical steep escarpment slope as well as from parts of slide scars on right fringe. Therefore, it would be better to provide surface drainage to divert this water into newly developed *nala* towards left fringe. Tentative alignment of *nalas* to be provided is plotted on the map (Plate-1). However, exact location, design etc. can be finalized by geotechnical/ civil engineers, as per the site conditions.
7) Two core bore holes are proposed in Kotrupi landslide area (Plate-2) towards hillside above the existing road level, with a view to know the exact location of toe of the

slide as well as to know the overburden-rock contact in the slide area (Refer Director's Comments and Annexure-I in Appendix-2; Appendix-4).

8) During the field work it was observed that people and commuters often stand at road and on valley sides to view the slide, many a times from critical locations like valley side edge of existing road/ platform. Similarly, during the 2nd phase of field work during February, 2018, it was observed that local/ nearby residents often takes slide debris, especially the rock blocks, by breaking them, probably to use as construction material at local level. Concerned administrative authorities/ HPPWD should ensure that these practices be strictly avoided from risk to life and property point of view.

9) It has came to the notice that the road stretch is under planning for widening by National Highway Authorities of India (NHAI). In that case, it can be better, if the present road alignment is shifted towards valley side, by way of providing a bridge in the zone affected by the existing slide (Appendix-4). Nonetheless, the final suggestions depend upon the planning of NHAI. In case of existing scenario, for the existing steep escarpment slope and slide zone, a lot of slope stabilization work would be required involving blockade of road for vehicular traffic and expenditures on high side towards treatment measures. Considering this scenario, shifting of road alignment on valley side appears to be an economic option.

Director's comments:

The Kotrupi slide is ~340m in length, ~220m wide (maximum width) and ~ 240m in height (refer Plate-2). Run out area of the slide is ~650m. The toe of the slide is tentatively inferred on the basis of geomorphology, distribution of slide debris and other field evidences. For identifying the exact toe core bore holes at two locations (triple tube with 100% core recovery) has been recommended to P.W.D., H.P. As the slide is huge and treatment measures will be very costly, therefore, possibility of bypass tunnel was explored which was ruled out on geological considerations (overburden and poor to extremely poor rockmass likely to be encountered). Also Mandi - Pathankot highway is slated to be four lane,therefore, it has been recommended to state govt. to shift the road valley side and a bridge may be

considered to bypass the slide affected zone. The level and location of bridge is to be decided byh the NHAI as they are in process of four laning the entire Pathankot-Mandi highway. It has also been recommended to state govt. that the agency which finalizes the layout of widened Mandi - Pathankot highway should consider the disposition of Shali thrust in the area and the likely slope stability issues while planning for road alignment (refer Annexure-II of Appendix-2, Director's comments in Appendix-2 and Appendix-4).

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REFERENCES

01. http://www.aboutcivil.org
02. Anbalagan, R., Chakraborty, D., Kohli, A. (2008): Landslide Hazard Zonation (LHZ) mapping on meso-scale for systematic town planning in mountainous terrain [Journal of Scientific & Industrial Research, Vol. 67, July 2008, p486-497]
03. Anbarasu, K., Sengupta, A., Gupta, G., Sharma, S.P. (2010): Mechanism of activation of the Lanta Khola landslide in the Sikkim Himalayas [Landslides, 7(2010), pp135-147].
04. Bureau of Indian Standards (2002): Criteria for Earthquake Resistant Design and Structures: General Provisions and Buildings [BIS: IS: 1893 (Part-1): 2002 (2002)].
05. CGWB (2013): Groundwater Information Booklet, Mandi District, Himachal Pradesh [Central Ground Water Board, Northern Himalayan Region, Dharamsala, pp1-3].
06. http://www.civil-engg-world.blogspot.com
07. http://www.geotechdata.info
08. Google Earth (Internet Based Software Application).
09. GSI (2011): Mission-IV: Standard Operating Procedure: Landslide Investigations (Non-NLSM) [Geological Survey of India, Kolkata].
10. Johnson, Robert B. and DeGraff, Jerome V. (1988): Principles of Engineering Geology [John Wiley and Sons Inc. New York, pp85-86].
11. Ranjan, G. and Rao, A.S.R. (2005): Basic and Applied Soil Mechanics [New Age International (P) Limited, Publishers (Formerly Wiley Eastern Limited), New Delhi, pp10-76].
12. Sharma, S.P., Anbarasu, K., Gupta, S. and Sengupta, A. (2010): Integrated very low frequency EM, electrical resistivity, and geological studies on the Lanta Khola landslide, North Sikkim, India. [Landslides, 7(2010), pp43-53].
13. http://www.sigmaaldrich.com
14. http://www.theconstructor.org
15. Wesley, L.D. (2010): Fundamentals of Soil Mechanics for Sedimentary and Residual Soils [John Wiley & Sons, Inc., Hoboken, New Jersey, USA), pp31].