Lithotectonic landslides and hazards in parts of Garhwal-Kumaon Himalayas

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Lithotectonic Landslides and Hazards in Parts of Garhwal-Kumaon Himalayas

R.S. Mithal
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SYNOPSIS

Landslides produce an aweome picture of the hill sides with steep scarred, hollowed and gullied geomorphic features devoid of vegetation particularly between the major thrust zones. A look on the tectono-stratigraphic map of the region with marked major tectonic features like the Main Central Thrust (MCT), North Almora Thrust (NAT) and South Almora Thrust (SAT) indicates that the region is highly prone to landslides and is affected by repeated tectonic and orogenic processes. These factors with the nature of the rocks, climate and the heavy monsoon rains are responsible for sculpturing the region. The mountain features and the valley slopes thus indicate the influence of the activities and the dynamic forces at a particular locality and time. Many times developmental activities have also contributed towards the degradation of the environs due to disturbance of the already stabilized slopes and the angles of repose e.g. along the Rishikesh-Badrinath Road, where a new alignment has been given, sometimes overlapping the old pilgrim route.

INTRODUCTION

In India, the awareness of the effects of landslides is hardly two decades old. Though the phenomenon has been going on, the importance of their occurrence and the resultant losses had been recognised only after the Belakuchi disaster in 1970 due to flash floods. As a result the whole Alaknanda valley got flooded, caused innumerable landslides in its course, dammed the river, formed new terraces in the wider valleys, breached the existing lakes and reservoirs, pulled down lines of communications and transmission, washed out roads and bye passed the existing bridges, wiped out a number of hamlets and habitations and road side shops etc. killed at least 17 people and loss of 23 vehicles, silted up the existing canals, changed the river courses and byes passed the bridges, washed off miles of road sections thus disrupting the life and livelihood of the people.

In fact, even this was being forgotten, when another similar catastrophe occurred close to Ganganani in July 1978 on the Uttarkashi Gangotri road another pilgrim route. Due to this calamity another 8 vehicles got lost and a number of pilgrims died with more than 2km road on the right bank washed away and a girder bridge byepassed. Later, a new alignment on the left bank had to be laid and cut through almost vertical precipices. This is still not stabilized and a team of workers with bulldozers are posted to keep the passage open.

Landslides are ambiguous processes of catastrophic events of which the most important and direct effects on mankind are loss of life and property, damage to natural resources, disturbance in the ecosystem and environment. Recently a number of papers have appeared on the Himalayan slides but not much has been said on their relationship to the geological and tectonic set up and the hazards caused (in the region), particularly with a view to civil works. Barring a few, the accounts portray only the events, though most of them, as major disturbances have disrupted the life of the local people and caused hazards to the developmental activities in the region. Majority of these slides chiefly lie in a belt nearly 30 to 50km in width and extend from a general level of 150m to nearly 2,750m.

The slope failures are largely due to rock falls, debris flow, slumps, creep flow, earth flows and certain complex mass failures including the rock avalanche types. Many a time massive and temporary blockages occur due to sudden inflow of waste debris forming small reservoirs, lakes or lakelets in the courses of rivers. However, the latter and sudden bursts or breaches of these lakes are often observed to have caused unimaginable havocs and catastrophes in the lower reaches of the catchment area. Of these, floods of years 1880, 1924, 1971, 1978 coupled with large scale slides are still memorable. The creation of Gohna Tal in 1893 and its later obliteration in 1971 due to high monsoon rains or flash floods is one of the most important events in the landslide history of the region.

Along the Rishikesh-Badrinath road and many other new excavations and cuts, landslides are more common now and numerous as old angles of repose have been disturbed. In brief, the horrendous topography with inhospitable terrain full of complex geomorphic features, all make the region most hazardous to the people, the locality as well as for any developmental activities.
GEOLOGICAL AND STRUCTURAL FEATURES

Geologically, the Garhwal-Kumaon Himalaya generally trend in NW-SE direction and are


divided into smaller blocks of highly crystalline schists, gneisses and massive quartzites (Klippe) on top of the mountains, which in turn are underlain and surrounded by the less altered unmetamorphosed arenaceous and argillaceous and calcareous rock units including minor meta-basics and basic sheets and dykes along with some nummulitic limestones dipping into the older ones. The Main Central Thrust (MCT) separates the older formations. The North Almora Thrust and the South Almora Thrust (NAT and SAT) divide the Garhwal-Kumaon rocks from the Dudatoli/Kumaon-Almora groups of rock formations, which are again separated from the younger formations by the Krol Thrust or the Main Boundary Fault (MBF) (Fig.1).

INDEX

VAIKRIITA GROUP
ALMORA GROUP - GRANITES AND GNEISSES
META SEDIMENTS AND SEDIMENTARY FORMATIONS
(Tejam - Jacsar - Krol etc.)
SIWALIKS SEDIMENTES/
METABASICS SILLS
MAJOR LANDSLIDE AREAS

FRACTURE PATTERNS

(a) Lineament Pattern - Garhwal - Kumaon Region, (b) Tehri Sector, (c) Dharasu - Uttarkashi Sectors, (d) Mussorie Area, (e) Rishikesh Sector, (f) Hardwar Sector, (g) Devprayag - Srinagar Sectors, (h) R.Ramganga Basin Slides and Fracture Patterns (Mean)
In addition, numerous faults and minor thrusts trend north in NW-SE and N-S directions also dissect the region along with many sets of joints, fractures, cleavages and lineaments and other discontinuities in almost all directions of azimuth. Of these, weak structures in NE-SW, NNE-SSW and N-S (in order) directions are prominent and fully responsible for the fragile nature of the rocks involved. Thus the rock units are highly vulnerable to erosion and even to other minor disturbances prevalent in this mountainous terrain.

Structurally, the rocks are more complex and complicated due to several tectonic episodes. In addition to the major thrusts, nappe sheets and klippen etc. at least three to four phases of tectonic and neo-tectonic events are recognisable and established in the field. The neotectonic activity appears to be spasmodic (Mithal 1968) as evidenced by the recent level disturbances and the most recent episodes in the river terraces along the valleys of the major rivers and the frequent seismic tremors felt in the area.

From the location of landslides or the potential zones of mass movements, the Garhwal-Kumaon groups of rocks are more susceptible to landslide activity (Table 1) and the major landslide zones are mainly confined to these formations.

**LITHOLOGY AND TECTONIC UNITS**

The sub-himalayan zone comprises of Neogene mollasse sediments (Siwaliks) and the lower Tertiary Subathu formations, north of which lie the MBF or the Krol Thrust and in the south these formations are overlain by the thick Indo-Gangetic alluvium. Structurally this zone is affected by NW-SE running asymmetrical folds bounded by large scale high angled reverse faults also cutting the axes. In the lesser Himalaya, unfoliated Pre-cambrian to Tertiary sediments of low grade metamorphism are predominant and are delimited by the MBF-Krol Thrust (in the south) and the Main Central Thrust in the north. These are highly folded and deformed due to multiple folds, faults and thrusts many times in association of meta-basic rocks or sheets. Thus they produce a highly complex structure with at least three sub-division: (1) Autochonous Pre-cambrian low grade sediments in the inner or the northern parts, (ii) the middle Krol Nappes (including the Nagthot quarzites, Chandpur Phyllites, Blaini and Infra Krol formations, Krol limestone and Tal and Subathu formations), (iii) Rocks of the Almora or Garhwal Nappe of low to high grade metamorphics. These litho-tectonic units are highly complex since these also are affected by many thrusts and faults with associated imbricate structures and shears in both transverse and longitudinal directions. Many of these features also appear to be still active. Many other minor features like joints, cleavages and fractures also affect these rock units. As such the massive competent rocks are crumpled and crushed while the non-competent types are foliated and have developed fissility. Likewise, the metabasics in thinner bodies are also foliated and fissile, while the thicker massive sills or dykes behave both as competent and incompetent bodies in the area, e.g. at Kallasaur, Dunda, Nakuri etc. in Garhwal and Ramgarh etc. in Kumaon.

**TABLE I. Tectonic Succession and its Correlation in the Garhwal-Kumaon Himalaya**

<table>
<thead>
<tr>
<th>FORMATION</th>
<th>LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amri</td>
<td>Phyllite, quartz-mica schist, mica schist, garnetiferrous mica schist, granite-gneiss</td>
</tr>
<tr>
<td>Raitpur</td>
<td>Muddy boulder bed, shale, limestone</td>
</tr>
<tr>
<td>Subathu</td>
<td>Shale, sandstone, fossiliferrous limestone</td>
</tr>
<tr>
<td>Tal Group</td>
<td>Unconformity</td>
</tr>
<tr>
<td>Middle Tal</td>
<td>Ortho-quartzite, shale, limestone, siltstone</td>
</tr>
<tr>
<td>Lower Tal</td>
<td>Shale, siltstone, phosphorite</td>
</tr>
<tr>
<td>Krol Group</td>
<td>Unconformity</td>
</tr>
<tr>
<td>Infra Krol</td>
<td>Massive limestone, dolomite, shale and red shale</td>
</tr>
<tr>
<td>Blaini</td>
<td>Shale, slate, limestone</td>
</tr>
<tr>
<td>Jaunsar</td>
<td>Unconformity</td>
</tr>
<tr>
<td>Mandhali</td>
<td>Muddy boulder bed, limestone, sandstone, shale</td>
</tr>
<tr>
<td>Krol Thrust/Main Boundary Thrust</td>
<td>Sandstone, quartzite, mica schist, grit, conglomerate, phyllite</td>
</tr>
<tr>
<td>Subathu Formation</td>
<td>Quartzite, phyllite, formation shale</td>
</tr>
<tr>
<td>Main Boundary Fault</td>
<td>Quartzite, conglomerate formation Slate, limestone</td>
</tr>
<tr>
<td>Siwalik Group</td>
<td>Krol Thrust/Main Boundary Thrust</td>
</tr>
<tr>
<td>Foot-hill Fault</td>
<td>Subathu Formation</td>
</tr>
<tr>
<td>Indo-Gangetic Plain</td>
<td>Main Boundary Fault</td>
</tr>
<tr>
<td></td>
<td>Siwalik Group</td>
</tr>
</tbody>
</table>
The rocks of the Higher (Central) or Tethyan Himalaya are 10 to 20km thick, dip northwards and are highly metamorphosed with associated tertiary granites. To the north, the Central Himalayan metamorphics grade into the fossiliferous, gently deformed Cambrian-Ondovician sedimentary sequence of the Tethys. The Siwaliks are comprised of NW-SE striking typical sandstones and sands – the latter being predominant in the upper and the clays and claystones in the lower succession. The folds are repeatedly faulted at their crests with steep strike faults and gently dipping thrusts at 25° to 30° to the north east. These all are responsible for steep south facing fault scarps and 'cuesto' type landforms with gentle bedding slopes to the north.

**Physiography**

Physiographically, the Himalaya are divisible into four sub-zones which are also concordant with the litho-tectonic units of the Lesser Himalaya, i.e. the Siwalik belt, the Krol Nappe Zone, the Almora Nappe and the Autochthonous zone. A study of their cross profiles indicates a close relationship and control between geomorphology, geology, lithology, tectonics and structure on the one hand and rainfall, climate and flora on the other.

As stated earlier the Himalayan region is very fragile due to tectonically folded, faulted and crumbled rock formations in the various thrust sheets. Secondly, the region is subjected to sporadic earthquakes and seismic activity. The activity is played in great role in the configuration and carving of the present topography of the region. Thirdly most parts of the terrain experience heavy monsoon rains followed by long severe winters and long summers. Fourthly, many areas are devoid of forest cover and lastly the indiscriminate grazing and construction activity of roads etc. have all been responsible for the degradation of the slopes and the valleys.

Morphologically, only two types of land forms (a) Erosional and (b) Depositional are predominant in the area. The hills and peaks are generally isolated, conical in shape and appear to be only the linear extensions of the crests of ridges which also form water divides. The valleys on the other hand vary from small ravines to deep gullies, narrow or wide valleys. Deep gorges are mostly controlled by the tectonic features of the litho units and the rock formations, for example, the valleys of Rivers Ramganga, Bhagirathi, Alaknanda and many others are generally controlled by the geology and tectonics. The control is mainly due to dislocations and fault zones. At many places the valleys are wide due to excessive erosion and mass wasting of the slipped slopes. Some valleys, particularly in the Lesser Himalaya, e.g. in Siwaliks are homoclinal, i.e. controlled by the strike of the rocks, while others follow the fold axes of the antiforms or the synforms.

**Slopes and their development**

As has been made out from the Survey of India topographic sheets, the aerial photographs and the actual field observations, the hill slopes in the region are very variable and seem to be controlled with the nature of the rock formations, the tectonics and the competency of the rock masses along with the climate of the region. These slopes could be classed as: (1) Gentle – with an inclination of < 30° best developed in gneisses, schists and phyllites of the Lesser Himalaya and in the shales and unconsolidated sediments of the upper Siwaliks, (2) Moderate – with an inclination of 20° - 45° predominantly in schists, phyllites, crushed quartzites, gneisses and limestones of the Middle Himalaya, (3) Steep – with an inclination of 45° - 75° are common in the hard, compact and well jointed quartzites, limestones of Central Himalaya and even in the coarse massive sandstones of the Siwaliks, (4) Scraps with inclination of < 15° best seen in the massive krol limestone (not influenced by weak characters) are comparatively less prone and affected by landslides only at few localities close to the major tectonic features like the NAT, MFB or MCT. However, the massive crushed, fractured and foliated rocks suffer from rock falls, rock debris, in the neighbourhood of the tectonic features/sherds or weak zones, particularly when associated with meta-basics or epidiorites, (Table II, Fig.2).

Almost all thrust faults and shear zones are evidenced by the presence of breccia, crushed and gouged materials. Such characters are best observed particularly along the recent and Neotectonic (7) features. Along the other weak zones meta-basics or their weathering products are invariably present, e.g. Almora-Dubatoli-Bijnath thrust sheet in Kumaon; Main
TABLE II. Characters of some Important Thrusts and Landslides Zones along Bhagirithi Valley in Garhwal Himalaya
(Modified and compiled after Jain, 1972)

<table>
<thead>
<tr>
<th>Thrust Zone</th>
<th>Characters of Thrusts</th>
<th>Characters of Landslide</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NORTH</strong> (Sainj)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Central Thrust (MCT)</td>
<td>Impersistant chlorite schist, increase in metamorphic effects towards top of Gamri quartzites near thrust; development of foliations, mica lineation and quartz sericite schist.</td>
<td>Intensely crushed, 3-5km wide zone on the sub-thrust slide, zone of intense landslide, e.g. Sainj landslide.</td>
</tr>
<tr>
<td>Uttarkashi Thrust</td>
<td>Persistent metabasics, metamorphic effects maximum, wherever metabasics are absent development of foliation, mica lineation and schistose quartzite.</td>
<td>Highly crushed and friable zone of 1.5 to 3km in width landslide zone with flowing highly crushed material e.g. Netala landslide.</td>
</tr>
<tr>
<td>Dunda Thrust</td>
<td>Persistent metabasics, metamorphic effect minimum wherever metabasics are thick</td>
<td>Highly crushed zone of 1 to 2.5km width, metabasic blocks in flowing debris.</td>
</tr>
<tr>
<td>Singuni Thrust</td>
<td>Impersistent mylonites, increasing metamorphic effects towards the sole of the thrust in Gamri quartzites, development of foliation, mica lineation and quartz schist.</td>
<td>Highly crushed limestone zone along Tehri-Dunda Road crushed zone upto 1.5 to 2km wide e.g. Khattukhal slides.</td>
</tr>
<tr>
<td>Srinagar/ North Almora Thrust (NAT)</td>
<td>Impersistent metabasics, increased metamorphic effects in Dharasu formation along thrust zone, crushing of rocks</td>
<td>Intermediate width (upto 1.5 km landslide zone of angular blocks and crushed rocks in flowing slide zone, e.g. Nail slide north of Dharasu</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust Zone</th>
<th>Characters of Thrusts</th>
<th>Characters of Landslide</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LESHER HIMALAYA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tons Thrust</td>
<td>Fault breccia and crushed slate, lack of metamorphism</td>
<td>Narrow zone of crushed rock material, also rock slides, 150 to 200m wide one, e.g. Nagun slide.</td>
</tr>
<tr>
<td>Basul Thrust</td>
<td>Sericite quartz schist and schistose quartzites in thrust zone, increase in metamorphic effects, development of foliation and mica lineation.</td>
<td>Localised landslides zones along less significant thrust faults, e.g. Jakh slide on the Tehri Chamba road.</td>
</tr>
<tr>
<td>Krol Thrust</td>
<td>Fault breccia, crushed Chandpur phyllite, friable carbonaceous matter, lack of metamorphism, typical of other thrusts in foothills</td>
<td>100 to 200m wide landslide zone of crushed and massive rock materials persistent, evidence of holocene movements, e.g. Rajpur Toll Barrier slide.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust Zone</th>
<th>Characters of Thrusts</th>
<th>Characters of Landslide</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOUTH</strong> (Rajpur)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Boundary Fault (MBF)</td>
<td>Fault breccia, crushed and powdered material.</td>
<td>Narrow, intermittent landslide zones of crushed rock material dip-slip slopes more problematic.</td>
</tr>
</tbody>
</table>
Central Thrust, Uttarkashi Thrust, Singuni and North and South Almora Thrusts in the Kumaon-Garhwal region and Uttarkashi, Singuni, Tons, Srinagar, Krol thrusts etc. in the Garhwal area. These metabasics are highly prone to weathering and erosion. They give rise to brownish clays - very similar to the 'bole' overlying the Deccan traps. This bole clay is expensive and rich in montmorillonite types of clay minerals. It flows on wetting, sometimes carrying huge blocks of massive competent rocks during rains or even later as at Kallasaur on the Badrinath road or near Dunda etc. localities on the Tehri - Uttarkashi road. Similar flowing brownish clayey mass has also been observed in a tunnel being excavated (August-Sept. 1987) for the Maneri (Stage II) Hydro power scheme, a little north of Uttarkashi.

Following the postulations of Reed (1964) for the correlations of metabasics and their characters along the Alpine faults in New Zealand, the marked occurrence of brecciated and mylonitised or weathered meta-basics (in Garhwal-Kumaon Himalaya) may also lead in deciphering their depths and the deepening or shallowing of the faults and thrusts. The main characters of certain important thrusts and the associated landslide features are shown in Table II.

On considerations of the morphology, lithology and tectonics of the Garhwal-Kumaon region it may be suggested that the estimation of the depth of slip surfaces and crown cracks should form essential aspects of the investigations of landslides in the Himalayan terrain before any preventive measures for their control are adopted.

DISTRIBUTION OF LANDSLIDES

As a sample for discussion, the Ramganga basin is chosen as an example. On a study of more than 500 landslides, it is concluded that in the (four sub-basins) the number of recent slides is comparatively more, where certain developmental activities are in progress. Similar phenomena are also observed along the pilgrim routes of Rishikesh-Badrinath-Rudraprayag-Kedarnath and Rishikesh-Uttarkashi-Gangotri roads etc. Wherever the new alignments occupy the old sections of these roads the sliding activity is almost absent or the slopes are least affected.

LANDSLIDE SIZE AND PERCENTAGE OF ACTIVITY

It has been noted that the recent slides are many times more in number and are mainly medium in size. Very large or giant sized slides are almost absent in the region, while the smaller ones are innumerable and not taken into consideration for this discussion. Table III shows the percentage of the mapped slides (522 Nos) in Ramganga Basin both in the field and on the aerial photographs:

In addition to the above, the major slide zones lie in the sparsely vegetated areas followed by in the agricultural strips of lands (irrigated and unirrigated) and maximum in the deforested and barren slopes. The deciduous forests suffer the least while the coniferous zones are appreciably more afflicted with medium slides.


TABLE III. Percentages of Recent and Old Slides (After Joshi 1987)

<table>
<thead>
<tr>
<th>Type</th>
<th>Recent</th>
<th>Old and Recent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giant size</td>
<td>Absent</td>
<td>2.7%</td>
</tr>
<tr>
<td>100,000 m²</td>
<td></td>
<td>historic</td>
</tr>
<tr>
<td>Very large</td>
<td>0.4%</td>
<td>4.1%</td>
</tr>
<tr>
<td>70-100,000 m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>2.6%</td>
<td>24.6%</td>
</tr>
<tr>
<td>35-70,000 m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium-Small</td>
<td>97.0%</td>
<td>68.5%</td>
</tr>
<tr>
<td>5000-35,000 m²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SHAPE

<table>
<thead>
<tr>
<th>Type</th>
<th>Recent</th>
<th>Old and Recent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongated</td>
<td>24-26.5%</td>
<td>24-26%</td>
</tr>
<tr>
<td>Equidimensional</td>
<td>&gt; 70%</td>
<td>&gt; 60%</td>
</tr>
<tr>
<td>Elliptical</td>
<td>3-14%</td>
<td>8-15%</td>
</tr>
</tbody>
</table>

LANDSLIDE ACTIVITY AND NEARNESS TO TECTONIC CONTACTS

Of the over 500 landslides, the majority of these occur within short distances of 1-1.5 km from the tectonic contacts. Further away the number of failures gradually decrease. From this, it is inferred that the slide zones lie close to the tectonic features (regional thrus and faults or even to the local faults). A review of the litho-tectonic units (Tables I and II) in the area also support such an inference, from which it is noted that the maximum number of hazardous slides occur in the belt (Fig.1) between the MBF-Srinagar thrust or the NAT and SAT and the MCT coupled with the minor and local structures affected by Neotectonics, e.g. near Dhrasu, Maneri, Ganganani etc. on the Tehri-Gangotri road, while along the Rishikesh-Badrinath road active zones are observed close to Pipalkoti, Joshimath, confluence of Patalganga and Alaknanda, the middle reaches of R. Birehi Ganga and near Nandprayag etc. etc. From the frequent slides and the percentage of landslides, it is also easily inferred that the dynamic forces are still active.

As a result of the landslides the morphology of the region has become rugged and exhibits an awesome picture of the barren mountain slopes, the hill sides or even in the once forested valleys. The hill sides are steeply scarred, hallowed and gullied, devoid of vegetation and serve important clues for the identification and recognition of the major tectonic and thrust zones on the aerial photographs. From Table III (recent and old slides) it is evident that the new and recent slides far outnumber the older ones. Human activities (including agriculture) coupled with deforestation, road and bridge constructions etc. on the fragile hill slopes are equally responsible for the degradation of the unstable slopes mainly due to the disturbances of the angles of repose. To sum up, Table IV gives the relationship of the geo-environments and landslides.

TABLE IV. Geo-Environmental Factors commonly Associated with Landslide Zones (Based on the study of the four selected sub-basins of Ramganga - after Joshi, 1987)

<table>
<thead>
<tr>
<th>Geo-Environmental Factor</th>
<th>Landslides more</th>
<th>Landslides less</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock types</td>
<td>Massive quartzites, slates, clay, Phyllite and Schists</td>
<td>Limestone, dolomite, gneisses.</td>
</tr>
<tr>
<td>Land use type</td>
<td>Barren or sparsely vegetated areas.</td>
<td>Forests, agricultural lands</td>
</tr>
<tr>
<td>Azimuth directions</td>
<td>North-east, South-West and West facing slopes.</td>
<td>North, North-West and East facing slopes</td>
</tr>
<tr>
<td>Proximity to shear zones</td>
<td>Areas lying within the range by 3 kms distance from the shear contact.</td>
<td>Areas lying away from the shear contact.</td>
</tr>
<tr>
<td>Relief of the area</td>
<td>Areas of higher relief and steep relief and slopes.</td>
<td>Areas of lower relief and gentle slopes.</td>
</tr>
<tr>
<td>Ruggedness of the area</td>
<td>Areas of higher ruggedness ruggedness and less develop-well developed drainage net work.</td>
<td>Areas of lower ruggedness ruggedness and less develop-well developed drainage net work.</td>
</tr>
</tbody>
</table>

From the above, it is considered that the Nagthat quartzites, Infra Krol slates, shales and siltstones and the low grade metamorphics of the region are relatively moderate to landslide activity, while the other formations are comparatively less prone. Whereas when these lie close or are affected by a tectonic feature they are highly susceptible to slides or rock falls. In the inner higher parts of Himalaya particularly close to the MCT the massive jointed rocks or the crystallines and gneisses with steep slopes are more prone to the rock falls. These are thus highly hazardous for road and bridge works or for any other developmental activities.
meta-basics or its weathered product 'bole' clay.

5. In order to visualise the magnitude, the calamitic effects and hazards caused by a particular landslide, attempt must be made to determine the depth of the slip circle and the amount and passage of percolation.

6. While treating a landslide zone, the original angle of repose of the rock or debris mass should be maintained as far as possible.

7. Large scale toe erosion is responsible for feeding the large number of rivers with huge amounts of sediment loads, and is a major cause of siltation in the river channels/reservoirs and even on the flood plains.

8. The dynamic activity is still continuing as indicated by recent disturbances affecting the collovium and terrace deposits along the river channels.

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