# Triggering mechanism vis-a- vis landslide susceptibility in the high altitude areas of North Eastern Himalaya – An observations from Se La Pass Road corridor, Tawang District, Arunachal Pradesh.

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**Abstract**

Landslide susceptibility mapping by the authors in higher altitude areas of Se La pass Tawang district, Arunachal Pradesh has able to identify various terrain specific triggering and causal factors responsible for initiation of landslides and slope failures in the terrain. Seasonal and diurnal thawing & freezing effects, snow melting, high anomalous snow and rainfall, wind action, ground vibrations, seismicity and excavation for road widening could be attributed for initiation of landslides and slope failures. The said triggering factors at various space and time acted on the upper exposed surface of the variably thick, loose to well compacted boulder laden older debris mass and resulted in the slope failure. Active to suspended landslides and slope failures having areas ranging from 600 sq m to 38000 sq m was identified at 17 locations mostly within the loose to variable compacted boulder laden debris. The said failures were largely related to the climatic aspects like snow melt, severe wind speed and high rainfall characteristics of the terrain. Further, ground vibration due to vehicle movement and seismicity can be related to rock fall, boulder fall and debris fall in some areas. The surficial deposits encountered in the area may be the result of diurnal, annual and millennial freeze-thaw cycles that acted over the crystalline rock-mass through ages. The identification of triggering and causal factors specific to this climatically significant terrain may form the basis for assessment of landslide hazard and risk scenario of the area.

## 1. Introduction:

As a part of the landslide susceptibility mapping of the National Highway corridor between Bomdila and Tawang townships, Arunachal Pradesh, the high altitude areas of Se La Pass Road corridor was studied for generation of a landslide susceptibility map. The studied area is part of the Higher Himalayan regime characterised by extreme rugged topography, lofty mountains, deep valleys, numerous small lakes and have altitude variations like 4050m in Se La pass, 3280 m in Jaswantgarh, 3400 m in Baishakhi and 3310 m in Nuranang. From mid November to mid March, the major part of the slope is covered with variable thickness of ice and Snow. The spatio- temporal distribution of snow and ice in the area is related to the variation in wind direction, slope aspect and diurnal & seasonal variation in temperatures. During peak winter (mid December to mid February) the entire slope including the lower reaches in the valleys are covered by snow. Se La Pass is often blocked from January to March as a result of heavy snowfalls. During monsoon the area also experiences frequent rain and some time snow fall. Snow melting normally starts during the month of March, which causes significant surface flow along the fragile slope, which in major part of the area is loose to variably compacted boulder laden older debris material embedded in pebbly matrix. The boulders are presumably released from the upper reaches where alternate thawing and freezing has effect on the bed rock like granite gneiss biotite gneiss, quartzite, mica schist and calc silicates. The very distinct climatic attributes, nature of surficial material and presence of recent and old landslides/ slope failures along and across the road corridor as documented during the study invokes identification of terrain specific triggering and causal factors that is responsible for slope distressing. An attempt therefore has been made in the present study to identify the range of triggering factors responsible for the initiation of the slope distressing. Simultaneously the causal factors on which the triggering factors acted are also evaluated in respect to the terrain. Finally, the scope for terrain specific slope stability modeling considering the climatic and physical factors are also discussed.

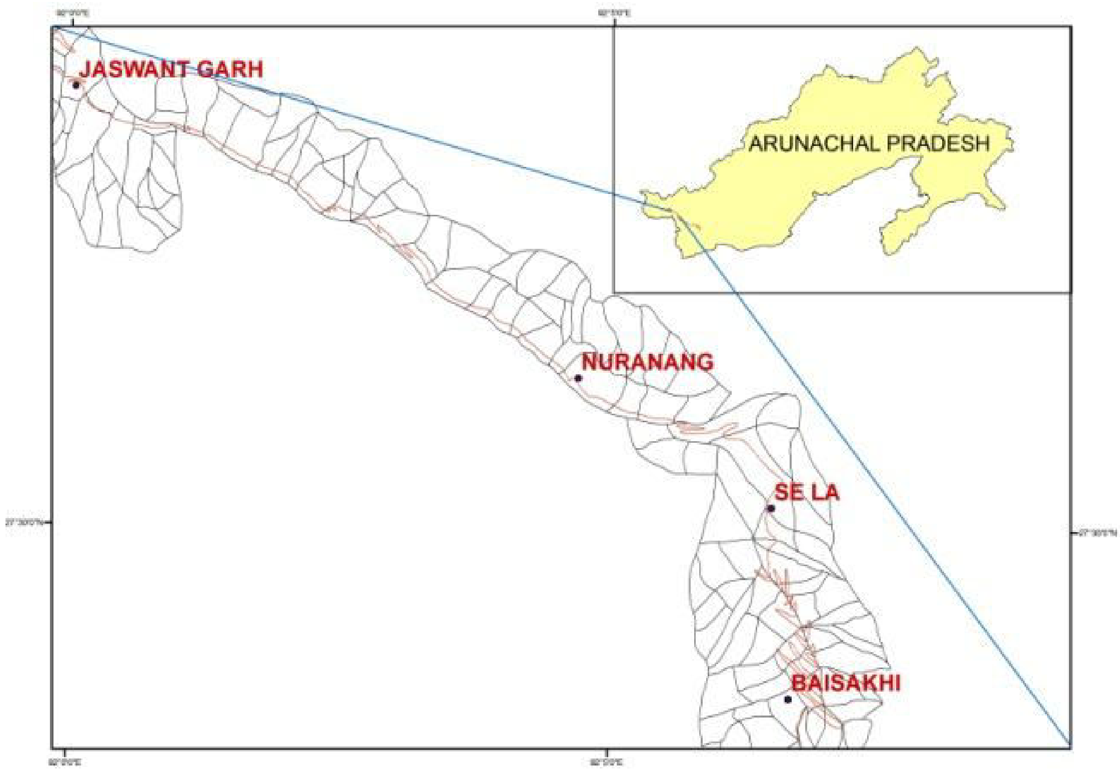


Figure 1 Location map of study area

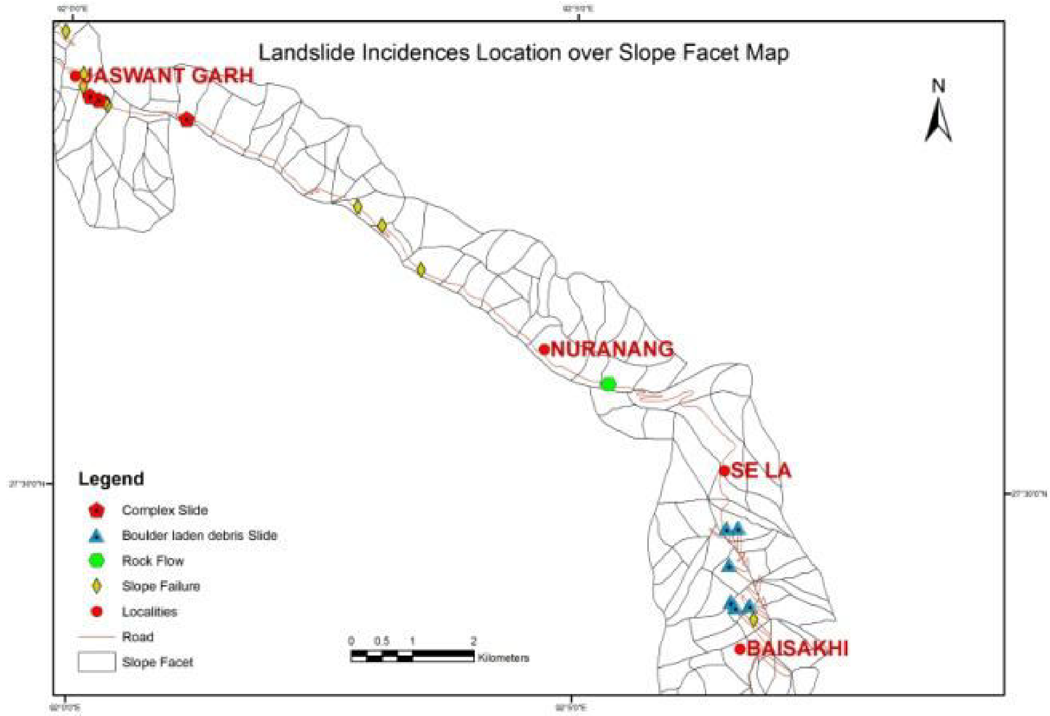


Figure 2 Landslide incidence map

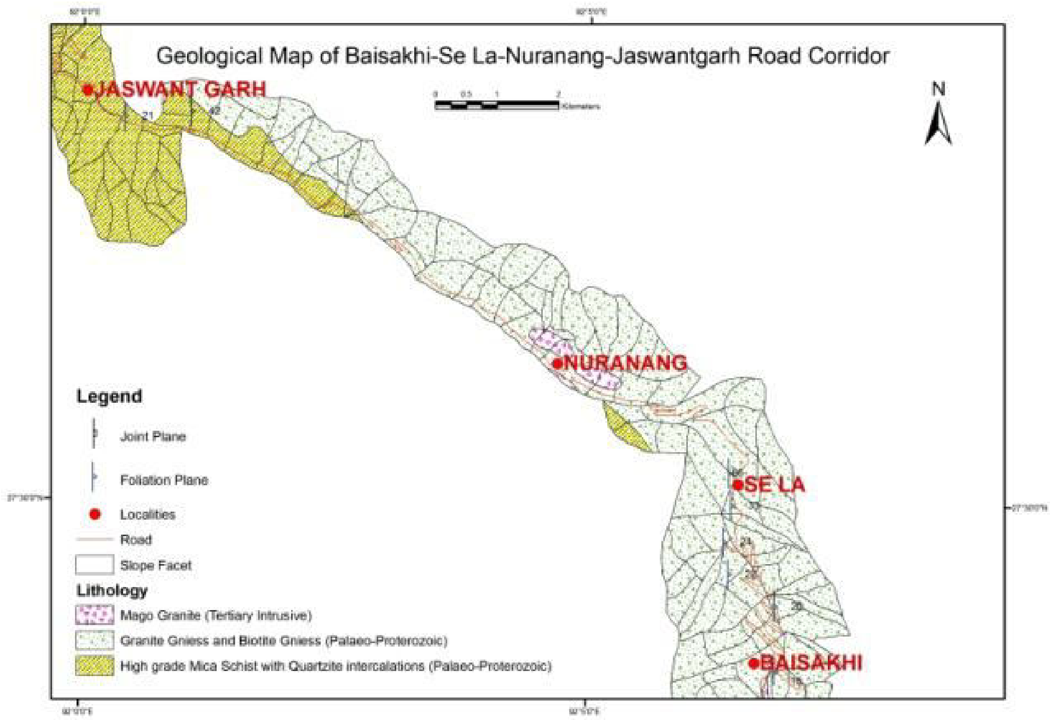


Figure 3 Geological map of the study area

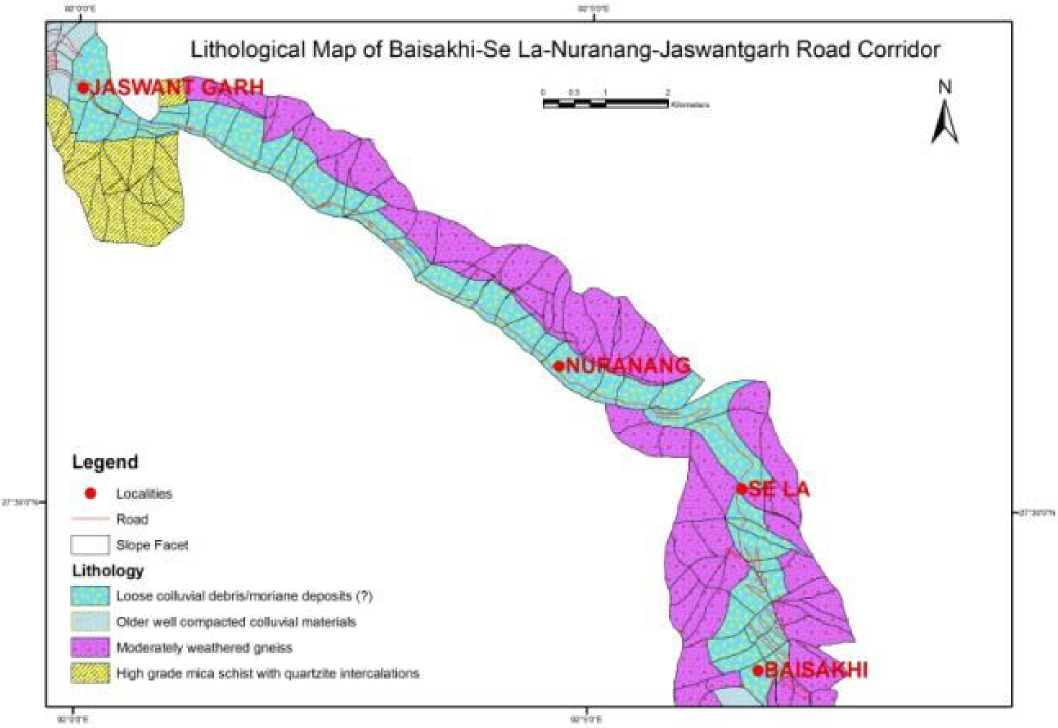


Figure 4 Surficial Geological map of the study area

## 2. Geology:

Geological mapping by Mathur and Mukhopadhaya (1999) had indicated Proterozoic Sela Group represented by granite gneiss, biotite gneiss, quartzite (bedded at places), mica schist, thin quartzite and calc silicate as the country rock which was later intruded by younger granites. The country rocks suffered three phases of deformation which resulted in schistosity (S1), crenulations cleavage (S2) and fracture cleavages respectively. The general trend of foliation in the area varies from ENE-WSW to WNW-ESE with low to moderate dip towards NNW or NNE. The last folding deformation (F3) has led to the formation of a major warp with N-S axial trace. A prominent fault mapped to the north of Sela found parallel to the axial trace of the said major warp.

During the present study, it is observed that the prominent surficial deposits identified in the area are the result of climatic interferences over the crystalline rock mass through ages. The slope forming material along and across the slope represented mostly by surficial deposits shows significant variations in terms of size and ratio of clast/ matrix, degree of compactness and nature of matrix material. In general, i) near the hill crest, dominantly bouldery quartzo-feldspathic rocks. ii) In the mid slope loose to variable compacted boulder laden older debris material. iii) At the base of the slope, younger loose boulder material has been observed. The thickness of the boulder laden older debris material and younger loose boulder material shows variation in the range of 10 -15 m as observed in the studied road sections.

Picture1 Perspective View of the Natural Slope

Picture 2 Debris slide with formation of Cone at the base of the Slope

Picture 3 Debris fall triggered by Ground vibration due to Vehicle Movement

Picture 4 Initiation of Snow melting and Consequent Debris flow

Picture 5 Slope Excavation for Widening of Road bench in Debris material

Picture 6 Strikingly Linear old rock flow Zone involving Disposition of huge Equi-dimensional Rock boulders.

Picture 7 Loose to variably compacted boulder laden Debris- the dominant Surficial Material

Picture 8 Partial collapse of the Retaining Structure due to Debris slide

## 3. Methodologies Adopted :

i) Mapping of all the landslides and slope failure in the area. ii) Preparation of a lithological map indicating the nature and distribution of both surficial material and bed rock. iii) Documentation of all the relevant attributes of landslides/slope failures. iv) Analysis and synthesis of the generated data to understand the triggering and causal factors.

## 4. Results:

Summary of the attribute data base generated in respect of the landslides/slope failures (Pictures 1 to 8) can be enumerated as follows:

a) The studied area is part of the right bank basal slope of the Nurang Chu River. The natural slope varies from 10 to 25 towards SW direction. However, along the studied road corridor the natural slope has been largely modified and became steep to very steep (26 to 45 ). The studied part is mostly barren with patchy shrubs at places.
b) The bed rock along the studied area and in adjoining slope has been mapped (figure 1) as assemblages of granite gneiss, biotite gneiss, quartzite, mica schist intercalated with thin quartzite and calc silicates which were intruded by younger granites. However, during the present study along the road corridor, variably thick, loose to variably compacted boulder laden debris as surficial material has been observed. (figure 2).
c) The slope forming material in most of the cases are found to be boulder laden loose to variable compacted older debris material. Boulders of 0.5 m to 2 m sizes (or some times more) are found variably embedded in a matrix made up of pebble to sand size material. The relative volume of clast and matrix and nature of matrix has also shows some variation. The matrix material in general has low cohesion which is further reduced during dry season.
d) The attribute data of 17 landslides and slope failures has been analysed and are enumerated below:

i) In 75% of the cases, the nature of failure surface is irregular. The same is irregular to planar in 20% and only in 5% cases failure surface is circular.
ii) In terms of dimension of slope area involved, 35 % is within 600 - 1500 Sq m; 30% , between > 1500 Sq m to 5000 Sq m, 12% between 5000 Sq m to 10,000 Sq m and remaining 23 % between 10000- 38000 Sq m.
iii) 53% of the slope failures are active, 41% are suspended and only 6% are old.
iv) Debris fall is the principal kind of movement (47%), shallow translational slide in debris is the next dominant type of movement (29%), toppling, rotational debris slide and rock fall are the other kind of movements documented in the area.
v) Multiple style has been recorded in majority of the cases (65%), complex, composite and single type of style are noted in 18%, 12% and 5% cases respectively.
vi) Flowing condition due to snow melting is the dominant hydrological scenario noted in 60% cases, only flowing condition noted in 30% cases and wet condition recorded in the remaining 10%.
vii) In terms of Triggering factors: 53% of the distressing can be related to combined effect of Snow melt, heavy rain, vibrations due to heavy convoy traffic and high intensity winds, 35% of the failure noted can be related to combination of snow melt, heavy rain, high intensity winds; seismicity, 6% of failures can be attributed to heavy rain with ingression of sewage water and in remaining 6% rock flow may be attributed to some seismicity.
viii) Anthropogenic interferences noted in most of the cases along the road, excavation work for widening of the road benches is continued which has resulted/accentuated the failures.

The various landslide attributes describe above are graphically shown in figure 5.

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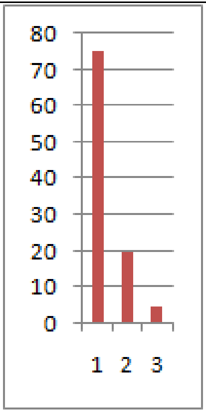
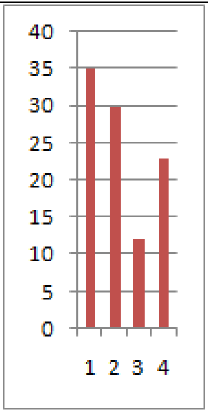
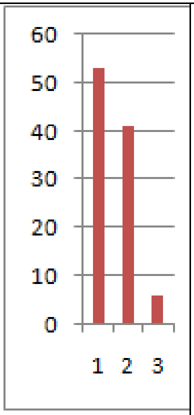
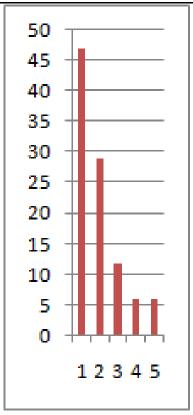
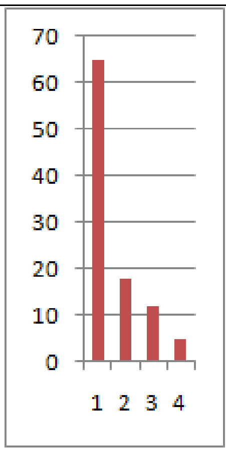
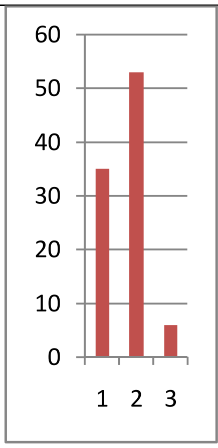
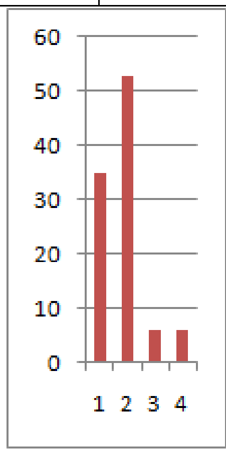
|---|---|---|---|
|  **Failure surface** |  **Dimension (area)** |  **Activity** |  **Movement type** |
| 1.Irregular,<br>2. Planar to irregular,<br>3. Circular | 1. 600-1500 Sq m<br>2. >1500 to 5000 Sq m<br>3. >5000 to 10,000 Sq m<br>4. >10,000 to 38,000 Sq m | 1. Active<br>2. Suspended<br>3. Old | 1. Debris fall<br>2. Shallow Translational slide<br>3. Toppling<br>4. Rotational debris slide<br>5. Rock fall |
|  **Style** |  **Hydrology** |  **Triggering factor** | |
| 1. Multiple<br>2. Complex<br>3. Composite<br>4. Single | 1. Flowing due to snow melting<br>2. Flowing<br>3. Wet | 1. Snow melt, heavy rain, high intensity winds<br>2. 1 & vibrations due to heavy convoy traffic.<br>3. Seismicity<br>4. Heavy rain with ingression of sewage water. | |

Figure 5 Percentage of various landslides attributes.

## 5. Discussion:

i. The study revealed that most important of the triggering effect for the landslides in the area could be attributed to rapid descends of large volume of snow melt during the onset of warmer period. Besides the snow melting, the other triggering mechanism for initiation of landslides in the area can be attributed to heavy rainfall, high (directional) wind speed, thawing and freeing, and even ground vibration caused due to movement of the heavy artilleries. Landslides triggered by the rainfall and snow melt were not homogeneously distributed in the region. Similar phenomena of triggering of landslide by water released after rapid snowmelt has been reported from the mid-latitude area of Europe and Japan by some workers (Chleborad, 1997; Cardinali et al., 2000; Guzzetti et al., 2003; Kawagoe et al., 2009).

ii. Fall of loose boulders and debris from the exposed slope due to the effect of strong wind and ground vibration caused due to the movement of convoy of heavy vehicles is a very significant terrain specific observation noted adjacent to Nuranang and at a place nearly one km away from Jaswantgarh. The said phenomena are mostly observed in the barren slope having loose boulder laden debris with sandy matrix. Because of the prevalence of the similar material in the slope along the road corridors it is likely that in the event of a moderate to large earthquake and consequent ground acceleration the dominant slope forming material may experience similar distressing in large scale.

iii. The strikingly linear old rock flow zone involving disposition of huge equi-dimensional boulders of quartzo-feldspathic rock for a distance of about 200 m near Nuranang is another significant observation. The disposition of the rock boulders descended from the crest of a granite hills are characterised by near equal sizes and shape of the boulders. The mode of disposition rock boulders suggests sudden flow of the jointed rock mass (resulted due to freeze-thaw cycles) from the hill crest which might have been initiated during some past seismic events.

iv. The nature and distribution of the landslides/slope failures, the causal and triggering factors responsible for the slope distressing in the terrain warrant appropriate assessment of the relative contribution of snow melt rainfall, high directional wind speed, seismicity, diurnal and seasonal temperature variation, anthropogenic activity which acted on the dominantly loose to variable compacted boulder laden older debris material. Further, the role of diurnal, annual and millennial freeze-thaw cycles in formation of the said characteristic surficial materials needs probing.

v. Understanding slope instabilities in the snow covered areas has been attempted through Terrain specific spatial distribution modelling by Bloschl et al., 1991; Zanotti et al., 2004; Garen and Marks, 2005; Herrero et al., 2009. Such models require several physical input parameters, the determination of which in space and time is only possible for very well-equipped experimental test sites (Lakhankar et al., 2013). Alternatively, temperature-index methods of Kustas et al., 1994; Rango and Martinec, 1995; Hock, 1999, 2003; Jost et al., 2012 using air temperature as an index to perform an empirical correlation with snowmelt has also been used. The same requires parameters on precipitation, air temperature and snow covered area. Temperature index methods are more simplistic than the Terrain specific spatial distribution models. Snow accumulation/melting model (SAMM) for integrated use in regional scale landslide early warning systems has been proposed by Martelloni et al (2013) for a regional scale early warning system based on statistical rainfall thresholds for the occurrence of landslides taking into account snow accumulation and depletion.

Therefore, from the above it can be summarised that the spatial and temporal susceptibility for landslide in the Se La pass region can be worked out using the generated spatial data base and data on variation in temperature, snow/rainfall, snow melting, wind speed and paleo-seismicity. Further work in this regard by the authors is contemplated.

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