ENGINEERING GEOLOGICAL STUDIES OF MANGTI LANDSLIDE AND ITS ENVIRON, PITHORAGARH, UTTARANCHAL

SUMMARY

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Summary of the Ph. D. Thesis
Entitled

Engineering Geological Studies of Mangti Landslide and its Environ, Pithoragarh, Uttaranchal

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Strategically vital mountainous areas bordering Pakistan, Tibet-China and Nepal has been experiencing extensive construction of road network; housing development schemes and expansion of present road network along major river valley projects and tourism centres. All these activities have accentuated indiscriminate cutting of the slopes and making them vulnerable to fail.

The strategically vital **Tawaghat – Jipti Route Corridor** of which **Mangti Landslide** forms a part in the eastern most extremity of Kumaun Himalayas, Uttarakhand along the Kali River Valley is witnessing stupendous growth in developmental activities, large scale cutting of slope and indiscriminate blasting for construction of road network along the Indo-Nepal border. This has resulted in development of a number of new landslides and reactivation of many stabilized and dormant landslides.

The significance of landslide hazard and its influence towards disrupting the economic growth in the Himalayan region, poor disaster management system and the lacuna in complete characterization and hazard assessment has tempted the author to choose his research problem and make an attempt for prediction of landslide hazard in one of the most strategic and economically developing Higher-Himalayan segment of Kumaun Himalayas.

The Kali River Corridor between Tanakpur on Himalayan foothills and Jipti in Higher Himalayan domain, in the eastern most extremity of the Kumaun Himalayas, Uttarakhand State forms the Indo-Nepal border zone. This particular stretch is under the maintenance of Border Roads Development Organization (BRDO). The entire corridor from Tanakpur to Jipti is divided into two road segments – (i) Tanakpur – Pithoragarh – Tawaghat Road and (ii) Tawaghat – Jipti Road by BRDO and it has been designated with the National Highway status.

The Tawaghat – Jipti Route Corridor (TJRC) is witnessing stupendous growth in infrastructure development activities. Dhauliganga Hydroelectric Project at Chirkila-6km from Tawaghat has been commissioned in 2006, Sobla Stage – II is under construction and Stage – III is in investigation stage, also the route for famous Kailash-Mansarovar pilgrimage passes through this route corridor. This area being so much economically important and strategically vital is witnessing indiscriminate cutting of slopes for road network expansion and has resulted into large scale development of landslides.

These landslides have also caused excessive damage to private and public property. Some recent noteworthy landslide incidences took place in this corridor are at Jauljibi (1984), Bangapani (1984), Khela (1988), Malpa (1998), Charma (2000), Teentola (2000), Khet (2001), Mangti (2001), Shyamkhola (2001), Elagad (2004-05), Lakhanpur-Jipti (2005), and in Nepal Side Margaon – Sunsera (2000), etc.

The study aimed at fulfilling following objectives –

- Carry out detailed Geological Investigation of the TJRC,
- Inventory of landslides and their historical accounts,
- Engineering Geological assessment of landslide environ along TJRC,
- Critical study of Mangti Landslide from the point of view of carrying out detailed geo-technical investigation, measurement and monitoring of its rate of movement and pore water pressure,
- Generation of various thematic layers such as landslide inventory, landuse, lithology, lineament, slope and slope aspect and preparation of database in Geographic Information System on various thematic maps and collateral data viz. geology, geotechnical properties, seismicity, etc.
- Preparation of micro-level Probabilistic Landslide Hazard Zonation **EIA** map using remote sensing and GIS techniques,
- Slope stability analysis and suggesting landslide specific mitigatory measures.

A multi-disciplinary approach has been adopted to investigate the study area. Although major study has been restricted in Indian side, a buffer zone of two kilometers on either side of Kali River sharing Indo - Nepal region was considered for hazard assessment. The envisaged methodology includes a three tier approach encompassing different domains of engineering geological investigations viz.

1. Collection of secondary data on geology, landslide hazards, meteorology and seismicity from various organization and their critical review; generate database in Geographic Information System on various thematic maps and collateral data;
2. Carry out detailed Engineering Geological Investigation of entire TJRC encompassing geological mapping, inventory of various discontinuities and their characterization using Rock Mass Rating (RMR) norms. Study of various geomorphic attributes using Survey of India Toposheets and Satellite Data. Detailed inventory of active landslides; their geometrical parameters, surface lithological profiles and geological attributes (i.e., spatial distribution of material types, discontinuity surfaces, etc.).
3. In-depth geotechnical study of the Mangti Landslide and its environ through-
    a. Development of 1m contour plan using Electronic Total Station & DGPS.
    b. Installation of movement Rods and Open Stand Pipe Type Piezometers for periodic monitoring of slope mass movement and pore water pressure respectively.
    c. Installation of rain gauge station for rainfall measurement.
    d. Collection of undisturbed and disturbed samples (regolith and rock) for determining various engineering properties in laboratory.
4. Integration of field and laboratory data to perform kinematic analysis to ascertain the factor of safety of slopes at critical places in the study area; carry out stability analysis and establish predictive model of landslide occurrence for Mangti landslide.
5. Empirical modeling using Information Theory to prepare Micro-Level Probabilistic Landslide Hazard Zonation (EIA) Map in GIS environment of the TJRC.
6. Field validation, accuracy estimation and suggestion of landslide specific mitigatory measures.

The investigated area forms a part of Dharchula block on the northeastern part of Pithoragarh district of Uttarakhand State bordering Nepal. The Tawaghat-Jipti Route Corridor sprawling over an area of 158.22 km^2 is geographically bounded between longitudes E 80°34'46" to 80°45'00" and latitudes N 29°53'37" to 30°02'37", dominantly embracing the Lesser Himalayan domain and partly the Higher Himalayan region of the Kumaun Himalayas. The entire road stretch from Tawaghat to Jipti runs along Kali River for about 33 kilometer distance till the last motorable point and is covered in the Survey of India Topographic Sheets 62B/12 and 62C/9. Correspondingly, the IRS-1D satellite path 98 & 99 and row 50 envelopes this area. Kali River forms the international border between India and Nepal in this region. The present study is carried out for a buffer distance of 2 kilometers on either side of Kali River Valley axis.

Physiographically the study area forms a small part of Kali Watershed embracing the realms of Lesser and Higher Himalayas. The Main Central Thrust (MCT) demarcates the boundary between the Lesser Himalayan domain to the south and Higher Himalayan domain in the north. The Lesser Himalayan terrain attains heights between 1,200 and 3,000m above mean sea level (a.m.s.l.) and represents a blend of young and mature landscapes with gentle to steep slopes and deeply dissected valleys. However, being tectonically active the Higher Himalayan segment is characterized by youthful topography and a rejuvenated drainage system rising to the altitude of 4800 – 6000m a.m.s.l.

Geologically the investigated area comprises lesser Himalayan sedimentaries and crystallines (Kumar and Patel, 2004). In this transect the Central Crystalline Zone coincides with the mountain ranges of the Higher Himalaya (Heim and Gansser, 1939). The southern margin of the zone is delineated by the outcrop of the Dharchula Thrust along which the crystalline units have moved over the rocks of the calc zone of Tejam. Its northern limit coincides with a probable dislocation at the base of the Budhi schist. Tectonically the zone can be divided into three units, namely, the lower Chipplakot Crystalline mass, the middle Sirdang Sedimentary Zone (SSZ) and the upper Higher Himalayan Crystallines (HHC); all being thrust bounded (Heim and Gansser 1939, Powar 1972, Valdiya 1980 & 1988).
The detailed litho-tectonic sequence is shown in Table 1.

Table 1 – Litho-Tectonic Succession of Tawaghat - Jipti Route Corridor

Tectonic Unit	Tectonic Unit	
Higher Himalayan Rocks	Higher Himalayan Rocks (Central Crystallines)	Porphyroblastic and Augen gneiss, migmatized banded gneiss, amphibolite, tourmaline granite; garnet mica schist, biotite gneiss, quarzite
	Main Central Thrust	
Lesser Himalayan Rocks	Sirdang Sedimentary Zone (Tejam Group)	Carbonaceous phyllite, schistose quartzite, amphibolite, arenaceous marble, calc-schist, marble
	North Chiplakot Thrust	
	Chiplakot Crystallines	Mylonite gneiss, Augen gneiss, quartz veins, chlorite schist, granitoids
	South Chiplakot Thrust	
	Calc - Zone of Tejam (Tejam Group)	Massive quartzite, schistose quartzite, schist, slate, massive and bedded marble, carbonaceous slate and phyllite

In order to work out lithological specific structural details of Tawaghat – Jipti Route Corridor, detailed mapping has been carried out. To record precise locations and observations Leica Make (GS5) GIS – GPS Data Collection System was used. Based on data gathered on foliation, joint sets and the major structural features developed in the area, stereograms have been prepared for each sub-area by plotting poles for different joint planes and foliation in lower hemisphere of Lambert's equal area projection net and subsequently, contoured by Dimitrizevic net (Dimitrizevic, 1956).

A brief description of these prominent joint sets is as follow –

Joint Set 1: The foliation joints are the most penetrative structural element of the area this joint set has dip varying from 25° - 64° and the amount of dip varies from as low as 12° to as high as 70°,

Joint Set 2: this joint set has dip varying from 110° - 150° and the dip amount varies from as low as 56° to as high as 88°.

Joint Set 3: this joint set has dip varying from 191° - 230° and the dip amount varies from as low as 50° to as high as 80°.

Joint Set 4: this joint set has dip varying from 240° - 289° and the dip amount varies from as low as 54° to as high as 80°.

Joint Set 5: this joint set has dip varying from 308° - 350° and the dip amount varies from as low as 30° to as high as 85°.

The joint set 2, 3, 4 and 5 occur at an angle and intersects each other, forming wedges at many places. The last set 5 does not have wide occurrence and is seldom seen in SSZ and CCB, while its frequency of occurrence is conspicuously seen more in HHC.

Geomorphologically, the Kali watershed with its tributaries viz. Kuti, Dhauliganga, Ramganga, Goriganga, Saryu, constitute a major drainage system, predominantly draining the terrains of Central Kumaon Himalaya. The Study area viz., The Tawaghat – Jipti Route Corridor exhibits a unique setting covering the Great Himalaya and Lesser Himalayan terrains. The Great Himalayan terrain is characterized by precipitous scarps, steep and narrow gorgeous valleys and turbulent reverberating rivers; illustrating a very youthful topography, whereas the Lesser Himalayan terrain displays a comparatively mild and mature topography with gentle slopes and deeply dissected valleys.

The area is characterized by lofty interspersed hills and elongated ridges, dissected by a number of deep and narrow tributary streams and rivulets. Some of the prominent height points in the Tawaghat – Jipti Route Corridor are viz: Jiunti Gad (3192m), Tankul (3256m), Galagad (3432m), Baj Lekh, Nepal (3013m). The overall shape of the Kali River valley segment exhibit a typical bottle necking in the upper reaches and quite open and wide in the lower reaches. It is also observed that couplets of joints/fractures controlled triangular facets in-variably leading to the development of narrow V – shaped valleys.

In the study area Jiunti Gad, Shymkhola Gad (India) and Ritha Gad (Nepal) drain into Kali River. The most common drainage type encountered in the basin area is the dendritic and trellis type. However, radial and re-curved trellis is also commonly observed.

The landform features witnessed in the study area are the products of different agencies that have operated since the rising of the mountains. The various geomorphic features can be enumerated as glacial, glacio-fluvial, fluvial, mechanical, tectono-genetic and anthropogenic.

The landslide investigation had been planned based on following elements-

Formulation of investigation

Data collection

Data interpretation

Application of analysis techniques, and

Hazard Zonation and Suggestive Mitigatory Measures.

The onsite engineering geological investigation information gathered can be grouped into two categories – Conditioning Factors and Triggering Factors. Details on various studied parameters under these factors includes:-

Conditioning Factors

The rock and regolith, their composition, thickness, size, structural fabric, relative position; position of partings with respect to topography (relief, slope, height and landform attributes), long term processes like weathering that influences the slope stability.

Triggering Factors

These factors generally determine the temporal occurrence of landslides. The information on the most responsible natural landslide triggers gathered in the study area are about earthquake shaking, intense rainfall, water-level change and pore water pressure, human activities such as excavation for road cuts, overloading, blasting, overgrazing and deforestation.

The Mangti Landslide falls within the domain of Higher Himalayas and located ($30^o00'15''$N; 80^o

The Mangti landslide constitutes a part of one of the most severely affected landslide zones in Uttarakhand State. A highway stretch of about 48 km between Dharchula – Tawaghat – Mangti (Jipti) is known for its intense landslide activities. This Mangti landslide represents a typical case of *multi-rotational slip* and currently passing through its 3^{rd} Phase. The geometric parameters of Mangti Landslide are elucidated in Table – 2 below-

Table 2 - Geometric Parameters of Mangti Landslide

Altimetric Details (m)			Landslide Zone			Slip Area Dimension (m)	
Crown	Toe	Tip	Total Area	Length	Breadth (m)	Breadth	Length
1800	1600	1570	11.66 Hectare. (Including adjacent shoulder region)	580m	Toe 200 Body 235 Top 125	Toe 125 Body 135 Crown 35	400

The Mangti Landslide may be placed into Deep Slide (5 – 20m) category of Zaruba and Mencl (1969) that has been judged considering slope of the landslide scarp and intact rock exposed on the shoulders, therefore, the landslide depth of **20**m has been adopted for other relevant studies.

Mangti landslide zone has been studied from the point of view of its material characteristics that are observed along crown, scarp, body, sides' scarp, toe-sides' scarp, zone of ablation and zone of accumulation. Measured dimensional parameters of these scarp geometries are as shown in Table – 3,

Table 3 - Element Characteristics of the Mangti Landslide

Scarp Geometry	Sides	Depth (m)	Angle	Material Characteristics
Crown Scarp	Left	2.00	Vertical	Sharp, un-vegetated colluvial material with predominance of medium sand, presence of sub-surface drainage-potholes, etc.
	Right	3.00	Vertical	Soil followed by colluvial material showing imbrications.
Zone of Ablation	Left	15.91	$38° – 45°$	Colluvial material with patches of bouldery debris. Ground surface is sharp, un-vegetated.
	Right	18.28	$48°$	
Body Sides' Scarp	Left	3 – 3.75	Vertical	Sharp, thin soil horizon followed by bouldery colluvial material, tilted trees on shoulder surface.
	Right	1.53 – 2.13	$35° - 40°$	Sharp, thick soil horizon followed by pebbly horizon with silty-clayey ad-mixture.
Toe Sides' scarp	Left	3 – 4.52	---	Thick gravelly, pebbly material with sandy matrix.
	Right	1.25 – 2.72	---	Thick coarse sandy material with intercalation of gravels.
Zone of Accumulation	Un-drained and drained depressions; hummocky topography, angular blocks, un-vegetated with isolated presence of in-situ bedrock blocks.			

A detailed quantitative and qualitative investigation of the Mangti Landslide environ has been carried out employing an established technique of 'Scanline Survey' (Priest &

Hudson, 1981). For the mapping purpose, especially to make inventory of litho-specific discontinuity surfaces, the following rationales were adopted –

- Scan line survey of every **30**m length at the interval of **500**m and/or change in lithology, whichever is earlier for Tawaghat – Jipti Route Corridor. Whereas, for Mangti Landslide including shoulder region entire stretch of **800**m has been mapped.
- Inventory of lithology and measurement of various joint sets, foliation plane, etc.
- Inventory of joint conditions based on Bieniawski (1989) Classification.
- Plotting of lithological contacts and discontinuity parameters at **1:100** scale
- Collection of rock samples and discontinuity infilling material for detailed engineering geological characterization through laboratory studies.
- Measurement of in-field Unconfined Compressive Strength (UCS) using Schmidt's Concrete Hammer.

Although the Mangti Landslide and its adjoining shoulder regions are predominantly characterized by biotite gneissic rock with stray occurrences of thin schistose bands; the RMR computed for 800m long stretch show considerable variation ranging from 00 – 75. However, overall condition of the rock masses fall within III to IV Classes signifying fair to poor condition. Scanline stretch exhibiting poor rock quality at times is attributed to excessive blasting carried out by BRO for road development. Scanline segments giving zero RMR (Class – V) are predominantly occupied by thick regolithic and talus/scree materials; there by indicates most vulnerable regions for slope failure. Obtained SMR for Mangti Landslide and its adjacent shoulder regions by and large fall within SMR Class IV and V, characterized by *Unstable – Completely Unstable* Stability Categories. Such deteriorated state of SMR is attributed to –

i. Biotite Gneisses, which is dominated by argillaceous minerals prone to enhanced weathering;
ii. High frequency of jointing; and their trends;
iii. Excessive and uncontrolled blasting and ;
iv. Predominance of Talus / Scree materials over the slopes.

RMR-SMR classification of various Scanline segments clearly depicts that majority of discontinuity induced rock and slope masses fall within III – IV and V rating classes.

Further, SMR of rocks belonging to Chiplakot and Higher Himalayan Crystalline mass predominantly fall within IV and V class ratings and all such segments are chronically affected by landslide hazards. Whereas, SMR of rocks belonging to Sirdang Sedimentary Zone by and large falls within Normal (Class-III) and Bad (Class-IV) ratings. Here, majority of schistose rocks fall in Bad Category and competent quartzitic and calcareous rocks in Normal Category. The assigned SMR values signifying Very Bad (Class V) and Bad (Class IV) conditions of slope masses could be attributed to deterioration of rock mass under the process of shallow, progressive physical and chemical alteration and its subsequent detachment and removal or re-distribution by transport agents (Nicholson, 2004).

The Mangti Landslide constitutes as the most young and active landslide. Field instrumentation installed at Mangti Landslide was setup with a view to gather information on the following parameters –

- Determination of the depth and shape of the sliding mass in a developed landslide with a view to define appropriate strength parameters at failure and design remedial measures,
- To monitor and quantify absolute lateral and vertical movements within a sliding mass,
- To estimate the rate of mass movement,
- Monitoring of the slope activity of marginally stable natural / cut slopes and identification of effects of precipitation,
- Monitoring of groundwater activity / pore water pressure normally associated with slope mass movement so as to perform effective stress analysis,

The Open Stand Pipe Casagrande Piezometer for determining soil pore water pressure is used because of its simplicity, cost effectiveness and reliability in comparison with transducer type instruments. Such factors are especially relevant when instrumentation is used on remote and inaccessible sites like Mangti Landslide.

The time lag observation results have provided highly satisfactory results showing Piezometers' response within the time range of 25 – 60 minutes for stress adjustment. Based on Hvorslev's (1951) plots, sub-surface in-situ permeability fall in the range of 10^{-2}

to 10^{-4} cm/sec. This obtained permeability range is in conformation with the granulometric characteristics of the sediment samples falling in GP – SP – SM groups and indicative of sandy nature.

Quantitative assessment (vectoral measurement) of slope mass movement within the landslide zone and adjacent shoulder regions has been made using traditional method of inserting metal rods in slope mass (Keaton and Degraff, 1996). The vector diagram clearly depicts that the overall rate of mass movement is more than 05 times (22.91 cm) on the right side half and shoulder region of the landslide with significant subsidence (-8.96 cm) as well as rise in the way of ground heaving (+4.68 cm) than what is observed in its counter left side half (Plate IV.6L). This differential behaviour in vector patterns may be attributed to difference in the material characteristics viz. composition, lateral continuity, hydraulic properties, etc.

Engineering properties of any soil regolithic mass depends on its basic mineralogical composition, particle size and moisture content. The variation in these basic characteristics in turn affects its all over strength parameters. Important physical and engineering properties of the regolithic mass determined are –

1. Granulometric Characteristics
2. Atterberg Limit's
3. Moisture Content and Density
4. Permeability
5. Cohesion, Angle of Internal Friction and Shear Strength

Granulometric or Gradation characters of sediments denotes the distribution pattern of size of grains in a collected sample. Gradation analysis of the various samples has been done using standard procedure specified in Earth Manual (USBR, 1965). Majority of collected disturbed surface samples show mixed characters and fall within the groups of **SP-SM** of Unified Soil Classification System (USBR, 1965), signified by " *poorly graded sand, gravelly sands with little or no fines (SP) and silty sands, poorly graded sand – silt mixtures (SM).*" Further the determined Co-efficient $\mathbf{C_U}$ and $\mathbf{C_C}$ ranges between **60.56 – 11.84** and **0.99 – 0.29** respectively.

Dry density (γ_d) ranges between **1.0217 – 1.7263 gm/cm^3** whereas, the **Bulk density (γ_m)** varies from **1.8036 gm/cm^3 to 1.0696 gm/cm^3.**

Moisture Content (w) also shows large variation ranging from **2.08% to 9.60%.** This obtained range of variation is attributed to sample specific change in relative proportion of fines and its depth.

Maximum Dry Density ranging between **1.861% gm/cm^3 and 2.07 gm/cm^3** with **Optimum Moisture Content** ranging between **7.00% and 12.00%.**

The obtained permeability results show variation ranging from **8.60 x 10^{-5} to 0.18 x 10^{-5} cm/sec** that are in conformation with the Granulometric characteristics of soil, i.e., predominantly of SP – SM Groups.

The engineering computations concerned with the strength of a soil deals primarily with its shearing strength, i.e., the resistance to sliding of one mass of soil against another. Shearing Strength (S) of soil mass has two major components;

(i) Amount of stress (σ) normal to the shearing plane and

(ii) Internal friction (tan Ø) and Cohesion (c).

$$S = C + \sigma - U \tan \emptyset$$

Direct Shear Test has been conducted on various collected soil samples in accordance with the Indian Standard IS: 2720 (Part 13) – 1986.

Results computed through Box Shear Test shows cohesion **'c'** ranging from **10 – 18 KN/m^2**; angle of internal friction **'Ø'** between **26° 42' – 32°**; and Shear Strength **'S'** between **91 – 130 KN/m^2.** These parameters have been subsequently used for carrying out stability analysis of the studied landslides.

To determine various physical and geo-mechanical properties of biotite gneiss rock, first block samples were subjected to coring and number of cylindrical core samples were extracted using laboratory drill machine. All relevant physical properties viz. Bulk Density, Dry Density, Absorption of Water Content, Bulk Specific Gravity, and Porosity were determined in accordance with the Indian Standard Codes of Practices.

Dry Density values of the Biotite Gneiss rock at Mangti Landslide varies between 2.66 and 2.75 gm/cc (Table 5.6) and an average value of **2.71 gm/cc** has been taken for subsequent use in stability analysis.

Bulk density (saturated) of these rocks fluctuates between 2.70 and 2.78 gm/cc (Table 5.6). The average bulk density of **2.74 gm/cc** has been adopted.

Porosity or Void Ratio tends to vary between 2.04% - 4.50% (Table 5.6). Average porosity of biotite gneiss comes to **3.17%** and Void Index stands at **0.13%**.

Water absorption of Biotite Gneiss rock samples ranging from **1.00%** to **1.725%** and an average value of **1.433%** is adopted.

The average adopted **UCS** values for biotite gneiss are **53.1 MPa** (along foliation), **82.2 MPa** (perpendicular to foliation), **25.26 MPa** (Saturated – along foliation) and **46.56 MPa** (Saturated – perpendicular to foliation).

Five core samples of Biotite Gneiss rock from the Mangti Landslide were tested under **triaxial compression** for determining 'c' and 'Ø' values as per IS 13047 : 1996. It may be observed from the results (Table 5.9) that on increase of lateral restraint the ultimate bearing load of the test specimens also increased proportionately. The resultant values for cohesion **'c'** and angle of internal friction **'Ø'** were **8.40 MPa** and **44.44°** respectively.

Three samples each were subjected to tensile stress along the foliation plane and perpendicular to the direction of foliation plane in compliance to the **Brazilian Test Method** mentioned in Indian Standards Code IS 10082 : 2001. The obtained Tensile Strength along foliation plane shows range between **5.456** and **7.856 MPa**. Whereas, perpendicular to the direction of foliation plane it ranges between **11.13** and **11.79 MPa** (Table 5.10). Thus average values adopted for Tensile Strength are **6.4 MPa** and **11.57 MPa** respectively.

Three important landslide triggers viz. *Rainfall, Earthquake Shaking and Anthropogenic Interference* are indentified in Mangti Landslide Environ; their influence on triggering landslides and threshold values along the TJRC are enumerated.

Annual average rainfall pattern in the study area shows that except during year 1997, it has received more than 2000 mm precipitation and the average annual rainfall stands at 2232mm. Out of the total average precipitation received by the area almost 79.59% rain is confined to rainy season (Table 6.1). Wherein, average precipitation 620mm (37.37%) is received during July month followed by August 496mm (29.90%) and months of June and September each received about 16.39% of rain. Therefore, almost 67.27% of average annual rainfall is received by the study area during July and August months only.

Careful examination of rainfall inputs received during monsoon period (June – September) and its correlation with the recorded landslide incidences show that majority of landslides (more than 90%) in the Tawaghat – Jipti Route Corridor have taken place during the months of June – September and predominantly during July – August months only. In all 293 landslide incidences have been recorded from the study area, out of which 116 (39.6%) landslides were recorded during the year 2004 alone. In that more than 50% **(58 nos.)** of landslides have been recorded during the month of July only (Table – 4).

Rainfall triggering threshold has been analyzed using daily recorded rainfall and landslide incidences. It is found that whenever the study area has received 22mm rainfall or more, there has been a land slide incidence.

The destructive impact of earthquakes, in many parts of the world, is greatly enhanced by the triggering of landslides during or after the shaking. There can be little doubt that after the direct effect of structural damage due to the strong ground-motion caused by earthquakes, landslides are the most important consequence of earthquake shaking.

The fundamental framework on which the entire characterization of earthquake induced landslide activity is based on two basic parameters viz. the susceptibility of the slopes to earthquake-induced instability and a measure of the intensity of the earthquake shaking.

Review of earthquake records points to the fact that this region is characterized by shallow focus earthquakes with their foci ranging from 05 – 93 km. The largest earthquake (M=7.5) in the region occurred on 28th August 1916 in Dharchula area.

Table 4 - Rainfall - Landslide Incidences Correlation
Tawaghat - Jipti Route Corridor

Year	Number of Days Rainfall Recorded >22mm and Number of Landslide Incidences								Total Rainy days > 22mm	Total Landslide Incidences
	June		July		August		September			
	R	N	R	N	R	N	R	N		
2000	5	17	18	6	11	9	-	-	**34**	**32**
2001	4	5	11	18	8	7	-	-	**23**	**30**
2002	3	1	7	5	12	15	8	8	**30**	**29**
2003	2	NIL	13	16	14	26	8	37	**37**	**79**
2004	-	11	3*	58*	4	22	2	18	**9**	**98**

Note: * Intense cloud burst witnessed on 18th July 2004 resulting into innumerable landslides

Rainfall Event (**R**) in days > 22mm and Number of Landslide Incidences(**N**)

Studies on risk through earthquake recurrence interval suggests that the region is susceptible to damaging earthquakes of magnitude 6.0 and more with the recurrence interval of 2 to 10 years.

However, an attempt has been made using study areas' earthquake events as gathered from Indian Meteorological department and U. S. Geological Survey and correlating with any recorded landslide incidence. As there exists number of epicenter locations in the near proximity of Mangti Landslide ± 50 km radius and important regional thrusts / tear faults etc.; large number of landslide incidences fits well with specific earthquake event. But, majority of landslide incidences are confined to monsoon period, therefore, it would not be wrong to ascribe both earthquake (M > 3) and rainfall event > 22 mm/day as triggering factor to cause landslides. Seismicity factor has been incorporated as one of the vital aspects for deriving an overall EIA of the area under Landslide Hazard Zonation studies.

In-depth studies of discontinuities carried out by the candidate through an elaborate Scanline survey and historical landslides record has revealed that the very inception of majority of landslides are attributed to the road development.

The stability analysis of Mangti Landslide has been carried out using GeoStudio's GEOSLOPE/W, 2004 software and using **BISHOP'S SIMPLIFIED APPROACH, JANBU'S SIMPLIFIED APPROACH, MORGENSTERN-PRICE APPROACH and GLE METHOD.**

An attempt has been made to apply lateral concentrated loads to simulate reinforcement in a limit equilibrium analysis to achieve the desired Factor of Safety, thereby, facilitating the development of Landslide Hazard Mitigation Plan. For this techno-economic viability has been chiefly considered towards choosing the type and quantum of a particular reinforcement for curtailing the costs. Three types of reinforcement viz. Uniform Pressure Lines (To imitate the load exerted by a Gabbion, normal to the sliding surface), Anchors and Soil Nails (Lazarte et al. 2003) have been conservatively used in simulation so as to achieve the desired Factor of Safety with minimal structural elements.

Mangti Landslide lies in Zone-V of Seismic Zones of India and looking towards the earthquake history of the study area the stability modeling is carried out including the seismic zone factors mentioned in IS 1893 (Part 1): 2002. The Factors of Safety Values obtained from various stability analysis approaches is tabulated below, Table – 5.

One of the objectives of this work is to develop a methodology with the help of remote sensing that could produce a hazard zonation map over a large area with higher degree of accuracy in a GIS environment. To derive landslide hazard zonation map. In this work, the information theory had been utilized to construct the map on landslide hazard zonation. The generated hazard maps were cross validated with field data and recent satellite data for accuracy.

Table 5 - Estimated Factor of Safety from Various Analysis Techniques, Applying Reinforced Structural Elements for Upper and Lower Level-Mangti Landslide

Reinforced Structural Elements		Bishop	Janbu	Morgenstern-Price	GLE
Upper Level Slide	Moment Equilibrium	1.140	-	1.125	1.125
	Force Equilibrium	-	0.942	1.119	1.125
Lower Level Slide	Moment Equilibrium	1.125	-	1.115	1.115
	Force Equilibrium	-	0.860	1.112	1.115

The information values of all the polygon elements are calculated and on the basis of histogram distribution, the polygon elements are classified into five hazard classes' viz. **Very Low** (Ij <= -0.02); **Low** (-0.02 < Ij < 0.103); **Moderate** (0.10 <Ij <0.23); **High** (0.23 < Ij < 0.40); and **Very High** (Ij > 0.40) landslide hazard prone zones. On the basis of this information, Probable Landslide Hazard Zonation Map of Tawaghat – Jipti Route Corridor is prepared.

The accuracy of information theory in predicting the slope stability was evaluated by the experimental probability. Thus, the derived accuracy of slope instability prediction for the Tawaghat-Jipti Route Corridor is **78%**.

The recommended landslide remediations for the Mangti landslide have been specifically worked out by simulation of introducing re-enforced structures into Limit Equilibrium Analysis. Whereas, for the route corridor buffer zone are broad based. The recommended measures are – anchors, soil nailing, rock gabion and development of surface drainage in case of Mangti landslide.

Whereas, for Tawaghat – Jipti Route Corridor landslide specific measures belonging to standard mechanical, structural and geometrical methods have to be adopted.