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Landslide and seismic activities of Darjeeling district: related problems and sustainable management

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Abstract: Darjeeling, the 'Queen of the Hills' has been suffering from landslide and seismic activities almost each year. Tourism industry is one of the principal modes of economic development of the area which is going to be hampered due to these uncontrolled natural calamities. The main aim and objective of the study is to recommend some sustainable measures to rescue the 'Queen of the Hills' from the calamities and to secure its economic development. The study is done on the basis of direct field observations and studying references. After studying the Genomics and Geophysical aspects of the district, it has been seen that the problems are basically related to the effects of thrusts, faults, avalanches, slope instability, sub-surface rainfall, hampered vegetation cover, population pressure and their unruly behaviors on the hilly terrain i.e. contractions of unplanned reservoirs, unplanned settlement, unplanned road constructions, vehicle pressures etc. The measures which are taken till today are not sufficient enough to rescue the district from vulnerability and thus all in vain. Along with some general mitigation measures newly innovated measures related to settlement patterns, road construction, warnings manners of landslides are to be introduced. Some suggested measures will help to control the vulnerability and enhance the development of tourism industry as well as the economic development of the local people.
Keywords: Landslides, Seismicity, Run off, Slope Instability, Ustacy.

INTRODUCTION

The name 'Darjeeling' comprises two Tibetan words i.e 'dorje' means thunderbolt (originally the scepter of Indra) and 'ling' means a place or land, hence Darjeeling is the 'the land of the thunderbolt'. Darjeeling, also known as the "Queen of the Hills" has some of the most attractive tourist attractions which attract large number of tourists each year to enjoy a vacation in this beautiful city of West Bengal. Darjeeling owes its grandeur to its natural beauty, its clean fresh mountain air and above all, the smiling resilient people for whom it is a home. Known for its natural splendour, the best gift of Darjeeling to its visitors is the dawn of a new day with glorious Kanchenjunga of Himalayan region and tea gardens of its foot hills. The mountains awaken first with a tentative peeking of the sun. A steep ride, five kilometers from Ghoom, or an invigorating walk up a steep incline, leads sun worshippers to Tiger Hill. The air is chilly with darkness and damp. To the East, a dull orange sun emerges painting the sky with brilliant strokes of magenta, gold, orange and fuchsia. The snow capped Everest, Kabru, Kanchenjunga, Jannu and other peaks slowly emerge from slumber to start a new day. The visitors gasp at the magnificent sight. As the fog lifts in the slowly penetrating sun, the town gradually comes alive. Amidst brewing of tea, the sing-song Gorkhali which is the local dialect, rises and falls like music. National Rail Museum (India), the focus of India's Rail heritage, submitted a proposal to UNESCO on 29th June 1998 for inscribing the Darjeeling Himalayan railway (DHR) as a World HERITAGE Site. Accordingly, UNESCO'S World Heritage Committee inscribed DHR as a World Heritage Site on 2nd December 1999. The DHR has popularly known by the name as 'Toy Train' which is in fact was never an official term is just a popular expression found in literature. Darjeeling tea, which is one of the most exported items from Darjeeling, occupies a place of pride in the entire world for its fresh aroma and taste. The history of tea production in Darjeeling dates back to1841 when Dr. Campbell, a civil surgeon of the Indian Medical Service, was transferred from Kathmandu to Darjeeling in 1839 as Superintendent of this new territory and of the Sanitarium. Dr. Campbell brought China tea seeds in 1841 from the Kumaon region and started growing tea on an experimental basis near his residence at Beechwood, Darjeeling. This experiment was followed by similar efforts by several other British. The experiments were successful and soon several tea estates started operating commercially.

Darjeeling stands today one of the quality tea producers in the world[18].

Above all these are the glorious sides for which the Darjeeling is considered to be the 'Queen of the Hills'. But unfortunately there are some unavoidable negative circumstances for which Darjeeling becomes a panic to the people. Seismic activities and landslides are most important points to mention in this connection. If Darjeeling can be rescued from Seismic activities and landslides then it will be delicious for the delegates who will visit here.

Location of the Study area

Darjeeling District is located (Fig.1) in the undulating topography of Eastern Himalayas and belongs to the State of West Bengal, North-East India. It is extended from 26° 27´ N to 27° 13´ N Latitude and from 87°59´ E to 88° 53´ E Longitude. Darjeeling District is surrounded by Nepal to the West, the Indian State of Sikkim to the North, Bhutan to the East and Bangladesh to the South-East. Darjeeling District includes parts of the lower Himalaya and along its base it has Terai (In Sanskrit, the meaning of which is "foot-hill" and in Urdu "lands lying at the foot of a watershed") areas and to some extent 'dooars' (Duars or *Dooars* literally *means* gateway / door to Bhutan and North East India) areas. Having an area of 3149 Km² the district comprises 4 sub-divisions (namely Darjeeling Sadar, Kalimpong, Kurseong and Siliguri), 12 Blocks and 134 Gram Panchayets.

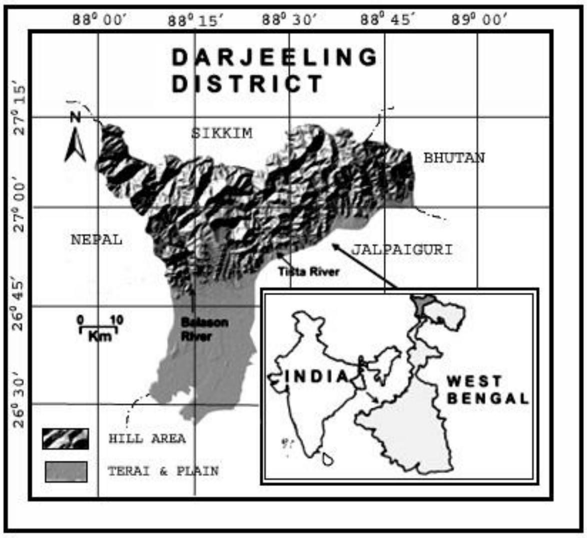

Fig-1: Location of the Study area

Aims and Objectives of the Study

The main aims and objectives of the study is to solve the seismology related problems of the 'Darjeeling' and to suggest some measures related to sustainability. The other objectives are-

- To study the seismic activities and its influence on landforms of Darjeeling
- To suggest the sustainable socio-economic processes to make Darjeeling economically sound.
- To represent the 'Queen of The Hills' for the visitors as one of the safest tourist spot.
- To increase the comfortability of the Darjeeling dwellers.
- To increase the awareness of the people related to their beloved town.
- To provide feedback to the executive agencies for the planning and development of the 'Queen of The Hills'.

MATERIALS AND METHODS

Direct field observation is the principal methodology of the study. Field visit had been done during the month of February, 2015. The seismic characteristics of the region and anxiety to the dwellers related to earthquake are noticed which influences to draw attention of the researchers. The information about the geological structure is collected from the secondary data sources whereas the socio-economic data are collected from the local people. The environmental conditions are also studied directly from the field observations and to some extent collected from the secondary sources also. The tourist guides had helped a lot to visit the surrounding regions of Darjeeling and added information which are very significant and interesting for the researchers. Information, mainly related to seismic activities are to some extent collected from different secondary sources as it was in various web sites. Remote Sensing data is also given importance to draw conclusions. The distinct study had never been done about the region in the past.

Geology, Relief and Drainage:

The Himalayas are considered as the youngest mountains on the Earth , originated from the collision of the Indian continent with Eurasia about 40-60 millionyears ago; India still continues to migrate with a speed of 5 cm/a; whereas the uplift of the Himalayas moves at a rate of about 5 mm/a. Geology of Himalaya, Though there is a classification of the Himalayan range from West to only the Sikkim Himalaya, which lies in the catchment area of the Tista river, is of interest, as the Darjeeling Hills belong to them.Furthermore, "the Darjeeling Himalaya is separated from the foredeep of the Ganga-Brahmaputra Plains by two active tectonic lines: the Main Boundary Fault and Himalaya Front Tectonic Line". Darjeeling Hills comprise of three belts:

- "An outer belt of Siwalik frontal range on the northern border of the young Quaternary alluvial plains;
- A middle narrow belt of the Damuda (lower element of Gondwana) range, and an inner range of metamorphites belonging toDaling and Darjeeling groups

➢ An inner range of metamorphites belonging to Daling and Darjeeling groups [1].

Geologically the entire Darjeeling hill area consists of six types of formations starting with Alluvium (Pleistocene to subrecent deposite, 1.8 million years - 10000 years), Raised Terrace of bouldery formation (Pleistocene period, 1.8 million years) and Siwalik (Miocene, 26 million years) successively upward at the foot hills and Damuda (Permian, 280 million years), Daling Series and Darjeeling Gneiss (Archaean; the Dharwar system, about 3787 million years) on rest of the hilly parts. The Geological set up of the Darjeeling town is comprised of Darjeeling Gneiss having coarse textured Gneiss with Kyanite and Sillimanite of the oldest Dharwarian system (Fig.2). This rock in comparison to the other geological formations is far more hard and resistant to denudation and thus having higher threshold value [2].

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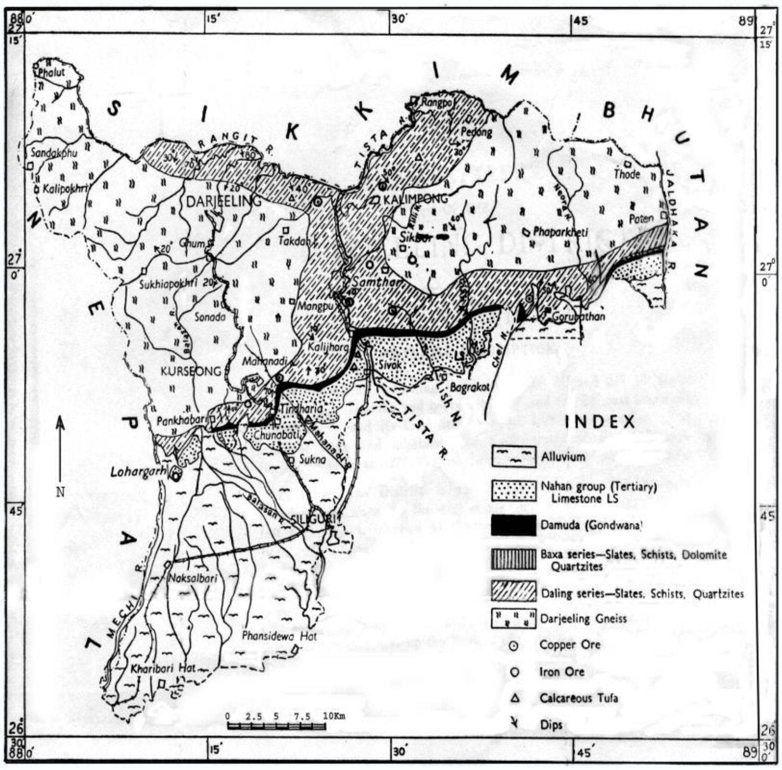

Fig-2: Geological Structure of the Study Area [1].

Geomorphologically Frimal village and the Haridas Hatta in the Darjeeling town where the landslides have occurred are situated on the rugged physiographic setup of the Middle hills of Darjeeling Himalaya having high amplitude of relief and infested by numerous rivers and streams with very steep valley side slopes.

The study area falls within the Lesser and Higher Himalayan regions with an elevation ranging from 65 m (around Dudhia, Darjeeling District) through 800-1200 m around Ranipul, Mangan, 1400 m around Darjeeling, 1800-2200 m around Gangtok, Pelling, Ravangla to 2800–3200 m around Kyangsla (near Nathula) with elevations increasing gradually from south to north. In the Lesser Himalayas towards south, the slope is gentler and in the undulating stretches, numerous streams and rivulets flow along the depression and finally join with the trunk streams. In the Higher Himalayan terrain, the topography is highly rugged, characterized by steep slopes with prominent gully erosion. The main rivers are Tista, Balasan and Mahananda. There are also many natural water streams, called *jhoras*, which exist in Darjeeling District [3], The Tista-Rangit water divide is the main north-south water divide within the Sikkim Himalayas. Another north-south water divide is between Lachen Chu & Lachung Chu which starts at about 3000 m and slowly increases up to 6700 m. North of Dikchu, steep ridges on the eastern side are there but of smaller extent as the Tista valley is sub-divided by the water divide between Lachen 2 Chu and Lachung Chu. On the western part long ridges are present – these are Talang Chu (River) and Zemu Chu water divide. Geologically, the mountainous regions of the Darjeeling and Sikkim Himalayas are part of the active Himalayan Fold-Thrust Belt (FTB), which is geologically and structurally complex exposing a number of overturned (towards south) and thrusted sequence of variably metamorphosed pelitic and psammitic rocks over Mesozoic (Gondwanas) and foreland rocks composed of Tertiary (Siwaliks) sediments in the south [4] .

Plate Tectonics and Seismicity

The Himalaya is originated as a result of continent–continent collision between India and Asia. The northward convergence of India resulted in crustal shortening of the northern margin of the Indian continent, accommodated by south-verging thrusts. The principal thrusts, namely the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Himalayan Frontal Thrust (HFT) show younging age and shall owing depth, suggesting southward migration of the main deformation front. Neotectonic activity and active faulting related to the thrusts are observed on the surface in some restricted segments. The MCT remains largely inactive, except some reactivated segments showing lateral strike-slip movement as in Central Nepal1. The MBT in certain localized areas exhibits neotectonic activity2. The Himalayan Frontal Fault (HFF), also referred to as the HFT, shows active faulting and associated uplift. The HFT represents a zone of active deformation between the Sub-Himalaya and the Indian plain. It demarcates the principal present day tectonic displacement zone between the stable Indian continent and the Himalaya with a convergence rate of 10–15 mm/yr3. There is an uplifted piedmont zone south of the HFT, extending from Yamuna to Ganga and suggesting active deformation related to the HFT In eastward extension of Kumaun, a narrow belt of seismicity follows approximately the topographic front of the Higher Himalaya in Nepal. The hypocentres of the earthquakes in central and western Nepal tend to cluster at mid-crustal level at a depth between 10 and 20 km. The 1934 Bihar–Nepal earthquake, with magnitude 8, had its epicentre located east of Kathmandu in the Lesser Himalaya18. The rupture zone of this earthquake extended 200–300 km east-west and spread ~ 150 km north-south19. The earthquake produced a zone of high intensity extending from Kathmandu Valley to the Gangetic plain, including the slump belt in Darjeeling and northern Bihar with near-total destruction [5].

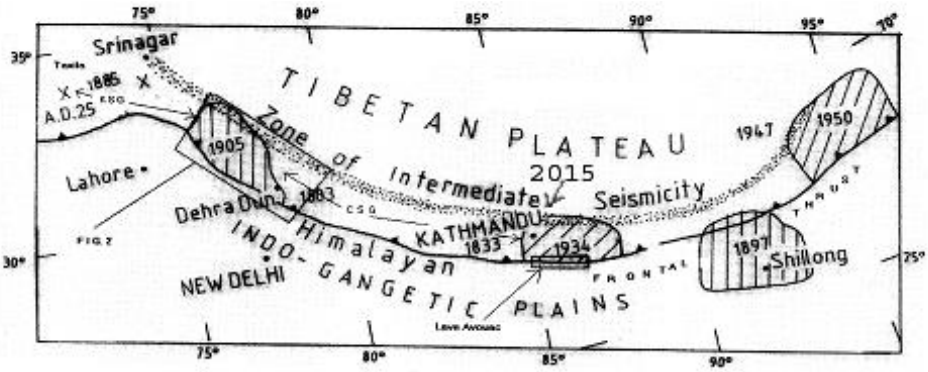

Fig-3: Sketch map of Himalaya showing Himalayan Frontal Thrust Zone [5].

As per the Seismic Zonation Map of India, the state of Sikkim comes under Seismic Zone IV – a zone of considerable vulnerability. The nearby region in the further north comes under Zone V and is highly susceptible to moderate to major earthquakes. In this area, most of the previous earthquakes were of shallow focus (< 40 km) and are commonly of 4.5 to 5.5 Magnitudes on the Richter scale. The regional distribution of earthquakes and lineaments/faults in Sikkim and adjoining Darjeeling areas indicates that a number of past moderate (M 5.0 to 5.9) and slight (M 3 to 5) earthquakes **5** are clustered around the Tista Lineament trending NW-SE direction. Northern extension of the Tista lineament cuts across the NE-SW trending Kanchanjungha lineament. Another NW-SE trending lineament marked as a fault along the Tista River between Lachen and Chungthang (and further southeast) appears to have been the cause of some high Magnitude earthquakes in the region [4]. So, Tista Linement has a better trend of effecting earthquake but the Darjeeling Himalaya is affected by earthquake a lot with comparatively lesser damage rather than Sikkim or Kathmandu.

Some important Earthquakes in the Himalaya

Although earthquakes have struck the Himalaya for millions of years, historical documents of these earthquakes go back to only the 13 th century and were compiled in the 19th century. The earliest Himalayan earthquake on record dates back to 1255 in Kathmandu in which (according to a historical document) 'one third of the Kingdom of Nepal perished.' In June 1505 an earthquake wrecked several monasteries in southern Tibet, and a month later, another earthquake hit Kabul in Afghanistan. The earliest historical record of Kashmir earthquakes is one that hit Srinagar in 1555 and killed hundreds of people. Since then, large earthquakes have been documented from the Himalayan region.

The 1833 Nepal Earthquake

On 26 August, 1833 an earthquake hit an area close to Kathmandu, followed by several large aftershocks with a magnitude of 7.7 on the Richter scale and the earthquake killed 414, injured 172 people, and destroyed 4040 buildings in Kathmandu.

The 1897 Assam Earthquake

On 12 June, 1897, the Shillong plateau in the Assam region of northeast India was hit by an earthquake with a magnitude larger than 8, killing over 1500 people.

The 1905 Kangra Earthquake

On 4 April 1905, a large earthquake struck the Kangra valley in northwest India. In this earthquake about 20,000 people were killed with an estimated magnitude of 8.6.

The 1934 Bihar-Nepal Earthquake

On 15 January 1934 an earthquake with a magnitude of over 8 shook a large area of about 100-300 km long in Nepal and Bihar, killing 10,500 people

The 1950 Assam Earthquake

On 15 August 1950 an earthquake with a magnitude of 8.7 struck Assam in northeast India and a fault of some 200 kilometres long was ruptured in this is placed rocks by nine meters.

The 1991 Uttarkashi Earthquake

On 20 October 1991 an earthquake measuring 6.6 on the Richter scale hit the Uttarkashi-Tehri area in north India, killing 769 people, wrecking 28,000 houses and severely damaging another 21,000. The focal depth of the earthquake was 12 kilometers.

The Chamoli Earthquake of 1999

The Chamoli district of the Uttar Pradesh state witnessed an earthquake of magnitude 6.8 on 29 March 1999, killing 103 people and causing extensive damage to property. The focal depth of the earthquake was 21 kilometres.

The Great Kashmir Earthquake of 2005

This earthquake, with a magnitude of 7.6, took place at 8:50 a.m. on 8 October 2005. The epicentre of the earthquake was 34.493° North and 73.629° East, some 10 kilometres (6.2 miles) northeast of Muzaffarabad (capital of the Pakistan-administered Kashmir), and very close to the boundary of the Indian and Asian tectonic plates. The focal depth at of the earthquake was about 26 kilometre (16.2 miles).

Earthquake-triggered landslides destroyed many houses on hillsides and blocked roads. In terms of death toll, this was the most fatal earthquake in the recorded history of the Himalaya [17].

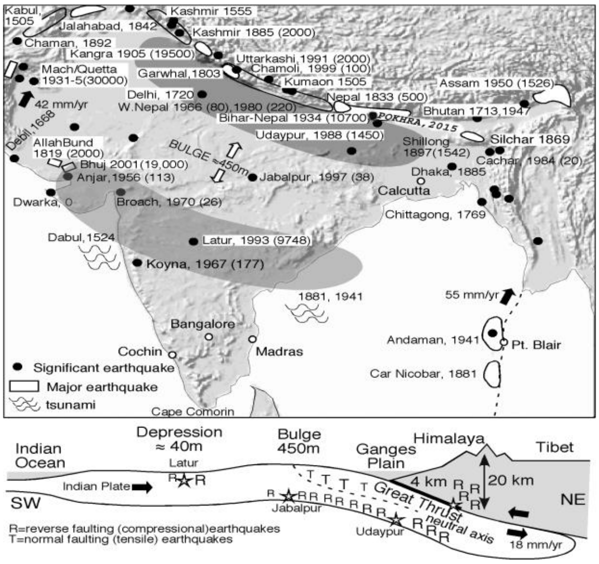

Fig-4: Some important earth quake events of Himalaya [6].

Nepal Earthquake of 2015

On 25th April, 2015 there was a massive earthquake (7.5 in Rickter's Scale) along with almost 340 aftershocks continued for 3months took place in Pokhra, Nepal and about 15000 people were killed.

CLIMATE

The climate of the Darjeeling town is associated with Koppen's Cwa (Subtropical Humid) type of climate. The Himalayan region acts as a strong orographic barrier for rainfall. Thus precipitation distribution in the windward and leeward sides of the mountains are effecting strong, Sometimes torrential rains occur on the windward side but dry conditions on the leeward slopes. Temperatures experiences a decrease with rising altitude at rate 6.5°C/Km, comparing to Dhubri and Darjeeling Town (at 2,256 m) experiencing 24.0°C and 11.8°C respectively. Due to the higher elevation, temperatures in Darjeeling Town are about 12°C cooler and therefore rather pleasant compared to the hot lowland areas. Humidity in the

Darjeeling Hills is all around rather high which belongs to 80 % in winter and 95 % in summer, while in Dhubri, the plains shows 58 % vs. 87 %."Even though Darjeeling receives an unbalanced distribution of rainfall as 71 % of the annual precipitation is during June–August, the mean relative humidity will not drop below 60 % even in the driest months of March and April" [7].

Table-1: Climate of Darjeeling

27°03' N / 88°16' E	Temperature (°C)	Relative Humidity (%)
Month	Average	Average
January	8.3	83
February	8.9	82
March	13.9	73
April	16.7	78
May	17.8	88
June	18.3	93
July	18.9	95
August	18.3	95
September	17.8	93
October	16.1	87
November	12.2	79
December	9.4	78
Year	**15.0**	85

Source: Von [1]

Another typical climatic phenomenon in Darjeeling District is consistency of foggy days. In an average over 100 fog days are normal phenomenon throughout the year.

Soil

Soil types in the Darjeeling District based on rock material are basically acidic; the colour varies from yellow to red-brown. Soils contain very poor amount of calcium, magnesium, potassium and phosphate and consists with a low amount of organic matter. Soil texture varies from silty loam to sandy loam, whereas the sub-soils are rather compact of grey and dark brown clay. Coarse pale yellow to red brown soils are found on the Siwaliks amongst them mainly sandy 35 soils over the Damuda series, compared to clayey dark grey soils on the Daling; red to brown silty and sandy soils dominate on the Darjeeling Gneisses and are poor in lime, magnesium, iron oxides, phosphorus and nitrogen, but have a *"high content of potassium, derived from feldspar and muscovite"*[8]. Grain composition of soils on Darjeeling Gneiss, Daling and Damuda series contains about 50-80 % sandy and coarse particles. Coarser debris can be found on steeper slopes. Soils classification of Darjeeling District can be into the following soil types: mountain and glacial soil, brown hill soil, forest soil, brown forest soil, tea soil, cinchona soil and terai soil [1].

Vegetation

The Tropical Evergreen Lower Montane Forest is characterised by high humidity and precipitation varying between 1,500-5,000 mm; in winter dew and dense fog occur more strongly than precipitation. As a result, steep slopes are covered with such montane forests, if good drainage is available. The height of the trees is about 20-30 m; a well-developed under-storey and tree ferns are present as well. Species that dominate are *Quercus* and *Castanopsis*. When *Castanopsis* appears above sal *(Shorea robusta)*, it is a clear indication of a montane forest. Furthermore, *Alnus nepalensis*(Nepal Alder), *Veeronica Pollita* occurs on water courses, but on plantation areas *Cryptomeria japonica*, Windmill Palm(*Trachycarpus fortune*) are prevalent. Furthermore noticeable are tea and cinchona plantations of man39 made origin. Secondary vegetation has grown on abandoned sites including *Alnus nepalensis, Schima walichii, Maesa chisia, Coleus Canina, Aster Umbellatus* and *Rhus semialata* [16]. The trees in the Tropical Evergreen Upper Montane Forest have a dense canopy and reach a height of 30 m. Undergrowth has bamboo(*Phyllostachys Glauca*), ferns, nettles and raspberries. These forests are often affected by fog and high humidity, hence not much direct sunshine can penetrate. Heavy rainfall occurs in summer, especially in June and August compared to heavy dew which prevails from November till March. Though the forests are mixed, certain species dominate: *Quercus* and *Lauraceae* (from 1,800- 2,000 m high up), while Rhododendron is almost entirely in the range of 2,500-2,800 m. Steep ridges are dominated by bamboo undergrowth and Rhododendron, but forest plantations by *Cryptomeria japonica* [1].

Plate-1: ***Ammomum Dealbatum***

Plate-2: ***Coleus Canina***

Plate-3: ***Aster Umbellatus***

Plate-3: ***Phyllostachys Glauca***

Plate-4: ***Veeronica Pollita***

Plate-5: ***Trachycarpus fortune***

DEMOGRAPHY

In 2011, Darjeeling had population of 1,846,823 of which male and female were 937,259 and 909,564 respectively. In 2001 census, Darjeeling had a population of 1,609,172 of which males were 830,644 and remaining 778,528 were females. There was change of 14.77 percent in the population compared to population as per 2001. In the previous census of India 2001, Darjeeling District recorded increase of 23.79 percent to its population compared to 1991.

It is noticed that the population of Darjeeling had been rapidly increased from 1991 to 2001 at the rate of almost 23.79% which influences the settlement pattern, landuse pattern and the pressure in the subsurface zone.

Table-2: Demographic Pattern of Darjeeling

Description	2011	2001
Actual Population	1,846,823	1,609,172
Male	937,259	830,644
Female	909,564	778,528
Population Growth	14.77%	23.79%
Area Sq. Km	3,149	3,149
Density/km2	586	511
Proportion to West Bengal Population	2.02%	2.01%
Sex Ratio (Per 1000)	970	937
Child Sex Ratio (0-6 Age)	953	962
Average Literacy	79.56	71.79
Male Literacy	85.61	80.05
Female Literacy	73.33	62.94
Total Child Population (0-6 Age)	193,169	204,643
Male Population (0-6 Age)	98,933	104,324
Female Population (0-6 Age)	94,236	100,319
Literates	1,315,585	1,008,288
Male Literates	717,673	581,420
Female Literates	597,912	426,868
Child Proportion (0-6 Age)	10.46%	12.72%

Source: Census 2011 [22]

LANDSLIDES

Landslide is perhaps the most rampant environmental hazard threatening the Darjeeling town itself. During or after monsoon landslips create havoc in and around the Darjeeling township area. Numerous slips have occurred in the past however the intensity, cause and severity of the slide are being recorded since 1899. Darjeeling, one of the most densely populated tourist centers in comparable environment exits on the verge of an environmental catastrophe as with just one concentrated shower of 50 mm/h would initiate numerous landslides endangering the lives and properties of the local inhabitants. For a better understanding of the geographical distribution of landslip-prone areas in Darjeeling town, the following five categories of susceptibility zones have been identified [9]:

Class I – Extremely high slip prone zone:

Almost after every torrential rain these tracts experience slips. They are mostly found on eastern slope of Jalapahar-Katapahar ridge it mainly covering the areas like Alubari, Munpari bustee, Toongsong, Pandam tea garden. Bhutia bustee and Hermitage, eastern lope of Lebong spur, it around Ging and Bannock - burn tea gardens and in small pockets on western slope of the Lebong spur i.e. Pattabong and Rangit tea gardens. It is also noticed a long western part of the town below Batasia.

Class II – Very high slip prone zone:

These are the areas where slips occur for more than 5 times in 10 years. They are found along both the eastern and western slopes of the edge. i.e. upper Alubari, upper Toongsoong, along Tenzing Norge road, C.R. Das Road, eastern slope of Mall, below Raj Bhavan. It is also to be found on both sides of Lebong spur mainly in the tea gardens of Bannock-burn, Rangit and Pattabong. On the western slopes of the ridge it covers Rajbari bustee, Kagjhora, Victoria Falls, Dr. Zakir Hussain bustee, Dhobitala, around the jail, below the railway station, Lochanger, Haridashatta and Singamari.

Class III – High slip prone zone

It covers the western spur of the town along the Hill Cart Road, Gandhi Road, Nimkidara, Police line, Marry Villa, Maypuri, Upper Kagjhora, below the convent cemetery, Dr. Zakir Hussain Raod, along the Birch Hill spur and the Lebong spur. Here landslips occur 2-5 times in ten years.

Class IV – Moderate to low slip prone zone :

In this zone landslips occur once or twice in last ten years. It is found mostly along the ridges of Jalapahar-Katapahar up to the Mall including the bazaar area and also along the Lebong spur including the Lebong cart road.

Class V – None to negligible:

It is found in pockets on the ridge tops of the Jalapahar Katapahar ridge, the Lebong ridge (Military Cantonment) and the Observatory hill and on the top of the Birch Hill ridge where slips occur rarely [9].

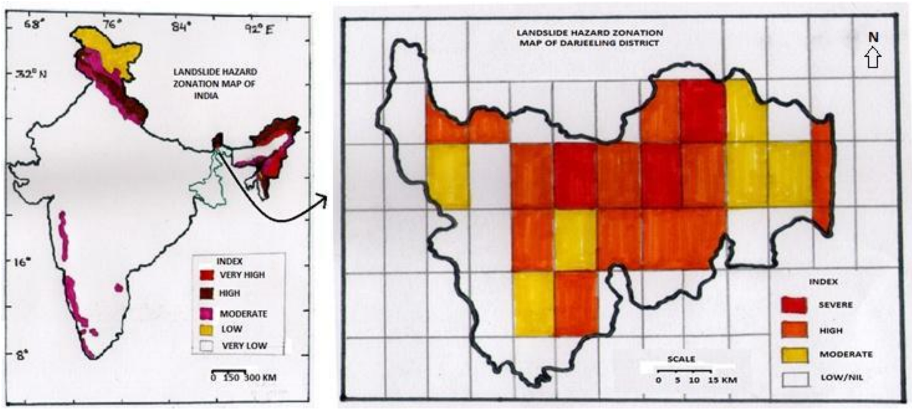

Fig-5: Landslide Hazard Zonation Map of Darjeeling, [10]

Major Landslide Events

The landslides in Tindharia on 15^{th} January, 1934 due to Bihar Nepal earthquake.

- Between 11^{th} to 13^{th} June 1950 a series of devastating landslides after a spell of 834.10mm rainfall around Kurseong , Darjiling Himalaya (127 people were killed).
- Landslides at Giddapaha near Kurseong damaged over 175 m of road and railway track and demolished many bostee Hamlets between 3^{rd} and 5^{th} Octobar in 1968 due to heavy rainfall of 1121.40mm.
- During 3^{rd} -4^{th} Septembar in 1980 again Tindharia was affected by severe landslide due to heavy and concentrated rain of 299.1mm.
- During 15^{th} and 16^{th} September, 1991 Numerous Landslide phenomena at Paglajhora and Chunabhati due 462.5 mm heavy rain
- During 11^{th} and 13^{th} July, 1993 innumerable landslides devastatd Mahanandi, Gayabari and Tindharia due to concentrated rainfall of 211.3mm.
- In the years of 1995, 1998, 2001, 2002, 2003, 2006 and 2007 are major cases of landslides along Hill cart road mainly Paglajhora, Giddapahar, Tindharia and Gayabari.
- A devastating landslide took place Shivitar Tea Estate in 2005 , which destroyed a tea Garden area of 1.5 acre.
- On 10^{th} September, 2006 a devastating landslide took place along the Hill Cart Road at 14 miles Bustee and blocked the railway line for few days due to sudden and catastrophic rainfall.
- A road Crack was formed along NH 55, the road from Darjeeling to Siliguri, at Tindharia following heavy rain in the past few days on 4^{th} August , 2007. Another Landslide event happened in the same year on 16^{th} July along the Hill Cart Road and completely broken down the guard wall nearby Kurseong town.
- A major Landslide at 14 mile near Paglajhora disrupted traffic along the National Highway-55 and toy train services between New Jalpaiguri and Kurseong on 16^{th} June, 2010 Morning.
- Heavy Sowers and the vibrations caused by the Sikkim Earthquake invited destructive landslide events at Tindharia and lower Paglajhora on 10^{th} May, 2011[11]. Due to heavy rainfall Landslides occured in St.Mary's hill of Darjeeling and Karseong on 17^{th} June, 2011 again.
- On 9^{th} August, 2014 due to massive 2miles broad landslide occurred in heavy rain, caused Poshyer village cut off from Kalimpong and other places.
- On 25^{th} June, 2015 at least 18 people have been killed in landslides triggered by heavy rains in Darjeeling, Kalimpong and Kurseong sub-divisions of Darjeeling district .The landslides have caused extensive damage to NH 10 (old NH 55A) and NH 55, cutting off road and telecommunication link to Darjeeling and Sikkim. 25 landslips were reported in the three sub-divisions. 18 people have been killed in the landslides. There are also reports of 15 people missing at 8 Mile and 11 Mile areas in Kalimpong.NH 55 connecting Siliguri, Matigara with Darjeeling was also damaged particularly in Mirik and Rohini areas. A bridge on NH 55 has been washed away at Nimbujhora. On 30^{th} June again more landslides were reported from other parts of the district, including Kuresong and Sukna. Rakti Bridge was washed away with boulders and rocks covering the main road in Kurseong, at Khahare Khola, the access to Siliguri Via NH 55 is cut off. At least 15 people are reported missing at 8 Mile and 11 Mile areas in Kalimpong. The rate of earthquake in Darjeeling district can be assumed by following chart.

Table -3: Landslide Events in Darjeeling

District	Road Streach	No. of Slides	Types			State		Major Subsidence /Cracks
			Rock	Debris	Soil	New	Reactivated	
Darjeeling	**Dudhia-Kurseong-Mahanadi-Darjeeling Section via SH-12A, Pankhabari Road and NH-55**	**5**	**-**	**2**	**3**	**5**	**-------**	**-------**
Darjeeling	**Darjeeling- Bijanbari-Gok- Nayabazar Road Section, Darjeeling District**	**12**	**2**	**8**	**2**	**12**	**--------**	**1**

Source: Chakraborty [4]

Plate: 7 Kalijhora Landslides on June, 2015

Plate-8: Debris Fall near Pankhabari

Factors Effecting Earthquake and Landslide

After making intensive field survey in and around Pagla Jhora region and closely analyzing these facts, the main reasons for the gradual rise in the occurrence of landslides in this region can be summarized as follows:

Ustatic Movement

Since recordkeeping began in 1895, the hottest year on record for the 48 contiguous U.S. states was 2012and was also the 10th-warmest year on record. A report by the World Meteorological Organization released July 3, 2014, said that deaths from heat increased by more than 2,000 percent over the previous decade. One of the most dramatic effects of global warming is the reduction in Arctic sea(Fig.6) ice: In 2012, scientists saw the smallest amount of Arctic ice cover ever recorded. Most analyses project that, within a matter of years, the Arctic Sea will be completely ice-free during the summer months. Glacial retreat, too, is an obvious effect of global warming. Only 25 glaciers bigger than 25 acres are now found in Montana's Glacier National Park, where about 150 glaciers were once found, according to the U.S. Geological Survey. A similar trend is seen in glacial areas worldwide [12].

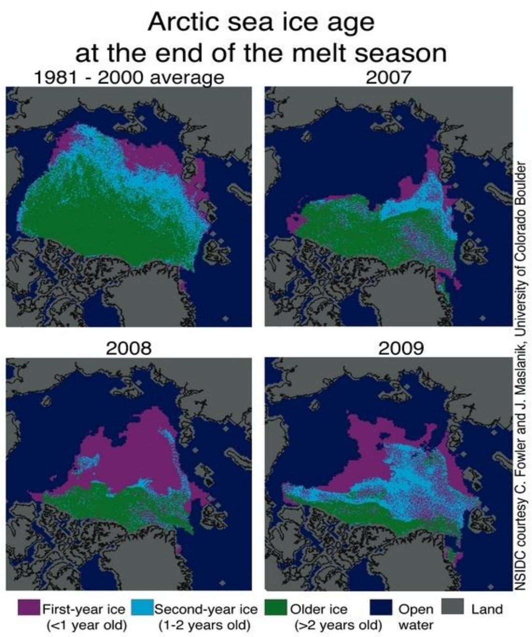

Fig-6: Ice Meltation of Arctic Sea, [12]

Due to meltation of ice, the water level of the oceans rises and creates huge pressure to the oceanic plate. The pressures are further injected to the Magma layer and help to create instability to the magma layer. Thus the plates move and create earthquake to the weaker zones like Himalayan Frontal Thrust.

Effects of Thrusts and faults

The entire zone is situated very near to Himalayan Frontal Thrust. Thus Earth quake as well as local shocks and vibration may cause landslides in most of the cases after the impact of moonsoon. It can cause maximum rapture and sliding in the Darjeeling and its Sorroundings.

Avalanche

The avelanches like Khumbu Icefall in 1996 and Lhotse Face toward the South Col of Everest in May 2012 can cause local shocks [13] and can kill the climbers.

Lakes or reservoir

The Senchal Lake is supplying more than 182000 m3 of drinking water to the Darjeeling to fulfil the demand of 10, 7530 people of Darjeeling town. At present only 8 out of 26 jhoras feeding the Senchal lakes are kept alive during the monsoons and the rest are cut off because there is no capacity to store. Thus other 18 Jhoras are being stopped which enhances much infiltration throughout the regions. The Rockville reservoir at the centre of the town above the railway station was affected by landslip in 1950 and it was feared that the reservoir also might be damaged and its bursting might cause further damage. The area that slipped involved only the superficial layer of sandy clay and boulders originally resting at an angle 40 degrees, which is greater than the angle of repose for such materials. Lubrications further lowered the angle of repose and caused the slip [9]. The huge pressure of the reservoir may influence the seismic activities of the area also.

Slope instability

The comprehensive and detail study of the geological setting of darjeeling and its surroundings reveals that high amplitude of relief combined with very steep valley side slopes makes the stability of slope highly vulnerable to mass movement [11]. Any change in the equilibrium between the shear strength and shear stress results into large scale landslides .The Daling series of rocks comprise of lingtse gneiss and mica schists with low permeability and low shear strength has lead to sinking of NH 55 at many intervals. As such, the onset of monsoon facilitates slope failure every year.

Soil

The Daling series clayey dark soils with high content of sand make the soil very weak and thus enhance the shearing stress and decrease the soil coherence. With the addition of water during long rainy season, the soil display high magnitude of expansions which in turn detaches the soil from its situ and causes soil creeps and debris fall around region.

Rainfall

The heavy shower during monsoon season in consideration with other host of elements is considered as the major factor. In fact, Pankhabari, Bijanbari, Tindharia, Pagla Jhora etc. are the wettest places in whole of Darjeeling Himalayan region. Being situated along the southern slope of Mahaldiram massif, south west monsoon winds strikes and causes plenty of rainfall. Thus, on an average 4198 mm of rainfall takes place with dry spell in between. However, some times this heavy shower lasts for 2 – 4 days, amounting to as high as 800mm rainfall with intensity reaching up to 100 mm per hour. Such severe rain lowers the slope stability and triggers sinking followed by slumping across the region. Simultaneous occurrence of rainfall .

Surface runoff and sub surface runoff

Owing to high slope intensity and high velocity Tista, Mahanadi, Kalijhora, Pagla Jhora etc. are playing significant role in propagation of landslide. Water percolating through the joints, cracks and pores of soil supplied by Jhora increases the hydrolysis process and produces good amount of kaoline clay which act like a lubricant, effects on run off and aid to further sliding of superficial materials as well.

Vegetation

The apex of the slide under the study area has long been deforested and turned into cultivated terraces with crops like large cardamom, potato and ginger being uprooted every year which further disturbs cohesiveness of the soil and makes it vulnerable to erosion. Thus, the slopes remains devoid of thick vegetation for lone period of time and gets fully exposed to heavy and concentrated monsoon shower making it susceptible both to sheet and gully erosion.

Anthropogenic activities

The change in the land use pattern is occurred due rampantly encroachment by unplanned constructions and deforestation of the district. The development of urban centers like Tindharia, Mahanadi and Ghayabari has brought drastic change in the morphology and land use pattern due to rapid explosion of population and the frequent movements of heavy vehicles over study region which has been increased considerably over the past. Such large scale construction and heavy vehicle movements are triggering mild to moderate tremors which in turn amplify and cause the risk of landslides. The frequent sinking of NH 55 and development of scars and cracks in and around the steep gradient slope of the district is to some extent human induced phenomena [14]. The exploration of dynamite for road construction can also inculcate the intensity of seismic activities as well landslides.

SOME MITIGATION MEASURES

Landslides with destructive nature can create havoc and catastrophic impact with in the short span of time. In order to prevent and control successive landslide incidents, following mitigation measures can be adopted:

Geological and Geo tectonic Investigation

Engineers mainly geologist, hydro-geologist, geotechnical engineers play a vital role. Before investigation it is need to know about spatial extent, historical data base, landslide type, shear strength characteristics, pore pressure variety, how far and how fast movement of debris took place etc. The term geological investigation covers both surface and sub surface attributes. The geological and geotechnical investigation took place in three stages i.e.

- Preliminary stage: In the preliminary stage the geological engineers should observe, investing and gather historical data base, remote sensing data (CARTOSAT-1 and 2), and field survey data.
- Geotechnical investigation stage: Geotechnical investigation includes slope analysis; tend to liquefy rock due to an earthquake shock etc. Co-seismic and post seismic landslide should be carefully investigated. The Indian Geotechnical Society (IGS) plays a vital role in this manner.
- Detailed geological investigation stage:Detailed investigation includes both surface and sub surface investigation. After surface investigation sub surface data including depth of bed rock, weathering limits, slip surface, permeability of strata, and depth of ground water table should be carefully investigate by the geologist [10].

Landslide Zonation mapping

It is one of most scientific and effective measures to control landsides. By identifying and mapping the landslide prone zone, drainage channels, scars and slope gradient etc, a specific mitigation strategy, emergency preparedness plan, allocation of disaster fund etc can be planned well before the disaster strikes the region. Such hazard mapping also helps to create awareness of risk and vulnerability natural disaster among the local people.

Treatment of slope confirmation

The relative heights and steep gradients of slopes are the limiting factors in the stabilization of sliding along the Darjeeling. Since the area is composed of weak rocks, unfavorable rock foliations on slopes make it highly vulnerable. A protective rock fill dumped on the surface of slopes, gravel fill protective retention wall, rock bolting and rock anchors, gravel pile walls etc can helps to increase the shear strength and abort sliding of the debris and rocks.

Maintenance of drainages

The surface drainage of Darjeeling is highly uneven hummocky and traversed by deep fissures. Thus, all streams and temporary water courses ion of surface drains to collect surface runoffs at different elevations, plugging of cracks and crevices to prevent runoffs to seep into the ground, construction of filters and drains behind the concrete and gabion walls to prevent loss of fines and safe passage of the surface runoffs will definitely lower the risk of landslides.

Vegetative covers

This is the cheapest and most effective way of arresting landslides. The growing of grasses and afforestation in the slope areas will help to prevent the slumping and debris fall. Illegal encroaching of steep gradient slopes for terrace farming should be checked and strict monitoring system should be implemented to check further deforestation on the isolated parts of the district.

Expansion of settlement

Unplanned construction of concrete structures over the geologically unstable slopes of Pagla Jhora area should be prohibited. Moreover, the mining activities practiced in the region must also be stop seeing the instability of the slopes. Nevertheless, people should be made aware about risk of disaster and encourage them to expand their settlements only on stable geological and tectonic part of the area and in this regards 'SAVE THE HILL' (STH), a group of concerned citizens are organizing the landslide awareness cum relief campaign across the Himalayan region of Darjeeling [14].

Traditional House Building Pattern

Due to the population pressure, increasing tourism industry the vulnerability of landslide increase day by day in Darjeeling hill. Planners, architect and engineers should design human settlement with consideration of ecologically fragile environment of the hilly area. Traditional three types of houses are quite safe i.e. *(**a**) Ikra; (**b**) Shing-Khim (c) kat-ki-kunni.* Satisfactory seismic performance of traditional construction typologies: house [15].

Plate-9: Ikra

Plate-10: Shing-Khim

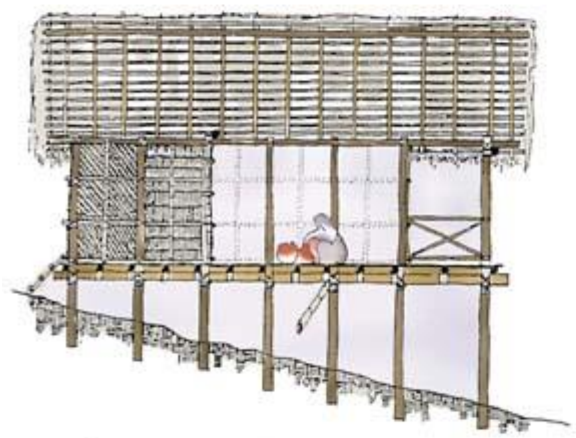

Fig-6: Construction design of ikra [15]

A massive earthquake had razed Shillong to the ground in 1897. This led to the creation of the 'Assam-type' construction that comprises bamboo frames, ikra(Plate 9) weed and mud plaster for walls, roofs of thatch or corrugated galvanised iron sheets. The walls, composed of wood posts, are spaced at 1.5-2 meters apart. A 15-centimetre diameter wood post beam supports the roof. A framework of bamboo with ikra reed panels is anchored to the frame from the walls. Ikra is normally plastered with mud or, sometimes, a lime mixture. The voids are in filled with plastered ikra reed or split bamboo panels, which keep the structure light. The 1950 earthquake in Assam was the real test of this technology.The quake measured 8.5 on the Richter, changed the course of the Brahmaputra river, submerged the old city of Dibrugarh, but the buildings were unscathed.

The merit of *kat-ki-kunni* (timber-cornered building) of Himachal Pradesh can be traced back to 1905, if not earlier. A massive temblor levelled every village from Dharamsala to Kangra. Measuring 8.0 on the Richter scale, it lasted two minutes and was felt over 416,000 sq km. But, buildings with *kat-ki-kunni* design in the Kullu valley survived, the design uses materials like timber and stone. The important feature is a pivoted wooden joint at special corners. This allows movement and takes care of tensile stress. Timber is one of the best materials for earthquake-prone areas, especially in the hilly areas of Himachal, Kulu and Kangra valley. Timber allows the flexible movement of forces[21].

Proposed House Building Patterns:

There are three models of constructing multi-storeyed buildings in the hilly region can be proposed on the basis of present study.

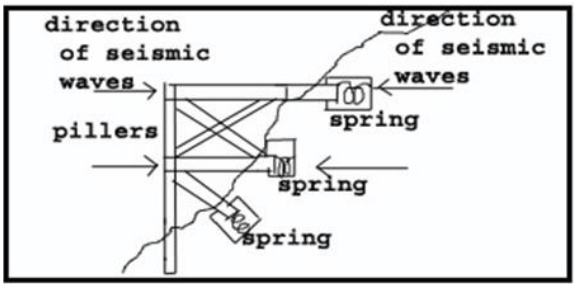

Fig-7: Construction of basement using spring and hydraulic

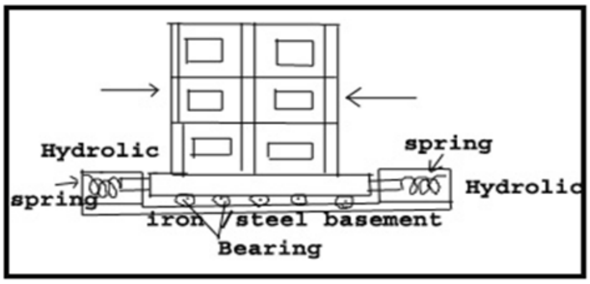

Fig-8: Construction of basement using bearing

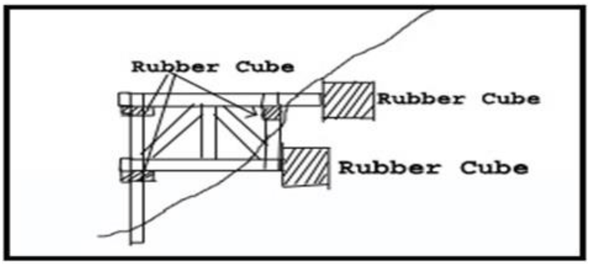

Fig.9 Basement of multi-storeyed building may be made with the help of rubber cube

The three models are architectures of three separate procedures to increase the stability of the multistoreyed buildings. The earth quake shocks mainly move from the epicenter laterally and thus there is very lesser chance to get vibration vertically from the below. The use of spring or Rubber in the proper place will increase the resistance of the building during the Earthquakes or the landslides. Other than that the bearing below the building over a metalled platform with hydraulic system can prevent the buildings during Earthquake in those buildings constructed in the relatively plain surfaces.

Road Constructions

The guard walls on the road can be constructed in such a manner in which the searing stress can be distributed and the normal infiltration will not be obstructed.

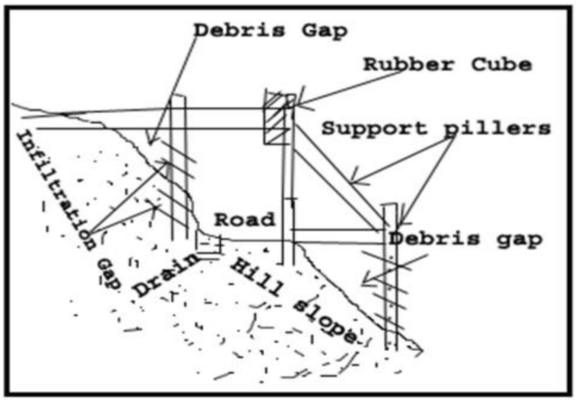

Fig-10: Road construction with Debris Gap

In Fig-10, there are some pillars constructed with guard walls in such a manner which can protect the damage from landslidings. There should have a *Debris Gap* which will work as storage of debris during the landslides. The slogan will remain as – 'Bigger the debris storage, lesser the damage' and the debris gap will have to be cleared on regular basis in the slide affected areas. The process suggested in the Fig.10 may be costly but it will protect the road for long times both from the Earthquake and the landslides. At the same time it will reduce the recurring costs of the roads in long run.

Warming Systems

Warning symptoms on landslide emerges earlier than the actual event. It is necessary to recognize these warnings. These signs are-

- Pattern of storm-water drainage on slopes, land movement, small slides, flows, or progressively leaning trees.
- Doors and windows stick or jams for the first time or new cracks appear in plaster, tile, brick, or formations of buildings.
- Landslide happens in areas where the ground or paved areas, such as streets or driveways, show slowly developing, widening cracks or where underground utility lines break or bulging ground appears at the base of a slope.
- Water breaking through the ground surface in new locations is another important sign.
- Tilting or movement of fences, retaining walls, utility poles, or trees tilt or move.
- In more advanced stage, a faint rumbling sound, cracking sounds of trees, knocking sounds of boulders might indicate moving debris. Collapse of mud, fallen rocks, and other indications of possible debris flow can be seen [10].

A model warning device can be injected in the depth of 2mts (Fig.12) which will alert the local people by red light and strong siren as follows:

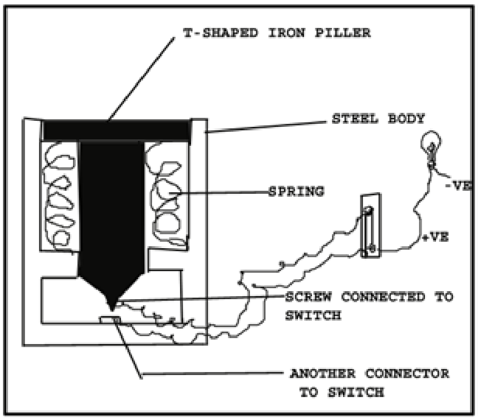

Fig.11: Formula of landslide model warning device

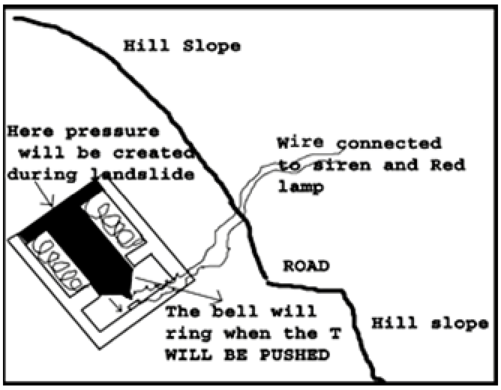

Fig.12: Utilization procedure of the said device

The 'T' shaped iron pillar connected with wire in one end, will get pressure during the landslide or earth quake shocks and it will move towards the knob set at the bottom of the device, will be connected with the wire in other end(Fig.12). Immediately after getting connection between the two wires(+ve and –ve) the light will start to blink and the siren will start to make violent sound. The people will be warned about the landslides or earthquakes and will go out from their houses/offices etc.

Reconstruction of Pipelines from Jalapahar

Nearly 100 m length of the topmost water pipe line located on the eastern slope of Darjeeling – Jalapahar ridge was damaged during 1950 monsoon. Slips had damaged and twisted the pipe at various places causing temporary stoppage to water supply. Such damages can be prevented burying them underground. This is however would be costly and frequent inspection is not possible [9] but it should be done for the sake of the people of Darjeeling.

Rules, Regulation and Enforcement

In India, It needs uniform rules for construction of buildings, dams, hydro electricity generation, mining, deforestation, land use pattern and tourism in the landslide prone hilly terrain. It is very unfortunate that some dishonest and corrupted politicians and officers are issuing license to the builders, planners, mining agencies, hydro electricity generating companies without considering the disturbance of environmental equilibrium and their further effect in the hilly terrain of study area. Though the Government allocated actual fund is too little and the government representatives declare lot of funds to the family of the victims for narrow political gain. We all know natural disaster cannot be delaminated by human effort but the losses may be minimized by allocating this fund before hazard by scientific improvement of land use pattern in the slide prone hilly terrain [10]. Plastic should be banned by making rules because it obstructs the normal drainage system of the town, creates stagnation of water, enhances more infiltration to the subsurface zone, reduces shearing stress of the soil and increases the risk of landslides.

Awareness

There is an immediate need to make local people aware about the landslide to reduce losses. The State Government, Uttarbanga Unnyan Parisad, Gorkha Hill Council, Organization like NDMA, IIT-Kharagpur, Local Schools, Local Hospital, Soldiers, Electronic and print media each and every body should launch comprehensive awareness programmed and campaign for the inhabited of landslide prone study areas. They should do and highlight the following points-

- They distribute handbills, posters in their regional language about the site and specific details of landslide with the experience of the past.
- They should prepare and display short video film, power point documentary for the local public about the importance of preparedness and mitigation method adopted by them before, during, and after the landslide disaster.
- The National Disaster Management Authority should launch power point presentation for Government organizations, Schools and Hospitals, Soldiers, NGOs, Local nodal agencies, Local clubs, and local people- about the role and responsibility before, during and after the landslide disaster.
- The land use planner, urban planner should make the local people aware about the importance of land use planning. The scientist and engineer should arrange awareness camp to increase geological, geo-hydrological investigation practice for contractor. They also make local people aware about the importance and use of eco-friendly building materials in landslide prone areas.
- The North Bengal University and colleges under this university should aware and encourage the students and research scholars providing necessary helps to research about the new method to mitigate landslide in the hilly terrain of Darjeeling district.
- The North Bengal Medical College associated with local hospitals should train as the Doctors, Nurses, staffs and locals how to respond in emergency period, as primary duty.
- They should develop awareness among the inhabited about the disadvantage of non-biodegradable materials.
- Media has a strong role which reaches all levels of society. Government should take the help of media for awareness programmed in the form of commercial advertisement, short documentary films, news analysis by expert etc. among inhabited, tourist and also it can reach grass root level of society [10].

Landslide Management Education from School Level

Landslide management including geo climatic region, landslide characteristics, landslide vulnerable zone, awareness and participation of students in the times of landslide etc. of their own particular area should be included in academic compulsory subject from primary school level of education [10].

CONCLUSION

Darjeeling is such a district which can be developed a lot on the basis of tourism Industry. The other options for developing the economy of the district are not enough because of its unfertile and undulating topography. Usually the tourists are interested to visit the areas having natural beauties, safety and security. If the mitigation measures which are recommended in the study can be made fruitful or effective in near future then the District may take an important role in West Bengal as well as India's economy. The slogan for the Hill-people of India may be aroused as 'Save Darjeeling to save the Queen and save the beauties',

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