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The Evaluation of Hydrological Impact through Temporal Resistivity Investigation at Lantakhola Landslide Area, North District, Sikkim Himalaya

[1]Dr. P K Gupta, [2]Rishi Kumar Gupta

[1]Professor, Department of Civil Engineering, Dr. C V Raman Institute of science & Technology Raman University, Kota, Bilaspur, Chhattisgarh, India

[2] Founder, Chartered Engineers, Bilaspur, Chhattisgarh, India

Abstract: ***Lantakhola landslide area of North district in Sikkim Himalaya has origin through cloud-burst in 1965 with it's continuation at present. It possesses instability circumstance to National Sikkim Highway [NSH] due to prevailing adverse hydrological impact. The rainfall of high intensity with large magnitude during each monsoon period leads to continuous easterly shifting pattern of crown portion towards top of hill range. The surface water as three active stream channels with their turbulent flow encourage charging of sediments, losing their shear strength and vibration due to cyclic load of traffic movement on NSH provoke liquefaction among soil. The enormous high recharge condition of groundwater has been due to presence of tensional- cracks, weak geological plane, foliation plane along steeply slope on account of the regional central Himalayan thrust, passing through area advocates excessive positive groundwater pore pressure. Temporal Resistivity investigation along 19 instrumentation sites has been carried out during successive pre-monsoon, monsoon, & post-monsoon period along five major portions of Lantakhola landslide area namely: Crown, Central along NSH, Southern NSH, Northern NSH & Toe. The objective of study has been to decipher the groundwater disposition in major part of area, role of water in it's different form during various seasons and the status of hard rock occurrence at subsurface, with factual information for pillar/ foundation of proposed Cantilever bridge construction.***

1. Introduction

Lantakhola landslide area of North district in Sikkim belongs to local lantakhola nallah across NSH. It is about 71.4 Km in north of Gangtok- capital of Sikkim state along eastern bank of Tista river. It has strategic importance- as being only road link to Indo-China border in North district of Sikkim state. It is originated through cloud-burst in 1965 and being more active since 1975 [merger year of Sikkim state into Indian Territory].

Several reputed and prestigious national organizations have studied it during the past. Central Road Research Institute [CRRI] New Delhi has studied during 1980 with suggestion for construction of retaining wall-as treatment measure, which were survived for two successive years only and washed away in monsoon period of third year. Geological Survey of India [GSI] Kolkata has studied in 1983, after heavy rainfall of september1982-damaging NSH. It has observed that successive slip failure, scarp development & headword erosion are the prominent governing factors for activation of crown portion of landslide. It has been again studied by them in 2002 for mapping the various portions of landslide area along-with hydrological impact. Jute Research Institute [JRI] Kolkata has studied in 1995 with suggestion of geo-textile blanketing for muddy slope portion with limited success.

The present study has been executed during 2005-2007 by CIMFR, Dhanbad [erstwhile Central Mining Research Institute-CMRI] as a part of consultancy project, sponsored by Border Road organization [BRO] New Delhi, Government of India.

2. Area of Study

It is in between Mangan [Head quarter of North district] and Chugtham, along Tista river, the famous localities. It belongs to Survey of India Topo-sheet no. 78 A/10 [1:50,000 scale]. It has disturbed NSH of 600 m stretch with shifting pattern of debris in east direction along crown portion as well as down word in toe portion. The northern NSH portion has strong hard rock formation without any geological discontinuity, as comparison to the remaining landslide area. The glance view for the area of study from northern and southern direction is illustrated as Fig.1

Figure 1: Lantakhola landslide area as viewed in field from northern direction

3. Methodology

Two conventional approaches have been evolved namely: field study and lab study. The field study incorporatescollection of relevant literature, field observation and temporal resistivity investigation during successive pre-monsoon, monsoon & post monsoon period for different portions of landslide along-with liquefaction. The lab study executes the interpretation cum analysis of field data with the correlation through standard master curves for obtaining the following desired objectives: -[5]

- Demarcation for the thickness of soil cover & weathered formation along crown portion,
- Role of various form of water and associated liquefaction in the area of study including groundwater disposition.
- Delineation of solid rock versus weathered formation for foundation purpose of the Cantilever bridge construction in toe portion.

4. Result & Discussion

Geologically, the area of study has regional central Himalaya thrust with trend NW-SE cutting across. It has produced tensional crack, geological weak plane as well as foliation plane among country rock as-pre-cambrian metamorphic rock. It is characterized by highly foliated Biotite gneiss inter-bedded mafic rich garnetiferous material. It is over-lained by debris cum cohesion-less soil watercharged with sediments under almost flow condition in major portion of area. The main cause of slope failure is the imbalance of forces in between strength of rock-mass & soil versus gravitational force, exerting beneath slip surface, weak plane [6].

Hydro-logically, the area of study has devastating role of different category of water. The rainwater during monsoon period of higher intensity with cloud burst is the genetic cause of landslide occurrence. The large magnitude of rainfall [3700 mm] in monsoon period with it's successive continuation during past fifty years seems to be mode for the shifting pattern of crown portion in east direction towards the top of hill range.[4]. The overall adverse impact of rainwater on the geometry cum dimension of landslide is illustrated as Fig.2 [3]

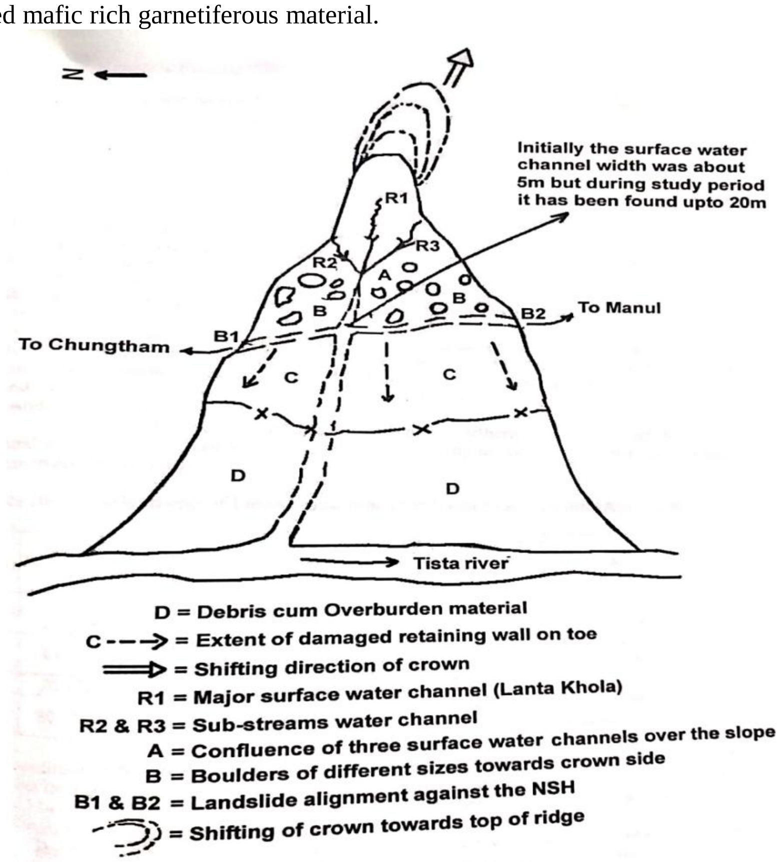

Figure 2: Adverse impact of Rainwater on geometry of Landslide

The surface water is present in the form of Lantakhola nallah with it's three sub-tributaries. They have turbulent flow condition in each season, encouraging weathering & erosion. It causes enhancing the width of sub tributaries initially from 1 m to 8-10 m presently. Besides, the production of charged sediments & reducing thickness of soil cover. It does increase infiltration rate to subsurface on account of lubrication. The lubricant action favourably occurs along tensional crack, weak geological plane & foliation plane a responsible factor for slope failure over entire landslide area.

The ground water occurs at shallow depth as unconfined aquifer on the account of reducing trend of soil cover thickness as well as presence of weathered formation with weak geological planes. The prevailing favourable condition for groundwater leads to generation of excessive positive groundwater pore pressure. When it is present over less to moderate slope area, causes cardamom growth along hard rock formation and mixed variety of vegetation along debris area. But the presence of excessive positive groundwater pore pressure over higher slope area causes devastation towards liquefaction.

Geo-technically the area of study has adverse phenomena of liquefaction occurrence along crown and NSH portion. It is oversaturated condition for cohesion-less soil, losing it's all strength, particular shear strength up to zero level and soil get start flow like liquid along-with charged sediment & water,[1] The mode of occurrence for liquefaction is governed by following aspects of LOVE [2]:-

- Lose behaviour of soil
- Oversaturation of soil by all kinds of water
- Vibration in surrounding & beneath strata
- Excessive positive groundwater pore pressure cum un-drained soil condition

Liquefaction is correlated with following condition of soil in field [8]:-

- Lose soil charged with water-sediment mixture along scrap, crown portion of landslide.
- Lack of sediment deposition due to turbulent flow of surface water.
- High base flow for surface water stream.

The severity of liquefaction index is governed by the thickness of soil cover. The soil cover having thickness of less than 0.5 m has maximum chances of liquefaction in the range of 2-4 mm [9].

The vibration in surrounding & beneath strata is basically governed by seismicity of the area [7].The area under study belongs to seismic zone IV as well as cut across by regional thrust of central Himalaya- responsible for releasing seismic energy. The vibration in the area of study is observed on account prevailing cyclic load due to vehicle transportation along NSH.

Geo-physically, Lantakhola landslide area has been studied through temporal resistivity investigation for three successive seasons namely; pre-monsoon, monsoon & post-monsoon period. The area of study has been divided into five portions namely: Southern end of NSH, Main slide area along NSH, Crown, Toe & Northern end of NSH for sake of convenience in instrumentation. The location of 19 instrumentation sites for entire five portions has been illustrated as Fig.3.

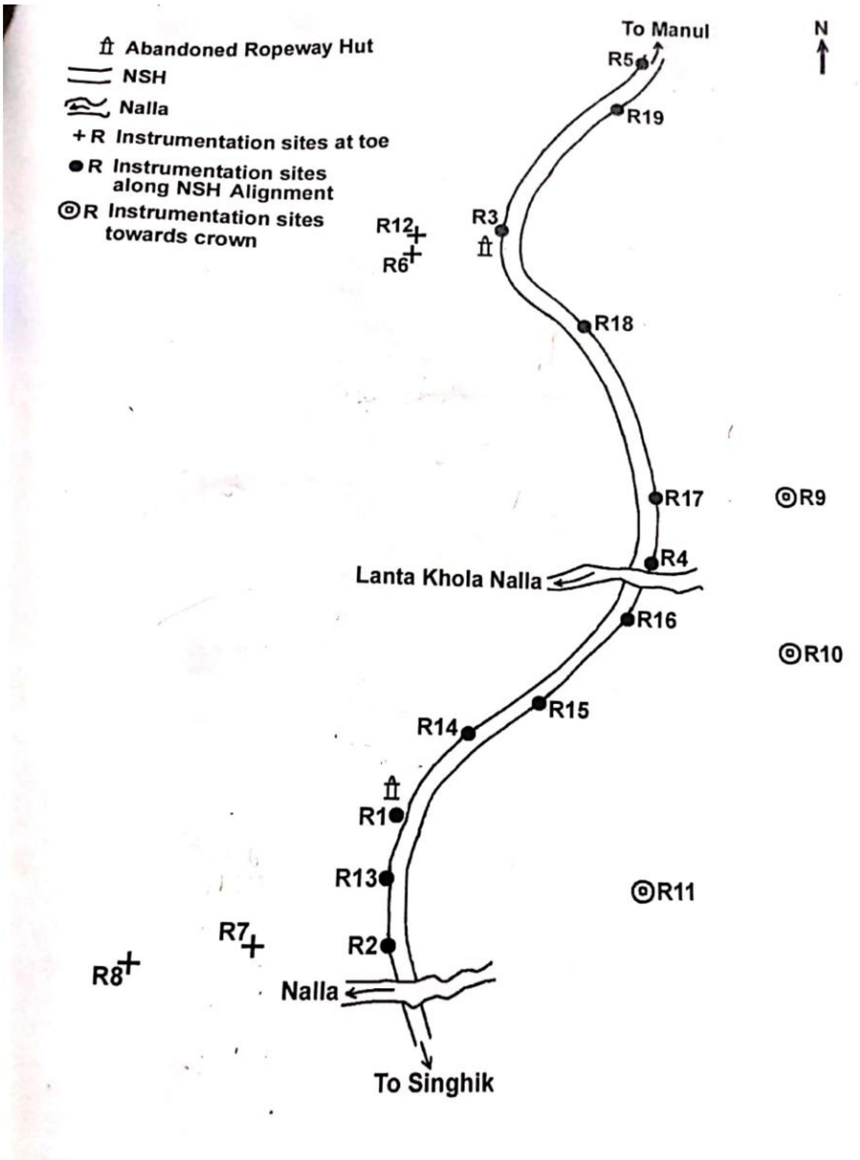

Figure 3: Field sketch showing 19 instrumentation sites along five major portions

The geophysical instrument namely D C Resistivity meter along-with necessary accessories has been employed using Schlumberger electrode configuration in conjunction with field observations. The apparent resistivity data collected through instrument has been correlated with standard master curves towards matching purpose. The interpretation of data has been assisted for decipher inferred information in order to fulfilling the desired objectives. The details of all 19 instrumentation sites for different portions in three successive seasons has been summarise in Table: 1.

Table 1: Details of all 19 Instrumentation sites for different portion in successive three seasons

S N	Name of major portion	Number of Instrumental sites	Name of Instrumental site	Pre monsoon	Monsoon	Post monsoon
1	Southern end of NSH	3	R1 R2 R3	Yes Yes	Yes Yes	Yes Yes Yes
2	Main slide along NSH	6	R4 R14 R15 R16 R17 R18	Yes	Yes	Yes Yes Yes Yes Yes Yes
3	Crown	3	R9 R10 R11	Yes Yes Yes	Yes Yes Yes	
4	Toe	4	R6 R8 R9 R12	Yes Yes Yes	Yes Yes Yes Yes	
5	Northern end of NSH	3	R3 R5 R19	Yes Yes	Yes Yes	Yes Yes Yes

Southern End of NSH Portion

It is located in between southern nallah [parallel to Lantakhola nallah] & abandoned ropeway hut. Three instrumentation sites namely: R1, R2 & R3 have covered this portion. The R1 & R2 sites belong to pre- monsoon and monsoon seasons, while R13 corresponds to all three seasons.

The R1 & R2 sites have been studied up 90 m depth of investigation from the ground surface. **The groundwater occurrence has been confirmed through characteristic value of apparent resistivity 4-6 ohm/m at the depth range of 25-30 m** and matching with standard master curve**.** The rubble zone – water charged sediment with foliation cum weak planes has been inferred through characteristic value of apparent resistivity 55-60 ohm/m at the depth range of 55-60 m. **The hard rock formation has been confirmed through characteristic value of apparent resistivity 750-800 ohm/m at the depth range of 78-90 m.** The R13 site has been also studied up to 90 m depth of investigation. It has not inferred any occurrence of groundwater at depth range of 25-30 m during any season, but has confirmed the presence of hard rock formation at depth range of 68-90 m.

Main Slide Portion along NSH Portion

It is located in between NSH abandoned ropeway hut and bulldozer sheltering place at the northern side. It has six instrumentation sites namely: R4, R14. R15, R16, R17 & R18 . All the six sites have been studied up to depth of 90 m investigation. The R4 site has been studied in all seasons-because of it's closeness to Lantakhola nallah, and association with **liquefaction**along NSH. **The hard rock formation has not been encountered** at **any one of six sites. The R17 & R18 sites have been associated with liquefaction during post monsoon season after depth of 5-8 m from the ground surface.** The liquefaction is matrix of sediment, cohesion-less soil under overcharge condition of all kinds of water.The other relevant information, inferred has been summarised as Table 2.

Table 2: Inferred information through temporal resistivity investigation at all six sites for main slide portion of NSH

S N	Depth range [m]	R4 Pre M Post	R14 Post	R15 Post	R16 Post	R17 Post	R18Post	app. resistivity [ohm/m]	Remark
1	4-5	L LL			UA				
2	6-8	L LL				L	L	20-22	L=Liquefaction
3	15	UA L L		L				5-8	UA=Unconfined Aquifer
4	25	L L							
5	55	WP L L	WP		WP			10-15	WP=Weathered Plane
6	90	WF L L						100-120	WF=Weathered Formation

Pre = Pre monsoon period, M= Monsoon period, Post= Post monsoon period

Crown Portion

It is located in between the top of hill range & NSH road alignment. It has three Instrumentation sites namely: R9, R10 & R11 and studied during pre-monsoon and monsoon period. The Instrumental sites R9 & R10 have been checked up to 90 m depth of investigation from their respective ground surface, while the Instrumental site R11 has been verified up 200 m depth of investigation, because of it's association with cardamom vegetation.

It is characterized by the rainfall of high intensity with large magnitude during each monsoon period leads continuous easterly shifting pattern of crown portion towards top of hill range. The surface water as three active stream channels with their turbulent flow encourage charging of sediments, losing their shear strength and vibration due to cyclic load of traffic movement on NSH provoking liquefaction among soil. **The R9 Instrumentation site has ascertained excessive positive groundwater pore pressure at depth range of 25-30 m during monsoon period, followed with the occurrence of hard rock formation at depth range of 65-70m during pre-monsoon & monsoon period, respectively. The R10 instrumentation site has provided excessive positive groundwater pore pressure at the same depth range of 25-30 m during monsoon period.** The other relevant inferred information through Instrumentation sites R9 & R10 have been summarise in Table 3.

The Instrumentation site R11 has been delineated excessive positive groundwater at depth range 0f 15-20 m, with characteristic apparent resistivity of 8-10 ohm/m during pre-monsoon and monsoon season, followed with mixed rock formation as palaeo-glacial deposit at depth range of 186-200 m with characteristic apparent resistivity of 60-80 ohm/m.

Toe Portion

It is in between NSH road alignment and eastern bank of Tista river along moderate slope with variety of vegetation cover over debris material. It has four Instrumentation sites namely: R6, R7, R8 & R12. The instrumentation sites R6, R7, R8 have been studied during pre-monsoon and monsoon period up to 90 m depth of investigation The instrumentation site R12 has been studied up to 8 m depth of investigation during monsoon period and could not proceed further due to sudden heavy rainfall. **The hard rock formation at instrumentation sites R7 & R8 has encountered at depth range of 15m -90 m and for R6 at depth range of 79-90 m.** The selected R7 & R8 instrumentation sites have proven to be good site for foundation purpose towards bridge construction. The other relevant information inferred have been summarise as Table 4.

Table 3: Inferred information through temporal resistivity investigation for crown portion

S N	Depth range [m]	R9 Pre Mon	R10 Pre Mon	Characteristic app. Resistivity value [ohm/m]	Remark
1	10	Boulder & surface water	- -	8-11	Infiltration of surface water channel through opening of different size bolder into sub-surface
2	15-20	Ground water -	- -	5	Upper limit of saturation
3	25-30	Mixed rock water	Charged sediment& water	80-120 [7-9]	Weathered garnetiferrous gneiss [lower limit of saturation]
4	40-45	Ground water	Ground water -	4-5	Confined Aquifer
5	55-60	Ground water & overcharged sediments	- -	8-10	Over saturated Impermeable Layer
6	65-70	Hard rock	Hard rock	300-400	Quartazite- feldspathic gneiss, as hard rock
7	85-90	Mixed rock -	Mixed rock	60-70	Paleoglacial deposit

Pre= Pre-monsoon, Mon = monsoon

Table 4: Inferred information through temporal resistivity investigation for toe portion

S N	Depth Range [m]	R6 PreM	R7 PreM	R8 PreM	Characteristic app. resistivity [ohm/m]	Remark
1	15-20	- UA	HF HF	HF -	2-4	UA= Unconfined Aquifer
2	35-50	- WF	HF HF	HF H F	80-200	WF= Weathered Formation
3	70-90	HF HF	HF HF	HF HF	450-500	HF= Hard rock Formation

Pre= Pre-monsoon, Mon = monsoon

Northern End of NSH Portion

It is in between boulder shelter place to hard rocky outcrop with stretch of 130 m. It has three instrumentation sites, namely R3, R5 & R19, and studied up to 90 m depth of investigation. The R3 & R5 sites have been studied during pre-monsoon, monsoon period, while R19 during post monsoon period. **The hard rock as Biotite hornblende gneisshas been encountered at depth range of 70-90 m for R3 & R5 sites, while for R19 site it has occurrence since 30 m depth onward.** The terrain condition for R19 is most suitable for foundation purpose towards Cantilever bridge construction. The information inferred for all instrumentations have been summarised Table 5.

Table 5: Inferred information through temporal resistivity investigation for northern end of NSH portion

S N	Depth Range [m]	R3 PreM	R5 PreM	R19 Post	Characteristic App. Resistivity [ohm/m]	Remark
1	4-5	SC -	SC -	SC	15-20	SC=Soil Cover
2	15-18	D D	D D	D	40	D= Debris
3	30-50	WF WF	WF -	HF	220	WF=Weathered Formation
4	70-75	BHF BHF	BHF -	BHF	410	BHF=Broken Hard Rock Formation
5	80-90	HF HF	HF -	HF	700	HF= Hard rock Formation

Pre= Pre-monsoon, M= Monsoon, Post= Post-monsoon

5. Conclusion

Landslide occurrence in Himalayan region is common due to young formation of mountain system, steep slope, deforestation and disturbance to prevailing drainage. It has been associated with adverse hydrological impact at some strategic places. The present case study is one of them for Sikkim Himalaya.

An attempt has been made for documentation and analysis of major adverse hydrological impact on Lantakhola landslide of North district- Sikkim state. The role of all kinds of water- rain water, surface water & ground water during pre-monsoon, monsoon and post monsoon period, has been evaluated for fulfilling the desired objectives with following summarised view:-

- Main slide portion including southern & northern end has debris cum rubble zone under the influence of cyclic load variation, on account of vehicle movement at NSH. It causes Liquefaction at shallow depth of 5 m from the ground surface. It has hard rock formation at depth of 30 m along northern end- a suitable northern site for foundation purpose towards proposed Cantilever bridge construction.

- Crown portion has been associated with various responsible cum integrated factors for triggering cum activation of landslide at every monsoon & post monsoon period. The excessive positive ground water pore pressure generating at depth range of 5-8 m accelerates surface water channel erosion and Liquefaction.
- Toe portion has been associated with hard rock formation at depth of 15 m at southern end- a suitable southern site for foundation purpose towards proposed Cantilever bridge construction.
- The saturation zone during post monsoon period of 20 m thickness occurs at depth of 5-8 m. It is responsible as contributing factor for variety of vegetation cover growth and cardamom cultivation at northern and southern end respectively.
- NSH has strategic importance. It acts as only available road link from Gangtok to Indo-china border in North district of Sikkim state. The clearance cum maintenance of it in all seasons has utmost importance in order to meet the defence requirement of nation from it's accessibility.

6. Acknowledgement

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