MAJOR FINDINGS AND CONCLUSIONS
Chapter - 9

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From systematic field and laboratory studies of geology, geomorphology, hydrology, soil, population and landslide the major findings have been summarised below:-

i) Lithologically, the Gangtok town and surrounding is characterised by Darjiling gneiss, Lingtse granite gneiss and Daling group of rocks. Although granite is hard rock but in this study area, it is very weak due to crushing leading to its low shear strength. These are lithologically fragile in nature and can create more instability during monsoonal season.

ii) Structurally, Gangtok town is characterised by several foliation, bedding, cleavage and fracture planes. Different micro and meso folds are also present as first generation structural elements. These are mainly primary and secondary planner and linear structures. Many high grade rocks are exposed with lineation, striping, thrust, pucker and fault lines and lineaments have also been demarcated through aerial photographs and satellite imagery LISS-III data.

iii) From Site response estimation using strong motion network and seismic microzonation, the entire Sikkim including Gangtok lies within the ambit of the seismic zone IV of I.S. code 1893-1984/1998. With reference to the MSK Intensity scale used for all engineering design purposes, the region lies in the very high damages risk zone of IX type.

iv) Engineering properties of soils and rocks exhibit moderate liquid limit and high plastic limit. As such, this has high plasticity index, I_p; is 20 only, in this case soil behave as plastic stage. Point load strength index of these materials indicate poor strength. The poor strength is likely to be due to partial decomposition of the constituent minerals of the rock samples.
v) From the above slope study, it has found that, major slopes are covered by slope-wash material which consists of displaced blocks and locally rolled boulders embedded in sandy clayey matrix. The slope angle in the eastern part is greater than the western part of the ridge. However, the stable and gentler slopes at many places have been endangered and accentuated by improper excavation for road, superimposition of excessive load of the buildings and poor drainage.

vi) From hill slope study, it has been found that the convex slope segments are formed on the upper part of the slope near the drainage divide due to the result of soil creep and raindrop splash and concave slope segments have been observed near river valley due to the depositional or transportation of slope materials. Straight slope segments have been identified in the lower part of the secretariat building, Tathangchen, Shari Lingding, Sichey, Bhurtuk etc.

vii) From the correlation study between Geology and Geomorphology, it has been concluded that, wherever the ridge axis passes through schistose country, the topography is flat for e.g. the lower schist zone has given rise 'Deorali flat top' and the upper schist zone has resulted in the 'Palace Ridge Road flat top'. Wherever, the ridge axis passes through gneissic country, the topography has become steeply ascending for e.g. the lingtse gneiss has given rise to Namnang ridge and the Darjiling gneiss, the Chanmari ridge. The Shari and Tathangchen valleys are formed on the lower and higher schist zone. The Namnang spur and the Chanmari spur are originated on the lingtse and Darjiling gneiss respectively. The scarp faces are developed in the Darjiling gneiss to the west of east slopes of Namnang ridge, where lingtse gneiss forms scarp faces.

viii) The correlation matrix of five morphometric variables clearly brings out that the relative relief has fairly strong correlations with average slope (+0.561), ruggedness index (+0.766) and dissection index (+0.661) while it is poorly correlated to drainage density (+0.174). Similarly drainage density has high positive correlation with ruggedness index (+0.728)
while poorly correlated to average slope (+0.104). On the other hand, drainage density is negatively correlated with dissection index (-0.047). Average slope on the other hand is positively correlated with dissection index (+0.281) and ruggedness index (+0.436). Dissection index is positively correlated with ruggedness index (+0.372). Fig. 1.10 enumerates the relationship properly.

ix) From the surface and sub-surface hydrological study of Gangtok town and surroundings, it has been observed that all the perennial and non-perennial streams are characterised by flowing hydrologic condition because domestic and industrial effluents as waste waters are continuously discharged into these Jhoras.

x) From time series analysis of rainfall data (through least square method), the value of correlation coefficient is $r = 0.8424$. It is noticed that the amount of rainfall is gradually increasing with the passage of time. From the co-relation coefficient value ($r = 0.8424$), it is concluded that, there is positive and strong relationship between time and rainfall. As a result, the landslide number and frequencies are also increasing day by day due to this particular triggering factor.

xi) The infiltration data shows that, a very high rate has been noticed at the sample sites Sichey, Hospital, Tashiview point, Rongyek and Deorali ropeway due to soft and brittle parent materials, fine soil texture and gentle slope. The slow to sluggish rate at infiltration has been found at upper secretariat, near Tadong Bazar, Bhurtuk and Amdogolai due to clayed soil which is impervious in nature and moss covered soil (generally reducing infiltration rate).

xii) Most of the precipitation in the area flows off as surface runoff through streams, Kholas and through intermittent springs. Only a minor fraction of total precipitation percolates down through the thickly vegetated permeable soil cover and through highly fractured rocks.

xiii) Hydro-geological study proved that, the isolated thin (somewhere depth above 3 metres) porous, permeable unconfined aquifers have been developed in different part of the Gangtok town and
surroundings. More specifically, near Rongyek, Sichey, Hospital, Lingding, Shari and Deorali, very fine water bearing and holding layers are being developed. According to CGWB, these porous unconfined aquifers have good storage capacity and hydraulic conductivity and it is composed of sand, silt and clay but at places gravel, pebble and boulders act as aquifers materials in the study area.

xiv) In the hard rock area e.g. Gangtok town and surroundings, the groundwater occurs in largely disconnected bodies under favorable geological condition, such as jointed, fractured, zones in various lithological units, weathered zones in the phyllite, schist, gneiss and quartzite.

xv) Relatively flat areas like those on tops of hills and ridges, saddles, spurs, gentle slope and secondary planner and linear structure are the groundwater potential zones and occur in areas like Sichey, Lingding, Deorali, near palace Jhora, south Tathangchen, Rongyek areas. These are high groundwater potential zones.

xvi) Very fine and thick soil has been developed in the western part of the study area where agricultural activities are being practiced. In Deorali, Sichey, Tathangchen, Bhurtuk, and near Hospital very good soil profiles have been developed but their colour, mineral concentration and organic carbon contents vary from place to place due to lithological diversity. From this ERS data it is known that isolated water bearing and water holding aquifer have been formed in and around the Gangtok.

xvii) From the report of NBSS & LUP (National Bureau of Soil Science and Land Use Planning) it is obvious that soil erosion is moderate in character in case of Gangtok town and the main cause of soil erosion is high orographic rainfall. Due to agricultural practices soil erosion is higher near the river valley. The maximum slides in Gangtok town and surrounding are debris cum rock slides. During and after slides mud flow has been noticed at several places. The surface and subsurface drainage diversification is the important rate of strategy for the mitigation of landslides.
From changing land use and land cover study, it is concluded that due to high urbanization, the forest covered area is being gradually reduced and urban construction (Multistoried buildings, Hotels, Lodges, Guest house etc.) have been gradually increasing day by day. It is estimated that just after five years the forest area and vacant land will be reduced 15 to 20% in Gangtok town and surrounding. Due to haphazard urbanization and unscientific land use on the unstable on high risk and vulnerable zones the frequencies of landslides are being occurred before time. Government should take the suitable protective measures, otherwise it will be very difficult to safe our ‘swapnil town Gangtok’ from these natural or manmade disaster.

The population density and household distribution of Gangtok have been increasing since 1991. From their correlation it has been found that very high and high population density and high house hold distribution zones are situated [sectors number 4 and 5] on very steep slope and geologically it is covered by fractured, sheared, frazile and vulnerable structures which create more instability during monsoonal months.

Month wise domestic and foreign tourists arrivals indicate that April, May, June and October appear to be the peak seasons. During this time period, the total population growth rapidly increases. According to 2001 census, the total population of Gangtok town was 29354 persons and domestic and foreign tourists were 1, 46,923 and 7757 persons. So the total population was in 2001 at Gangtok 1, 84,034 persons.

The incidence of recent landslides plotted on the landuse map, shows that most of the slides occured within the urban agglomeration, followed by cultivated land. This is one of the main causes for such heavy human causalities and loss of property even in comparatively smaller slides. Further, it has been observed that 25% of the slides have been either reactivated or are adjacent to the old landslides.

The township of Gangtok, with multistoried buildings, unplanned growth and inadequate drainage system will suffer from such losses, if the
municipal authorities do not impose severe restrictions on construction activities. The building rules for hill slopes, as prepared by the Bureau of Indian Standards should be followed. These rules clearly specify the minimum restrictions to be observed while constructing buildings on hill slope. Some of these pertaining to slope instability are highlighted below:

a) In areas of old slide zone and within 200 m from the probable slip zone, no building should be constructed,

b) Areas subject to landslides, sinking zone should be avoided,

c) Before planning the construction of a building complex on hilly terrain a detailed stability analysis of the slope should be carried out,

d) While conducting stability analyses in the area of proposed construction, changes in the subsurface water condition should be evaluated and its effect analyzed.

Similarly, on uphill slope, drainage requires special consideration and in the natural flow of water should be so diverted to ensure slope stability.

xxiii) Recent landslides when plotted on a lithology-cum-slope map indicate that most of the slides took place in areas where slope is between 25°-45°. Five slides took place in a steeper slope (>45°) and 7 slides took place in a gentler slope (<25°).

xxiv) Though gneisses are more stable than mica schist, lingtse gneiss is the most unstable rock type in the study area due to its sheared and fractured nature.

xxv) Most of the low and moderate hazard zones are restricted to the western part of the Gangtok ridge. This is because of low drainage density, structure and less landslide incidence.

xxvi) Higher the slope and drainage density, higher is the landslide susceptibility.

xxvii) The areas under over burden cover are vulnerable to landslide.

xxviii) Maximum landslides are found on the habitation with light forest and human agglomeration.
xxix) The ridge top and midland areas of plateau and flat terrain are stable and unstable areas are confined mainly to the edges of the denudated hillocks and overburden areas of steep slope.

xxx) BIS technique is more rational and accurate than LSI technique because the entire region has been divided into no. of facets which are natural units. The landslide incidences have not considered for the preparation of hazard zonation map but maximum active old and new slides comes under very high and high hazard zones. In case of LSI technique no. of landslides have been considered for the preparation of hazard zonation map but after preparation it has been found that the maximum landslides are situated on moderate to high hazard prone zones.

xxxi) The high risk prone localities are mainly Lingding, upper and lower Sichey, Rongyek, north and south Tathangchen, lower Bhurtuk etc. and covering as area of 7.0% out of this total area. The facets no. 38, 54, 57, 95, 96, 102, 107, 130, 132 have been noticed under this category.

xxxii) A detailed systematic study presents the landslides in the area caused by the rainfall on the night of 8th June, 1997. A total of 33 major and medium slides have occurred in Gangtok and surrounding area, of which 8 (i.e. 24%) fall in phyllite and quartzites of Daling group of rocks, 12 (i.e. 37%), fall in Lingtse gneiss and the rest 13 (i.e. 39%) fall in schists and gneisses of Darjeeling group. Such a grouping, however, does not give a correct picture of landslide distribution based on lithology. In order to get a precise idea, the total area wise distribution of rock types and number of slides in each type has been calculated. It has been found that the number of slides occurring per sq. km. of the affected area in the Lingtse gneiss, the Darjeeling gneiss and the Daling phyllite/quartzite area 5, 0.6 and 0.9 respectively. The above pictures show that the frequency of landslides in maximum in Lingtse gneiss / granite which is jointed in nature and forming slope failure wedges and blocks.

xxxiii) It has also been observed that in and around Gangtok, some buildings have wall resting directly over retaining walls, which are constructed of
dry "rubble masonry". Since the deformability of such masonry walls is very high, the constructed building often collapses. Such prevalent, bad practice should be discontinued. Similarly, multi-storied building constricted in Gangtok, generally ignore the stability of the rock slope and load on the foundation.

xxxiv) From the case studies it is concluded that slides are debris slides in nature. Saturation of soil and toe erosion of nallahs, choked drainage and wedge failure, heavy rain, poor drainage and increase in pore pressure due to blocked drainage are the active triggering factors of landslide in the study area.

xxxv) The significance of vegetation for stabilization of sheet slides is often underrated. Mangan, Lantakhola, Padmachen, Chanmari, Tathangchen, Lingding slides and many others in the study area have been stabilized to a great extent by afforestation although different engineering techniques (retaining walls, piling, and surface and subsurface drainage diversification through engineering construction) are using recently for the stabilization of landslide in the study area.

Conclusion:

Natural process of land sculpturing, such as, weathering, erosion, slope failures, is faster in the Sikkim Himalayas, mainly because the area receives intense and heavy precipitation owing to unhindered access of the south-western monsoon originating from Bay of Bengal. The east facing hill slopes of the north-south trending hill ranges are directly hit by the south-western monsoon, and as result, receives high and intense rainfall, suffer fast weathering and are most affected by large landslides and related slope stability problems.

Large scale mass movements not only cause degradation of the mountainous terrain but also affect developmental activities. It is rather impossible to stop the mass wastage as these are caused due to natural geological processes of weathering and erosion. However, these may be and need be controlled when their incidences directly interfere with the human activity and cause damages to life and property. On the other hand, environmental
degradation of mountainous terrain all over the world is the result of certain types of damaging human activities, such as, mass deforestation due to progressive encroachment of hilly terrain due to increase in population. The area under study is no exception where large scale landslides have developed during the last few decades.

While planning construction of a new road alignment or a railway line on a hilly terrain, specially in Himalayas, a detailed geological investigation evaluating all essential informations on structural and tectonic behaviour of the slope material during and after the slope cutting, stable and unstable zones which the proposed alignment may have to negotiate, is a pre-requisite and must. For example, had adequate data been collected on terrain condition, such as, geological set up, structural and tectonic behaviour of the slope material, etc., the road alignment of North Sikkim Highway could have been located on rocky and stable right bank of Tista between Mangan and Tung. For the similar reasons, the alignments of Gangtok- Nathu La Road in Sikkim Himalayas has been located on more stable slopes and the realignment of part of all these roads, now being inevitably thought of, could have been avoided.

In India, the studies and investigations on slope stability problems are normally taken up on ad-hoc basis after the occurrence of a landslide. Of late, awareness has developed amongst user agencies and slope stability analysis are being conducted in advance by the Geological Survey of India and other specialized organizations for the proposed civil engineering construction in the mountainous region. However, pre-construction evaluation of slope stability is not mandatory in India whereas certain countries provide laws and obligatory provisions to be implemented during construction against slope failures causing degradation of mountainous terrain. Similar legislative provisions are required to be framed and enforced in India so as to control slope failures and wastage of landmass related to inadequate protective measures undertaken during construction activities.

Shortage of plain ground is a compelling factor for progressive extension of human activities over the mountainous region all over the world exposing facilities so generated to frequent natural disasters. More we encroach upon higher and
the snow bound Himalayas and similar terrain elsewhere, the more chances of suffering from such disasters as landslide, become imminent and inevitable. Nevertheless, the modern tools of hazard monitoring, prediction and mitigation through weather satellite and periodic data collection may fruitfully be utilized to forewarn an imminent approaching hazard. Thus, precious lives and property may be saved by flashing timely warning about a prospective disaster over mass media.