Chapter - IV

L A N D S L I D E S

A. INTRODUCTION

With rapid urbanisation the town of Darjiling at present is experiencing a phenomenal growth in population 71,479 (Census, 1991). Moreover, as the Queen of Hillstations, it attracts a lot of tourists every year approximately 80,000 during the peak season. As a result of which during May to October every year the population of Darjiling town almost becomes double. To cater such an overwhelming population, pressure on the land for urban and tourists amenities, is ever increasing. Forests have gradually been eliminated, steep slopes generally unsuitable for human habitations have already been occupied and as a result Darjiling town has of late been turned into a concrete jungle without paying any heed to its ecological balance. Curiously, sliding which was a minor physical phenomena in Darjiling a hundred and fifty years ago, has become quite rampent now a days leading to great loss of life and heavy damage to land and property. Therefore, at present suggestion of remedial measures and their active implementation is of vital concern to the nation as a whole, for on it depends the ecological balance and geo-political stability of this extremely sensitive region.

1. Aims :

The aim of this chapter is to fill in the gaps of information regarding the subject with a view to finding the causes of this menace and suggest measures for its prevention. It hopes to fulfil a number of specific purposes, firstly to identify the causes and mechanisms behind various types of slips. Secondly to study the different slope failures during the last 100 years and the identification of landslip prone areas, to provide corrective measures and ensuring an all round protection against the menace . Finally the investigatior, has tried to undertakes a detailed study on Toongsoong area, the most vulnerable tract in Darjiling Town.

2. Methodology :

The methodology employed in this chapter is a rationalistic one, comprising of the quantitative determination of the instability factor of slope, careful analysis of soils, detailed tabling of the composition and orientation of geological structures and the examination of geomorphological processes involved in sculpturing land surfaces together with the study of the nature and extent of human interference. Data for such studies have been mostly collected by the author through intensive field investigation.

B. HISTORICAL BACKGROUND

Historically speaking, a hundred and fifty years ago, landslips in Darjiling town and its environs were a minor physical phenomena. Ever since, the British occupation, the physico-cultural set-up of this region has been seriously disturbed. Extensive and headless deforestation, haphazard construction works and inadequate drainage, in other words unscientific and unplanned usages of land have led to the establishment of the vicious cycle of denudation, heavy and concentrated rainfall aggravating soil erosion, landslides and associated phenomena (Basu and Sarkar, 1987).

From the available records, it may be said that the first disastrous landslip occurred on the 24th September 1899; when the unprecedented rainfall which occurred during the 23rd to 25th September, 1899, caused the loss of many lives (72 persons killed in Darjiling Town) and widespread destruction of houses, roads and property. After the disaster, the Government of Bengal had appointed a Committee to enquire the causes of the slips and suggest preventive measures (Griesbach's Report 1899-1900). The Committee had gone to show that the instability of the hill sides generally increased with the increase of saturation caused by absorption of moisture during a heavy shower (Table 4.1 and Fig.4.1) and the cutting of hill-slopes by natural and artificial needs, further increased instability.

The second major event of landslips in the town took place on the 15th January, 1934 due to the Bihar-Nepal earth-quake, which was responsible for widespread destruction though not of equal magnitude as was experienced during 1899.

On the 11th and 12th June, 1950, the hill slopes in and around the town was affected by disastrous landslips causing several deaths and heavy damages to roads, houses and public works, due to heavy shower from 10th to 14th June 1950 (Table 4.1). A.M. Ghosh (1950) was the first to give a scientific account of the landslips of Darjiling which was carried out just after the disaster. The next scientific study on the same disaster was carried out by Nautiyal (1951) followed by Dutta, Soudhi etc. (1966) of G.S.I.

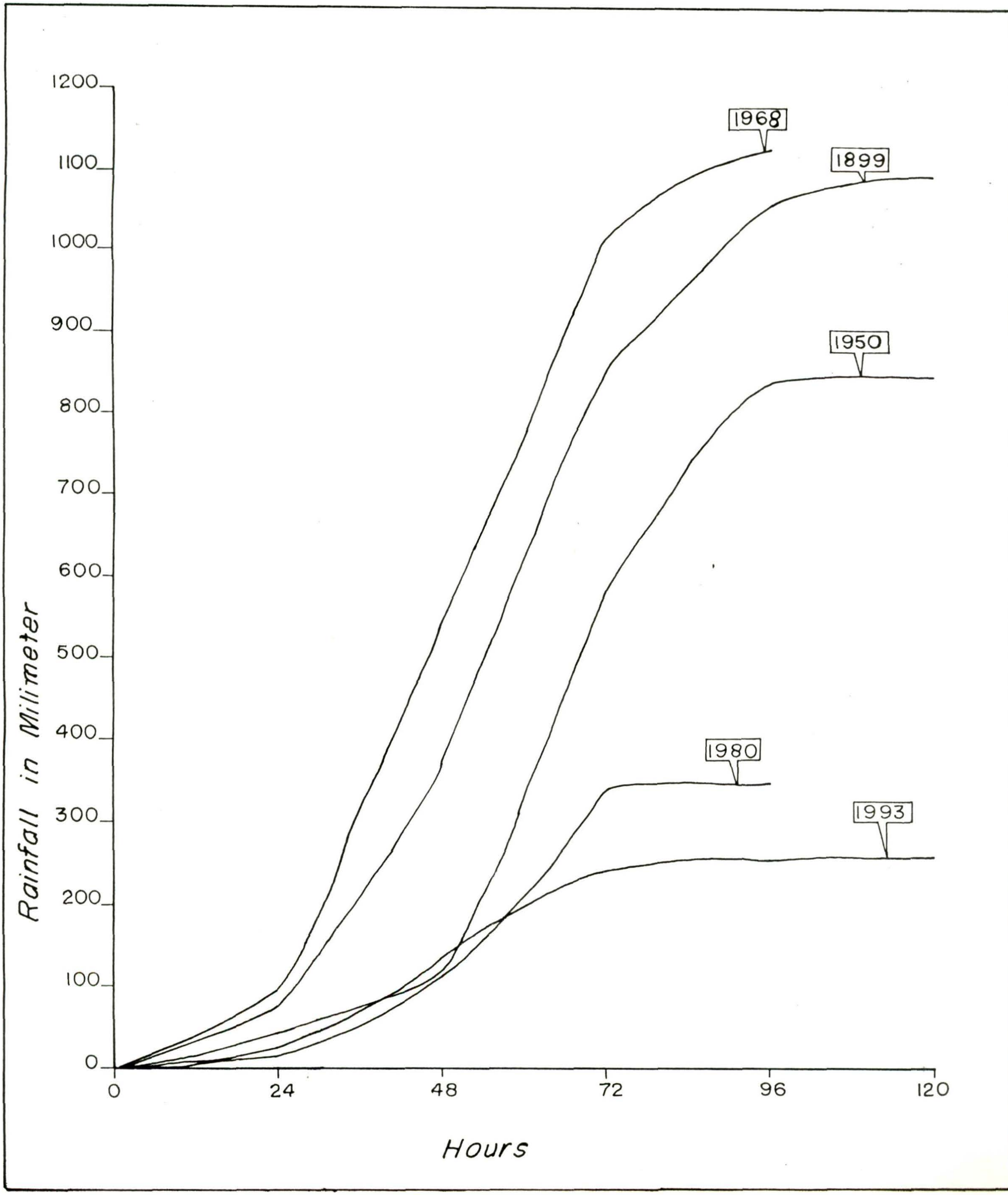
Darjiling town and its environs were again eclipsed with large scale landslips owing to heavy and incessant rainfall that continued

Table 4.1

Intensity of Rainfall during major landslips in Darjiling town

No. of days	Rainfall in mm	Cumulative Intensity
22-9-1899	76.0	76.0
23-9-1899	291.5	367.5
24-9-1899	485.0	852.5
25-9-1899	213.0	1065.5
Total 4 days	1065.5	1065.5
10-6-1950	14.1	14.1
11-6-1950	104.0	118.1
12-6-1950	462.0	580.1
13-6-1950	254.0	834.1
Total 4 days	834.1	834.1
2-10-1968	95.25	95.25
3-10-1968	439.42	534.67
4-10-1968	481.33	1016.00
5-10-1968	105.40	1121.40
Total 4 days	1121.40	1121.40
2-9-1980	45.0	45.0
3-9-1980	72.0	117.0
4-9-1980	222.0	339.0
5-9-1980	5.0	344.0
Total 4 days	344.0	344.0
10-7-1993	47.0	47.0
11-7-1993	87.5	134.5
12-7-1993	102.0	236.5
13-7-1993	15.0	251.5
Total 4 days	251.5	251.5

INTENSITY OF RAINFALL DURING MAJOR LANDSLIPS IN DARJILING TOWN SINCE 1899



Fig—4.1

between 3rd to 5th October, 1968.

The period between 1969 to 1979 was relatively undisturbed. But heavy and continuous rain on the 27th August and 3rd to 4th September 1980 again tiggered off widespread landslips in and around the township.

Since, 1980 onwards, it has been found that almost every year some part of the town has been suffering from major or minor landslips and thus, landslips have become an integral part of the urban life in Darjiling (Fig.4.2). Fig.4.2 and Table 4.2 show the major areas affected by 1899, 1934, 1950, 1968, 1980, 1991, 1993 landslips in Darjiling town.

Geotechnical investigations of the hill slops stability of Darjiling since 1964, have been carried out by the Geological Survey of India, in close collaboration with the engineers of the Project Swastik of Border Rd. Development Board. Amongst the recent and useful work, Nautiyal (1951 and 1966); Ramachandran (1966); Roy and Sensharma (1967); Basu (1969, 1970); Verma (1972); Paul (1973); Sinha, Verma and Paul(1975); Bandopadhayay (1980); Chatterjee (1983); Basu and Sarkar (1984, 1985 & 1987); Basu (1986); Sarkar (1990) etc. are noteworthy.

C. FACTORS, MECHANISMS AND MATERIALS OF LANDSLIPS

Darjiling Town is situated on a long spur, projecting north-wards from the Senchal-Singalila range. The general slope characteristics show that the percentage of area having high angle of slope (30 -45° or more) is more in the Eastern slope than in the

Table 4.2

Major Events of Landslips in Darjiling Town and the sectors & human beings affected

Dates of Major events of Landslips	Localities/Sectors affected due to landslips in Darjiling town	Remarks
	<u>Settlement Sector</u>:	
24th and 25th Sept. 1899	Toongsoong busty, Pradhan busty, Singamari, Hermitage, Eastern slope of the Observatory hill, Jalapahar, Alubari and below the Railway station. <u>Road Sector</u>: Jalapahar Rd., Tenzing N.Rd., Birch Hill Rd., Rangit Rd., Hill Cart Rd. and Lebong Cart Rd.	72 lives lost within the town (62 natives and 10 Europeans). The value of property destroyed amounted to lakhs of rupees. The precipitous eastern slope from Toongsoong busty to Observatory Hill experienced a series of devastating landslips. Most of the houses were destroyed.
	<u>Settlement Sector</u>:	
11th and 12th June, 1950	Jalapahar catonment, Pradhan busty, Mohar lal busty, Lebong, Hermitage, Toonsoong, Bhutia busty and Eastern slopes slopes of Katapahar. <u>Road Sector</u>: Gandhi Rd., Jalapahar Rd., Convent Rd., East Mall Rd., Birch Hill Rd., Lebong Cart Rd. and Lebong Circular Rd. <u>Railway Sector</u>: Large portions of Darjiling - Siliguri R.L. were washed and was not relaid until late 1951.	Several hundreds of people were rendered homeless, as the whole hill sides with buildings, farms and trees came down. The loss of life reported from the district was 127 out of which 100 was in the Sadar Sub-division alone. The slips breached the main arterial roads and the town was cut-off for 5 days from the outside world. Total stoppage of water and electricity. Tea gardens like Happy Valley, Bloom Field Pandam, Badamtang, Takdah, Glen Burn sustained ravages.

Date of Major events of Landslips	Localities/Sectors affected due to landslips in Darjiling town	Remarks
	Settlement Sector:	
3rd to 5th October, 1968	Lebong near Gompa, below Race course, Bhutia busty, Limbu busty, Toongsoong, around the Jail, Vineeta house(Jalapahar), Kotwali, Rajbari, Kagjhora, Butcher busty, Mayapuri and Manpari busty.	The Hill Cart Rd. was blocked at 18 different points and parts of National High Way No.31. was completely wipped out. Heavy loss of life and property especially in the neighbouring tea gardens.
	Road Sector:	
	Hill Cart Rd., Gandhi Rd., Lebong Circular Rd., Victoria Rd., Tenzing N. Rd., Tonga Rd. and Acharya Jagdish Ch. Bose Rd.	
	Settlement Sector:	
3rd and 4th Sept. 1980	Opposite Glenery's near Planters hospital, Toongsoong, Bhutia busty, Manpari busty, near Mt.Hermon School, Butcher busty and below the railway station.	Heavy loss of life, damage of dwelling houses and disruption of communication. Drinking water and electricity disrupted. In some areas of the district helicopters had to be sent to help the affected people. According to the Dist. report (1980) the total damage to the property amounted to 647.90 lakhs.
	Road Sector:	
	Hill Cart Rd., Lebong Circular Rd., and parts of T.N. Rd.	
	Settlement Sector:	
September 1991	Almost all old sites. Near missionary of Charity, below Birch Hill near North Point College. Toongsoong and Singamari.	Two people killed. Drinking water stopped in certain parts of the town. The Darjiling-Siliguri railway line had to be stopped for some months.
	Railway Sector:	
	Certain parts of Darjiling-Siliguri railway line.	
	Settlement Sector:	
13th July 1993	St. Paul's School behind the Padry's graveyard.	Disruption of water pipes as a result certain parts of the town could not get water for more than 15 days.
	Road Sector:	
	Certain parts of Hill Cart Rd., Jalapahar Rd. near Youth Hostel, and near Cathrin Villa.	

CHRONOGICAL INCIDENCES OF LANDSLIPS IN DARJILING TOWN

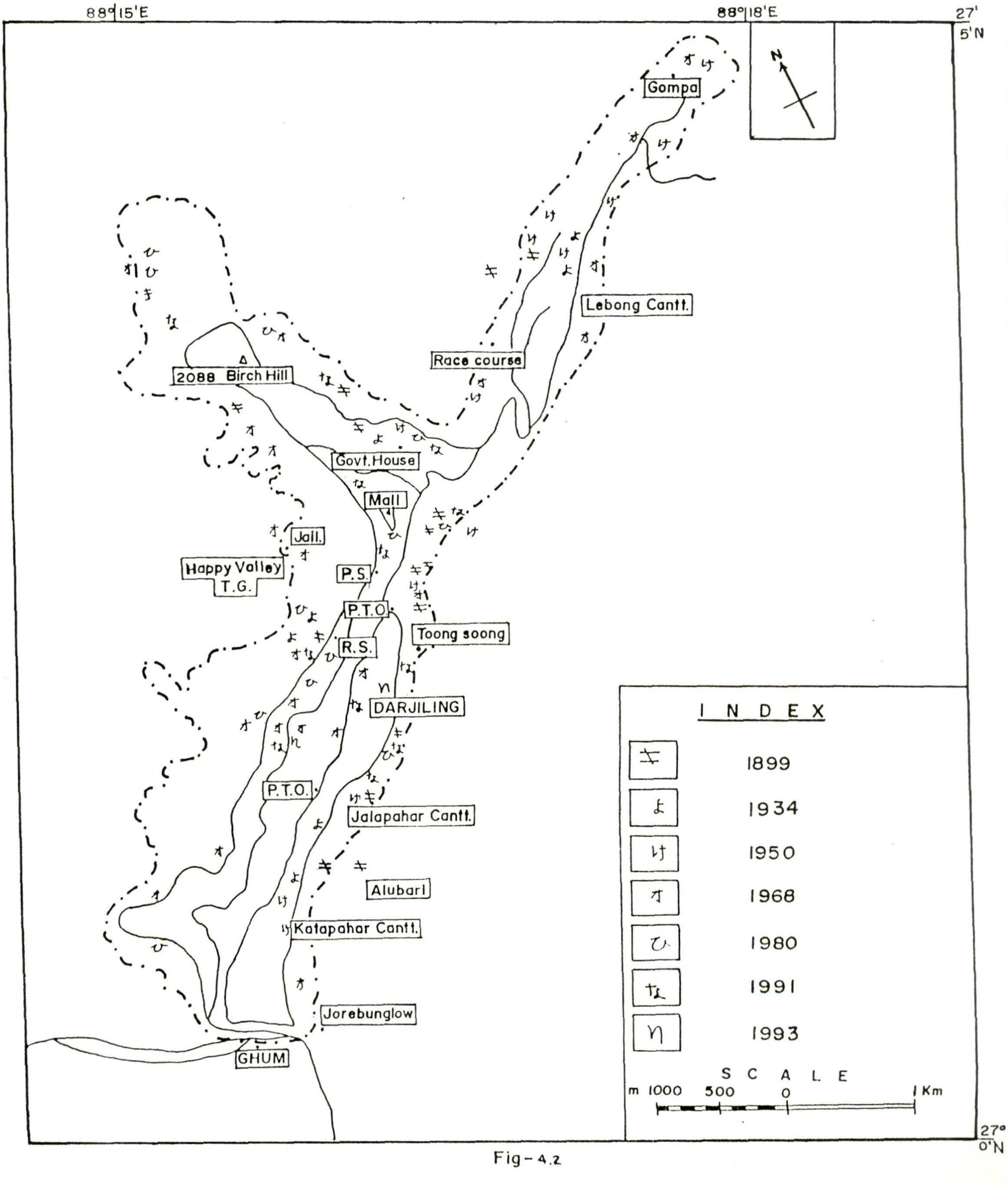


Fig-4.2

Western or Northern slopes. But low angle of slope (12 -22° or less) covers more area in the Western and Northern slope than in the Eastern slope. The rocks have a general NNE-SSW strike and dip at variable degrees towards the West in the Eastern slope and towards the east in the Western slope. The rocks are highly puckered and jointed and the joint sets divide the rock mass into blocks of variable dimensions. (S.B. Sen Sarman and S. Ray, 1968). As a result blocks of rocks are generally found encircled on all sides by highly weathered rocks of the nature of clay. The parts of the hills usually affected by landslips are either composed of soft rocks such as schists, shales and clays or support thick mantles of soil and weathered rocks on steep slopes. The thickness of the waste cover varies between 0.5-2.0 m on the steep deforested slopes, from 2-4 m on the more gentle slopes and in the forests. It ranges even between 6-10 m. on the flattened spurs. Most of the landslips affect only the thin-veneer of unconsolidated soil and scree along the eastern, north-eastern and north-western slopes (L. Starkel, 1972). The differentation of the type and intensity of the slips is related to the seepage pressure of percolating water, steepness of the slope and the thickness of the waste mantle. The flows occured on slopes with an inclination mostly of 25 -45°, the mantle being sufficiently thick. Where the infiltration was deep, no flows occured, large debris - rock slides formed there (L. Starkel, 1972).

D. MAJOR TYPES OF SLOPE FAILURES

Darjiling town and its environs is characterised by various types of slope failures. It has been observed that each landslip has its own peculiarities, therefore, for the rational solution of the

4.1 Leaning trees showing the unstability of the slope.

4.2 Unstable slope utilised for housing above the Lebong Cart Rd.

problem it is imperative that the mechanism and the causes responsible for slope failure should be apprehended properly. The following are the important types of slope failures that have been recognised by the investigator in Darjiling town.

1. Creeps :

The slow downslope movement of superficial soil or rock debris is called creep. This is usually imperceptible except to observations for long duration. The study area possesses many types of field evidences which have been held to demonstrate the existence of soil creep including outcrop curvature, tree curvature, tilting of structure i.e. telephone posts, electric posts, fencing wall etc. and cracks in the soil (Photo 4.1 & 4.2). A good example of creep is found along the slopes below the Hill Cart Rd., near West Point. Another can be found on the slopes above the Lebong Cart Rd. near Loreto Convent and further north along the same road. Also on the slopes just below the Jalapahar Rd., above Mt. Everest Hotel. Any slope formed of unconsolidated material such as residual soil or rock debris creep may develop into a slide and the slide may be followed by creep. Typical rock-creeps have been identified in the north of Mall round, just above the Central School and near the Cemetry above the Lebong Card Rd. (Photo 4.3 & 4.4).

2. Slumps :

Slumps generally have curved failure planes, and involve rotational movement of soil and rock materials. Slumping along many roads within the study area may be either due to the removal of basal support by water action or by overloading. Another potent cause of such slumping in the urban centre is due to human carelessness i.e. leakage in water pipe lines of the municipal water works (Photo 4.5 & 4.6).

3. Soil Slips :

The soil slips are generally of a small magnitude regarding their lengths and their affected areas. Such soil slips are very common and in fact found almost everywhere within the town particularly along the western spur of the ridge. (Photo 4.7).

4. Debris Slides :

Debris-slides are generally of greater magnitude and are quite common and devastating too. Debris-slide is caused along the weak plane even when they have gentler inclinations than the "angle of sliding friction" by the reduction of cohesion due to weathering and the rise of piezometric head (Photo 4.8).

5. Rock Slides :

Rock slides occur along certain definite planes. They may be bedding planes, foliation planes, joints and also shears or other planes of weakness of a tectonic nature. For slips to occur, such planes should be steeper than the slope and their inclination sufficient to counteract the resistances offered by the rock. The resistance to sliding is due to (i) friction, (ii) cohesion between the mineral constituents of the contact layer and (iii) rise of the piezometric height (h) during rain-strom. When, the weak planes exceed the "angle of sliding friction" and less than the slope, rock slide may occur.

4.5 Digging out soil leads to the loss of basal support.

Water erosion in the subsoil 4.6 leading to caving of roads.

4.7 Mud flow and debris slide near Lebong.

4.8 Tonga Rd. (New Rd.) Landslip.

6. Mud-rocks Flow :

Most slips found in and around Darjiling town are confined to the slopes formed of talus material and where the slope angle is slightly more than 40°. Slips in most materials occur by seepage pressure of percolating water as a result of heavy rain-strom. After a slip starts, the saturated material rushes down transporting big blocks of rocks eroding the channel of its own. These are known as "Mud-rock flows". Hence in the talus slopes though the angle of 40° appear to be within the safe limit, the incidence of clay materials within the talus derived by weathering of the biotite-rich bands tend to prevent drainage thereby permitting an increase of seepage pressure. Mud-rock flow is very common in and around the town, particularly along the natural and artificial water-ways.

E. LANDSLIP PRONE AREAS

In order to identify landslip-prone areas it is relevant to distinguish between the environs and the site. Those environs where landslips may be expected to occur, have been identified from Topographical Sheets 78A/4 & 78A/8 and from the past incidences. Site on the other hand, refers to the exact location of a particular landslip along a specific slope. For the identification of such a site, investigation can be made with a "check list" (Appendix I) where, each separate and individual slope unit may be classified according to their stability rating. Rating has been done according to a scale from stable through the degrees of potential instability to those slopes which have already failed. Special attention has been paid to the old slips which could become reactivated.

In the present study, however, the excavation position and depth, drainage diversion across the hills, loading of the upper slopes and valleys, cutting up of basal support, unscientific urban constructions,terracing, deforestation, legacies from the past slope movements, relief, drainage, materials etc. have been accounted for in the "check-list." Data for such investigation has been collected from the direct field observations (35 sample sites) as well as from other secondary sources and a map has been prepared for landslilp-prone areas (Fig.4.3).

The map as represented in Fig.4.3 shows some striking features such as some tracts, especially along the eastern slopes Jalapahar-Katapahar-Birch Hill-Lebong ridge posses a very high susceptibility to landslips while, the ridge itself shows a moderate to moderately low susceptibility to landslips. In this context it is interesting to note that the study of soil erosion (Chapter III) also shows a more-or-less similar trend. However for a better understanding of the geographical distribution of landslip-prone areas, the following categories of susceptibility have been put forward :

<u>Class I</u> : Extremely high slip-prone zone : These are the areas where landslips are very common, almost after every torrential rain these tracts experience slips. They are mostly found on the eastern slopes of Jalapahar-Katapahar ridge mainly covering the areas like Alubari, Manpari busty, Toongsoong, Pandam tea garden, Bhutia busty and Hermitage. The eastern slope of Lebong spur around Ging and Bannockburn tea gardens and in small pockets on the western slope of the Lebong spur i.e. Pattabong and Rangit tea gardens. It is also

found along the western spur of the town i.e. below the Jail and the southern part of the town below Batasia.

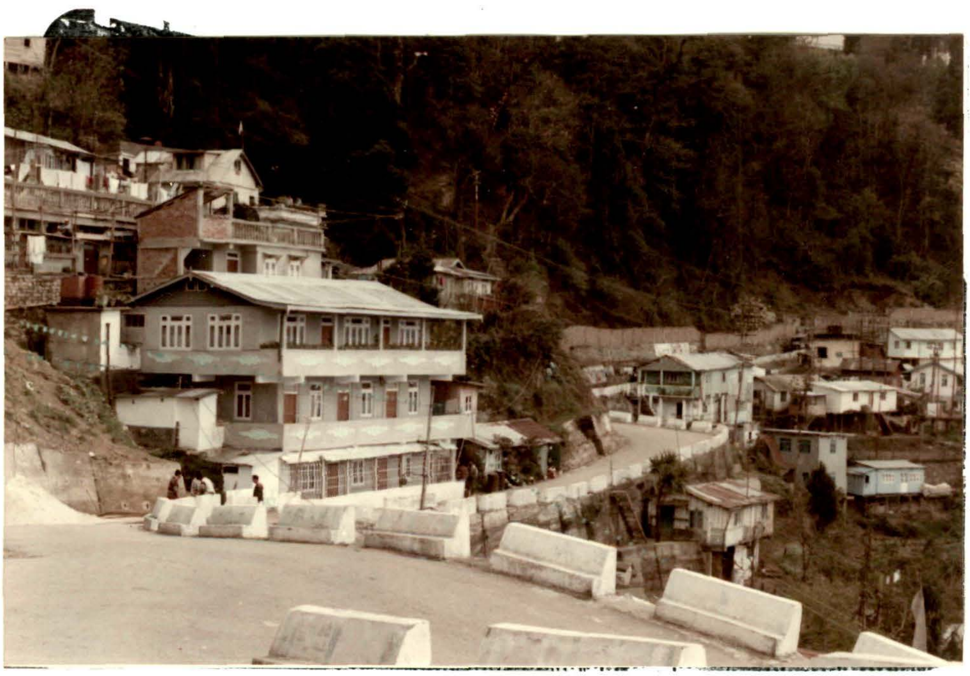
<u>Class II</u> : Very high slip-prone zone :
These are the areas where the slips occur for more than five times in ten years. They are found along both the eastern and western slopes of the ridge i.e. upper Alubari, upper Toongsoong, along the Tenzing Norgey Rd., C.R. Das Rd., eastern slopes of the Mall, below Raj Bhawan (Govt. house). It is also found in both sides of the Lebong spur, mainly the tea gardens like Bannockburn, Rangit and Pattabong. On the western slopes of the ridge it covers Rajbari busty, Kagjhora, Victoria Falls, Dr. Zakir Hussain busty, (Butcher busty) Dhobi tala, around the Jail, below the Railway station, Lochangar, Haridashatta and Singamari.

<u>Class III</u> : High slip prone areas : It mostly covers the town area i.e. the western spur of the town along the Hill Cart Rd., Gandhi Rd., Nimkidara, Police line, Mary Villa, Mayapuri, Upper Kagjhora, below the Convent cemetery, Dr. Zakir Hussain Rd., along the Birch Hill spur and the Lebong spur. Here the landslips occur between 2-5 times in ten years.

<u>Class IV</u> : Moderate to low : In this zone the landslips occur between 1-2 times in ten years. It is found mostly along the ridges of Jalapahar-Katapahar upto the Mall, including the Bazar and also along the Lebong spur including the Lebong Cart Rd.

<u>Class V</u> : None to Negligible : These are the areas where the landslips are said to occur for less than one time in ten years. It is found in pockets on the ridge tops of the Jalapahar-Katapahar

4.9 Massive construction at upper Toongsoong (for commercial purpose)



4.10 Vulnerable slopes being utilised for construction in upper Toongsoong.

GENERALISED MAP OF LANDSLIP- PRONE AREAS
IN AND AROUND DARJILING TOWN

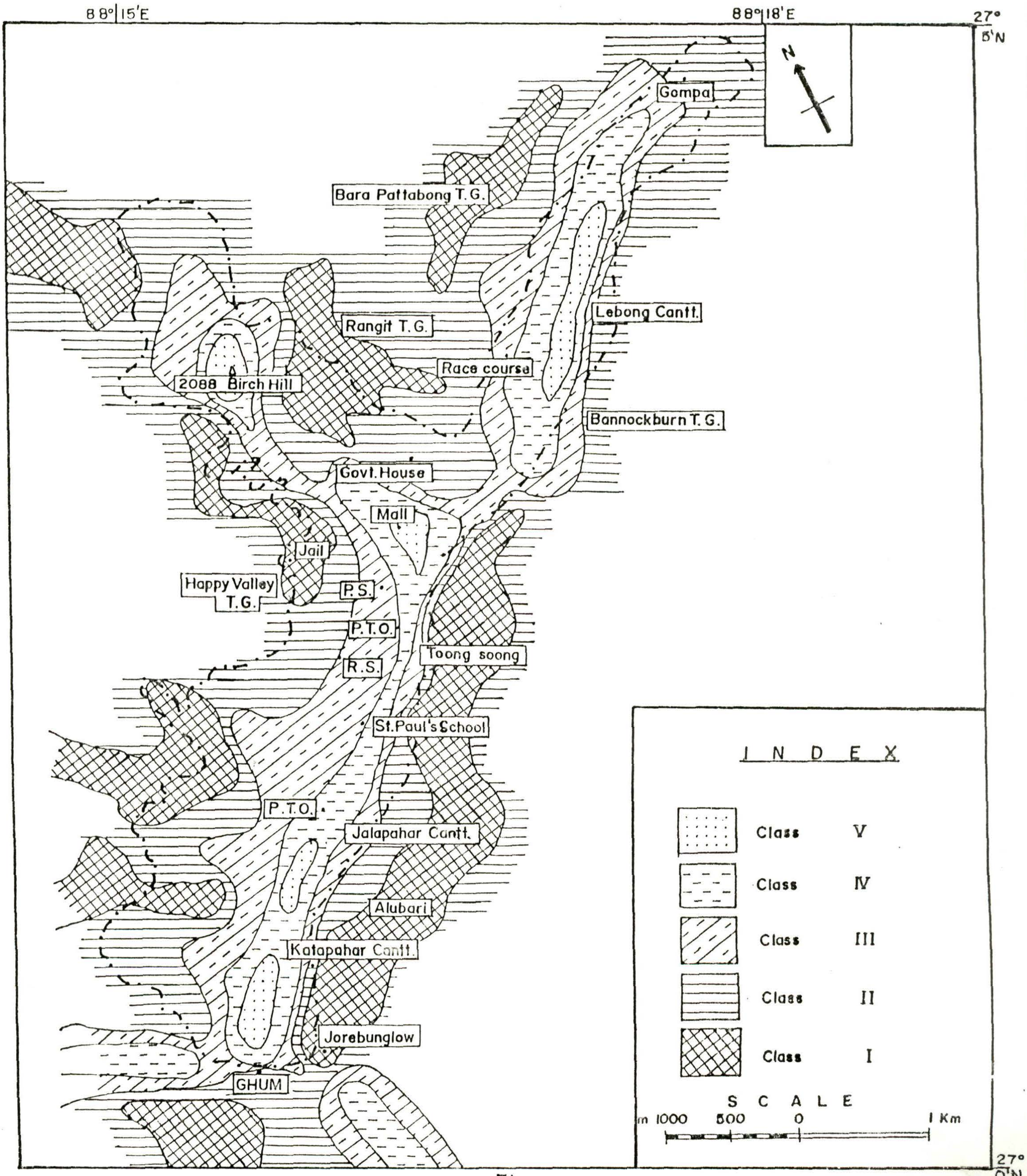


Fig – 4.3

4.11

Landslips behind St.Paul's School above Tenzing N. Rd.

4.12

ridge, the Lebong ridge (military cantonments) and the Observatory Hill and the top of Birch Hill ridge.

F. CASE STUDIES OF SELECTED SITES

From the foregoing analysis it is clear that the eastern slopes and spurs of the Katapahar-Jalapahar ridge i.e. Toongsoong and Bhutia busty of Ward No. 7 and 9 have most seriously been affected by landslips and related phenomena since 1899. After the 1950 disaster, the G.S.I. Scientists advised not to allow any more construction along this slope. But, construction has been carried out even along the disturbed slopes and at present the investigator has noticed many new massive constructions of both residential and commercial nature, during the field study (Photo 4.9 & 4.10). Consequently, landslips have become more frequent and since 1980, almost in every year the Toongsoong and Bhutia busty have been affected by landslips of different magnitude and intensity (Photo 4.11 & 4.12).

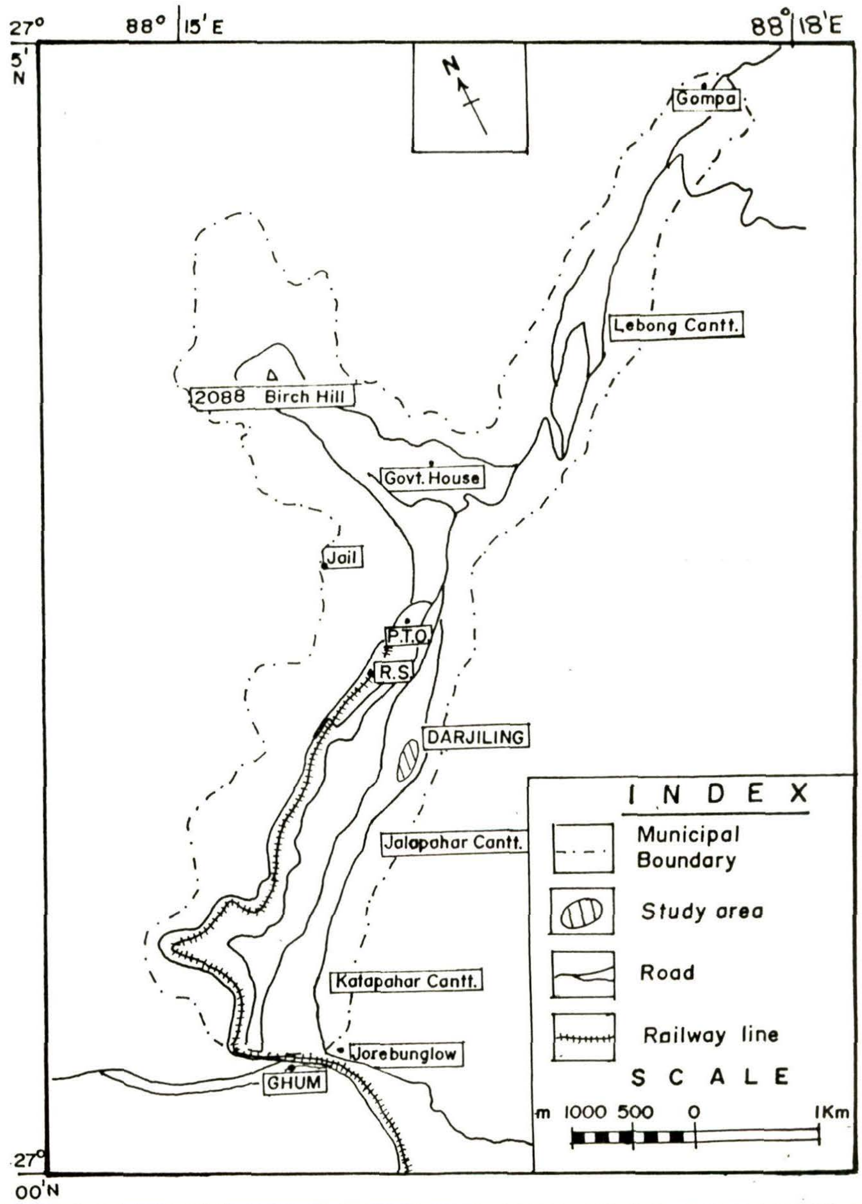
1. Slope Stability study of Toongsoong area :

The present investigator, has conducted a detailed study of this area in order to apprehend the exact sequence of landside and to understand the mechanism behind the failures. The area between Monpure and Dingle jhora, below St. Paul's School (Ward No. 7) has been surveyed in detail for preparing maps at a scale of 1 : 2500; covering an area of approximately 0.5 sq. km. (Fig.4.4).

a) <u>Geology of the area</u>

The study area is composed of Darjiling gneiss which is by

INDEX MAP OF TOONG SOONG



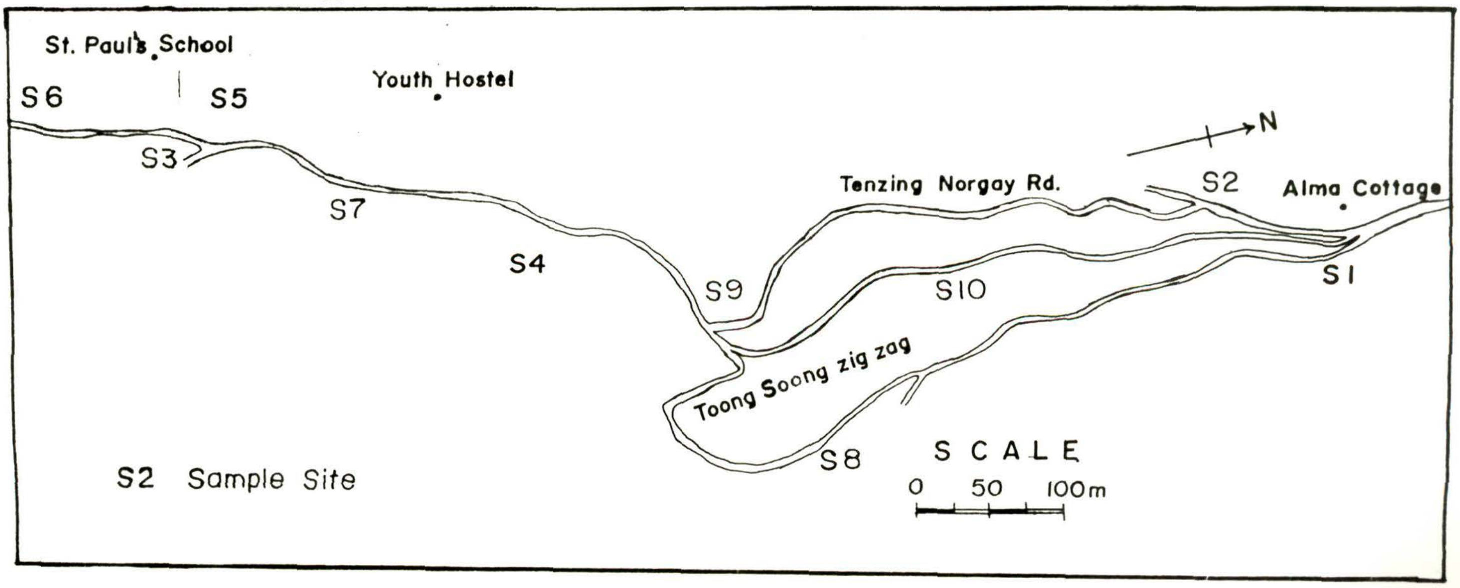


Fig-4.4

nature highly weathered and jointed both horizontally and vertically (Fig.4.5). The slopes below the St. Paul's School from Dingle jhora and beyond have huge blocks of dislodged rock mass, resting on soil. Here, the slope is about 60°, covered by luxuriant growth of Dhupi (Cryptomeria japonica) tree and are less disturbed by human activity. The slopes become gentle (35 -45°) towards the ridge, upto the Tenzing Norgay Rd. The vertical rock face below St. Paul's School show joints. Joints are sub-horizontal E-10, N-S, NE-SW, N50W-S50E and the inclined joints trend N75°W-S75°E, 15°S, N25°E-S25°W and N30°W slip 6° towards N60°W and N10°E dip 25° towards S80°E.

The gneisses are faulted at least in two places, near the Toongsoong zig-zag Rd. with an attitude of N50°W-S50°E dip 50° and near Dingle jhora with an attitude of N40°E-S40°W dip 50°. Some garnetiferous gneisses and granites with pegmatitic veins i.e. tourmaline and muscovites are seen near the zigzag on Tenzing Norgay Rd. (Bandopadhyay, 1980).

The rocky slopes and hill tops show a mantle of brown sandy micaceous soil with rock fragments varying from large blocks to boulder and pebble sizes. The thickness of soil at the hill top ranges from 3 to 7.7 m. near the Youth Hostel on the Dr. Zakir Hussain Rd.

Schistosity in the gneisses varies from N-S to N60°W and the amount of dip 15° to 20° (Bandopadhyay, 1980). The rocks are also highly jointed.

b) <u>Slope characteristics and Soil Development</u>

Weathering affects the parent rock (gneiss) conspicuously.

Both diurnal and seasonal ranges of temperature characterised by alternate expansion and contraction, gives rise to cracks and the solid rock mass disintegrate into blocks. High rainfall coupled with adequate temperature helps in decomposing feldsper to form Kaolin which often act as a lubricant for further sliding of rock materials.

The changing profile of a rock involves the removal of material from the crest through chemical and mechanical breakdown. In the Toongsoong slope, both rock out crop and the soft zone prevail. The thickness of the soil profile varies from 3 to 9 m. and on these slopes there is a clear indication of deep weathering (Photo 4.11). Here two types of soil have been identified.

i) Micaceous sandy soil with poor cohesion, found along the bare slope and ridge and

ii) Brown clayey soil with decomposed minerals like mica, sand, feldsper etc. having good cohesion is found under forest cover.

c) Rainfall

Fortunately, a good number of rainfall recording stations are situated in and around the study area. An analysis of rainfall statistics of recording stations at St. Paul's School, Bloomfield, Arya, Tukvar, Barnesbeg and Planter's Club show that the annual rainfall ranges between 4200 mm to 2560 mm in the study area. Rainfall is concentrated within the 5 moonsoon months, (June to October) about 85% fall during these months. High intensity rain-strom associated with 'cloud burst' (20 mm/h^{-1}) is also quite frequent and perhaps these constitute the "trigger mechanism" for slip to initiate.

d) Field and Laboratory analysis

The following field tests and laboratory analysis have been carried out :

Cone Penetrometer and Vane shear tests have been carried out in the field while, 10 samples from different sites (Fig.4.4) were taken to the laboratory, Dept. of Geography & Applied Geography, North Bengal University, for the analysis of grain size, consistency limits, moisture content etc.

e) Results and Discussions

i) Cone Penetrometer Test

Cone penetrometer test (field type) made in the field show that the penetration resistance ranges between 4.1 kg/cm^2 to 7.1 kg/cm^2, upto a depth of 1 m. The penetration resistance in the field showed a rather narrow range, which is the ability of the layer to sustain load.

ii) Vane Shear stregth

This study has been conducted with the help of a Vane Shear Apparatus (field type) at 2 sites and the G.S.I. had conducted a study on 3 sites (1980) and these are represented in the following table 4.3.

The field Vane Shear strength results range between 0.43 kg/cm^2 to 1.68 kg/cm^2 and the laboratory results range between 0.138 to 0.510 kg/cm^2. In cone penetration study, the resistance have been estimated to range between 4.1 kg/cm^2 to 7.1 kg/cm^2 upto 1 metre

Table 4.3

Vane Shear strength of Soil in Toongsoong busty

Sl. No.	Localities	Undisturbed Soil ($S=kg/cm^2$)	Remoulded Soil
1.	Near micro wave tower*	1.68 kg/cm^2	0.138 kg/cm^2
2.	Near Youth Hostel*	0.72 kg/cm^2	0.174 kg/cm^2
3.	Below Toongsoong zigzag*	0.43 kg/cm^2	0.510 kg/cm^2
4.	Near St. Paul's School	1.09 kg/cm^2	
5.	Near Dingle jhora	0.57 kg/cm^2	

*Estimated by Bandopadhyay, 1980.

depth. Bandopadhyay (1980) mentioned, that taking a safety factor of 3 the maximum bearing capacity can be taken as 2.2 kg/cm^2 corresponding to the three storeyed buildings.

iii) Mechanical Analysis

The mechanical analysis has been carried out at the Pedological laboratory, Dept. of Geography & Applied Geography, N.B.U. with the help of a Row T p Shaker. The analysis show that the predominent fraction in soil is the sand fraction lying between 0.6 to 2.0 mm in size (Table 4.4). Texturally, the soil may be defined as loamy sand to sandy loam.

Thus, it has been apparent that the soil of Toongsoong slopes, lie in the sand grade between 0.06 to 2 mm i.e. fine to coarse sand. The silt fraction ranges between 6.63% to 16.81% falling in the coarse silt grade.

Table 4.4

Mechanical Analysis of Soils in Toongsoong busty

Sample No.	Over 2 mm	1 mm to 2 mm	0.5 to 1.0 mm	0.25 to 0.5 mm	0.125 to 0.25 mm	0.063 to 0.125 mm	Below 0.063 mm
1	14.94	6.89	12.64	32.18	16.09	1.14	16.09
2	49.79	11.61	10.78	13.87	7.46	6.41	6.63
3	42.59	7.40	11.11	14.81	11.11	1.85	11.11
4	21.23	7.07	14.15	21.23	14.15	5.30	16.81
5	41.02	10.25	10.25	14.10	8.99	5.12	10.25
6	19.29	21.68	15.66	18.07	12.04	6.02	7.22
7	25.58	8.13	12.79	22.09	13.95	6.97	10.46
8	43.41	8.05	12.12	15.91	8.31	4.12	8.01
9	24.01	7.93	14.15	10.82	17.91	8.31	16.41
10	12.05	5.76	10.15	19.81	18.71	6.93	25.93

iv) Consistency limits

The consistency limits of different soil samples have been carried out at the Pedology laboratory, Dept. of Geography and Applied Geography, N.B.U. with the help of a Motorised Liquid Limit Device. The analytical results have been represented in Table 4.5. The consistency limits of the soil as expressed by the the pasticity index ranges between 7.54 to 10.94 showing a rather narrow range.

v) Seismicity of the area

Earthquakes of different magnitudes may induce landslips in many parts of the world. In 1934 the famous Bihar-Nepal earthquake induced large scale landslips in and around Darjiling town. However

GEOLOGICAL MAP

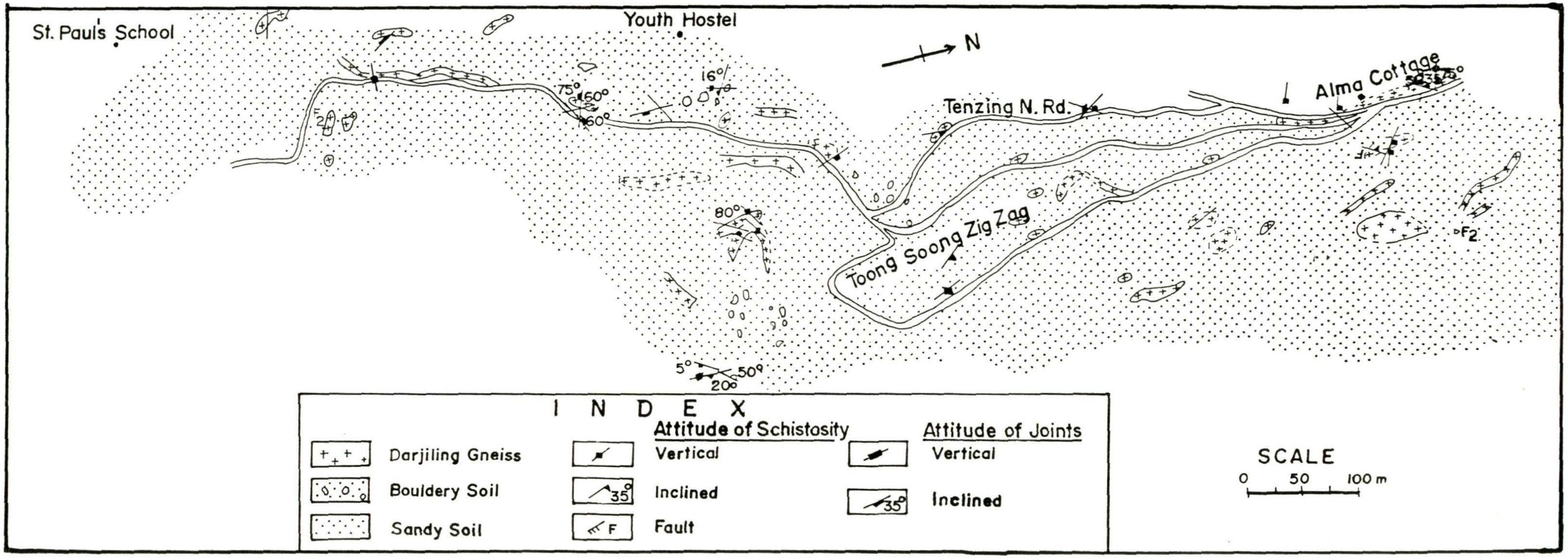


Fig – 4.5

Table 4.5

Consistency limits of Soils of Toongsoong busty

Sample No.	Moisture content in %	Liquid Limits	Plastic Limit
1	13.63	39.66	28.70
2	12.35	30.09	24.06
3	29.87	43.47	37.36
4	16.27	45.34	37.74
5	11.11	41.08	35.50
6	12.86	38.08	30.54
7	15.34	41.71	35.86
8	27.51	41.75	36.32
9	14.73	39.89	29.39
10	13.93	36.75	28.75

most of the devastating landslips in Darjiling (1899,1950,1980 etc.) were definity not earthquake induced. According to the seismic zone map of India, prepared by the I.S.I. (1970) Darjiling area falls in zone v and the soil type is (Type T). The horizontal seismic coefficient will be 0.08. According to Bandopadhyay (1980) this coefficient should be taken into consideration while formulating the design. There is a complex interaction between the effects of soil type, soil depths, the amplitudes of ground motions, the frequency characteristics of ground motions and the structural characteristics of buildings. The performance of engineering structures may be viewed in the light of the above analytical factors.

TOPOGRAPHICAL MAP OF TOONG SOONG

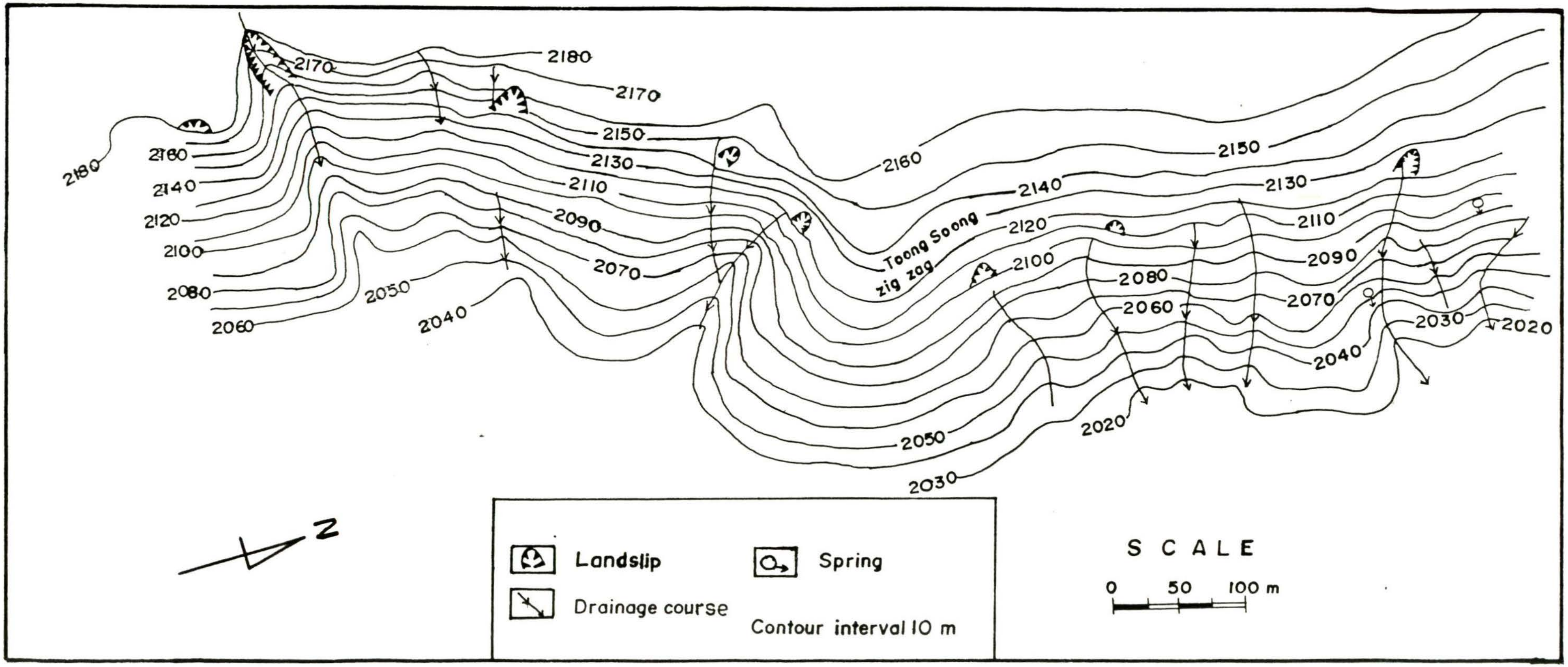


Fig -4.6

f) Geotechnical Assessment of Toongsoong area

The rock and soil materials of Toongsoong slope have undergone a reduction in shear strength, primarily through losses in cohesion. Mechanical breakdown of rocks produce debris and then chemical weathering promotes minerological changes, thus producing clay minerals, iron, aluminium, calcium etc. In this way there is a continuous process of sheer strength reduction of the slope material in the study area.

The aim of this study is to demarcate the stability of Toongsoong slopes for various urban uses. Three maps have been prepared (Fig.4.5, 4.6 & 4.7) and analysed for the geotechnical assessment of this area.
i) Topographical Maps, ii) Geological Map and iii) Geotechnical Map.

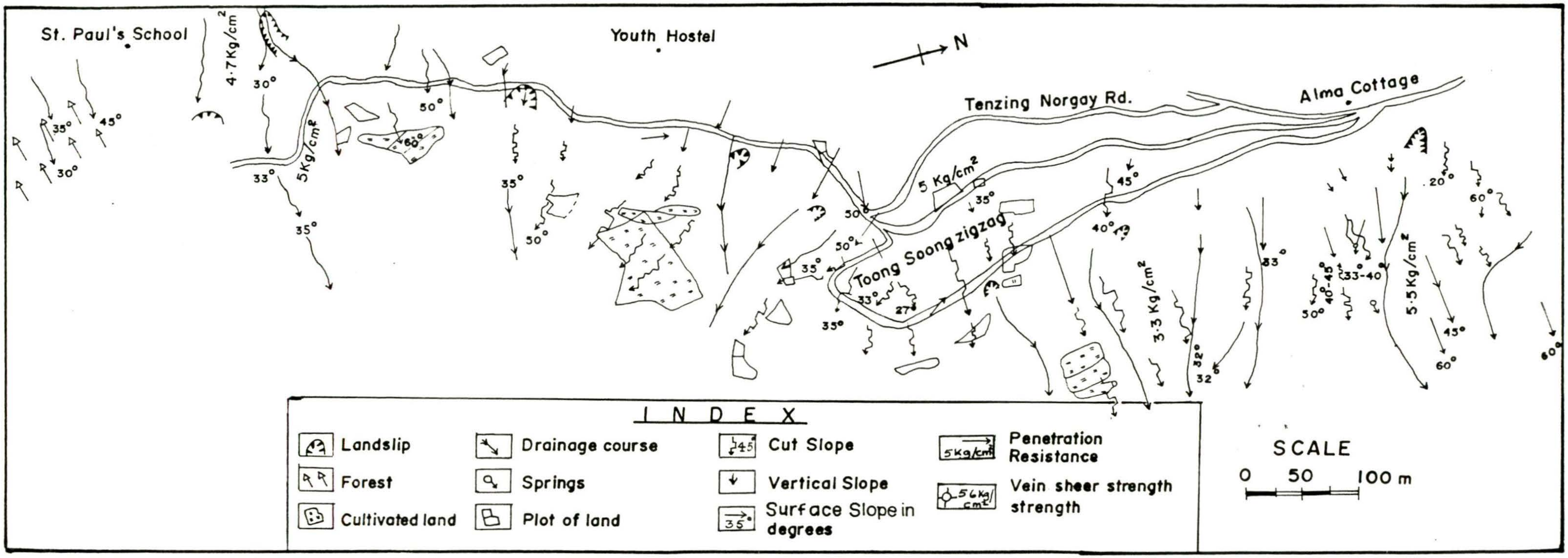
i) Topographical Map analysis (Fig.4.6)

A topographical map with a contour interval of 10 mts. and a scale of 1:2500 has been prepared based on an intensive field survey along with materials compiled from Darjiling guide map (1:10,560) and topographical sheet 78A/4, 78A/8 (1:50,000). The map (Fig.4.6) shows the contour lines, landslip scars, springs and waterways.

ii) Geological Map analysis (Fig.4.5)

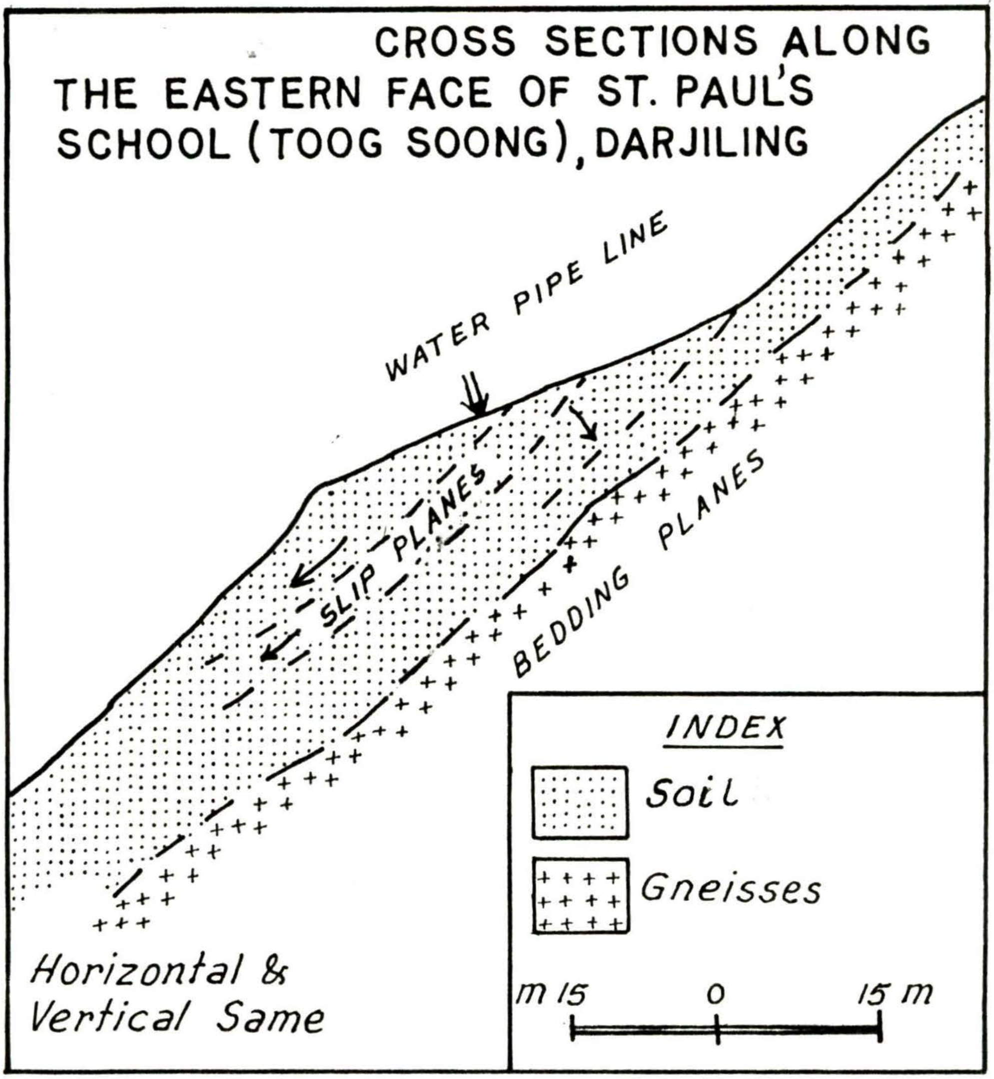
A geological map has been prepared based on the extensive field work carried out by Bandopadhyay in 1980. The investigator has made a detail geological field-work for supplementary information. The map (Fig.4.5) depicts the in-situ rock exposures and rock and soil types. Attitude of schistosity and joints have also been

GEOTECHNICAL MAP OF TOONG SOONG



Modified From Bandopadhayay (1980)

Fig – 4.7 (a)



CROSS SECTIONS ALONG THE EASTERN FACE OF ST. PAUL'S SCHOOL (TOOG SOONG), DARJILING
WATER PIPE LINE
SLIP PLANES
BEDDING PLANES
INDEX
Soil
Gneisses
Horizontal & Vertical Same
m 15
0
15 m

Fig-4.7 (b)

mentioned. Attempts have been made to classify the soil and rock samples at various places to specify their physical properties, bearing capacity by penetration resistance with cone penetrometer, unit weight determination and in-situ vein shear strength of the soil. These information are mainly gathered from the unpublished work of Bandopadhyay, 1980.

iii) Geotechnical Map analysis (Fig.4.7)

This is perhaps the most important aspect of this study. The map has been prepared with the help of a careful compilation of all available physical and cultural information of the Toongsoong slope. In this map, cut slope, land under cultivation, vacant plot, nullah course, landslips, forest, surface slope in degrees, vertical slope etc. have been depicted along with rock types.

g) Conclusions and Recommendations

It has been mentioned earlier that the primary objective of this study is to demarcate the stable areas and differentiate them from the unstable parts of the study area. The topographical map showing the slope may be zoned as follows, on the basis of the slope angles, which depict the slope morphology and indirectly reflect the stability (Table 4.6).

The above mentioned slope zones portary progressively more stable localities on the slope. Areas between 0° to 30° are the most stable parts. The zones between 30-45° also may be utilised for constructions where there are in-situ rock exposures. While, slope beyond 45° should be treated as vulnerable tracts and any urban-use must be considered after a thorough geo-engineering investigations.

4.13

The author standing near the Tonga Rd. landslip.

Table 4.6

Nature of slope stability

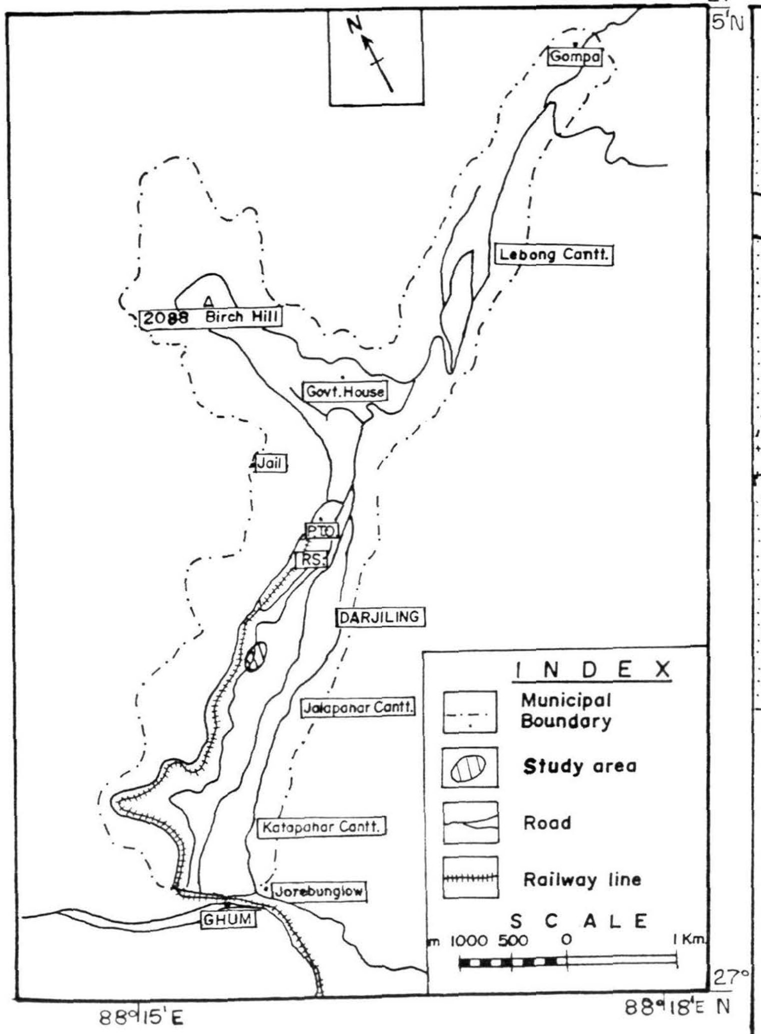
Slope angle	Nature of Stability	Recommended land-use
ASbove 60°	Unstable areas	Should be kept under nature's domain
45°-60°	Less stable areas	Very restricted urban-use
30°-45°	Stable areas	Urban-use upto 2 storeyed buildings
15°-30°	Stable areas	Intensive urban-use upto 3 storeyed buildings
0°-15°	Highly stable areas	Intensive urban-use of big structures

The investigation of materials indicate the predominance of sand fraction in soil and in debris. The bearing capacity ranges between 4.5 to 6.6 kg/cm^2, corresponding to the strength suitable for construction of three storeyed buildings (Bandopadhyay, 1980). Areas below Alma cottage (around Monpure) are composed of disturbed soil and are treated as unstable site for urban-use. Along the nullah courses spaces should be left on either side of the nullah at an angle of 45° with nullah bank, which are unstable zones for construction as there are chances of slope failure within that zone.

2. The landslip on the Tonga Road (New Road)

On the 12th July, 1993 following a heavy rain-strom of about 236.5 mm within a period of 72 hours, (recorded at the Agricultural Office, Darjiling town) the hill slopes on the left handside of the newly constructed road (constructed during 1991-92) connecting the

INDEX MAP OF TONGA ROAD LANDSLIP



GEOLOGICAL MAP OF TONGA ROAD LANDSLIP

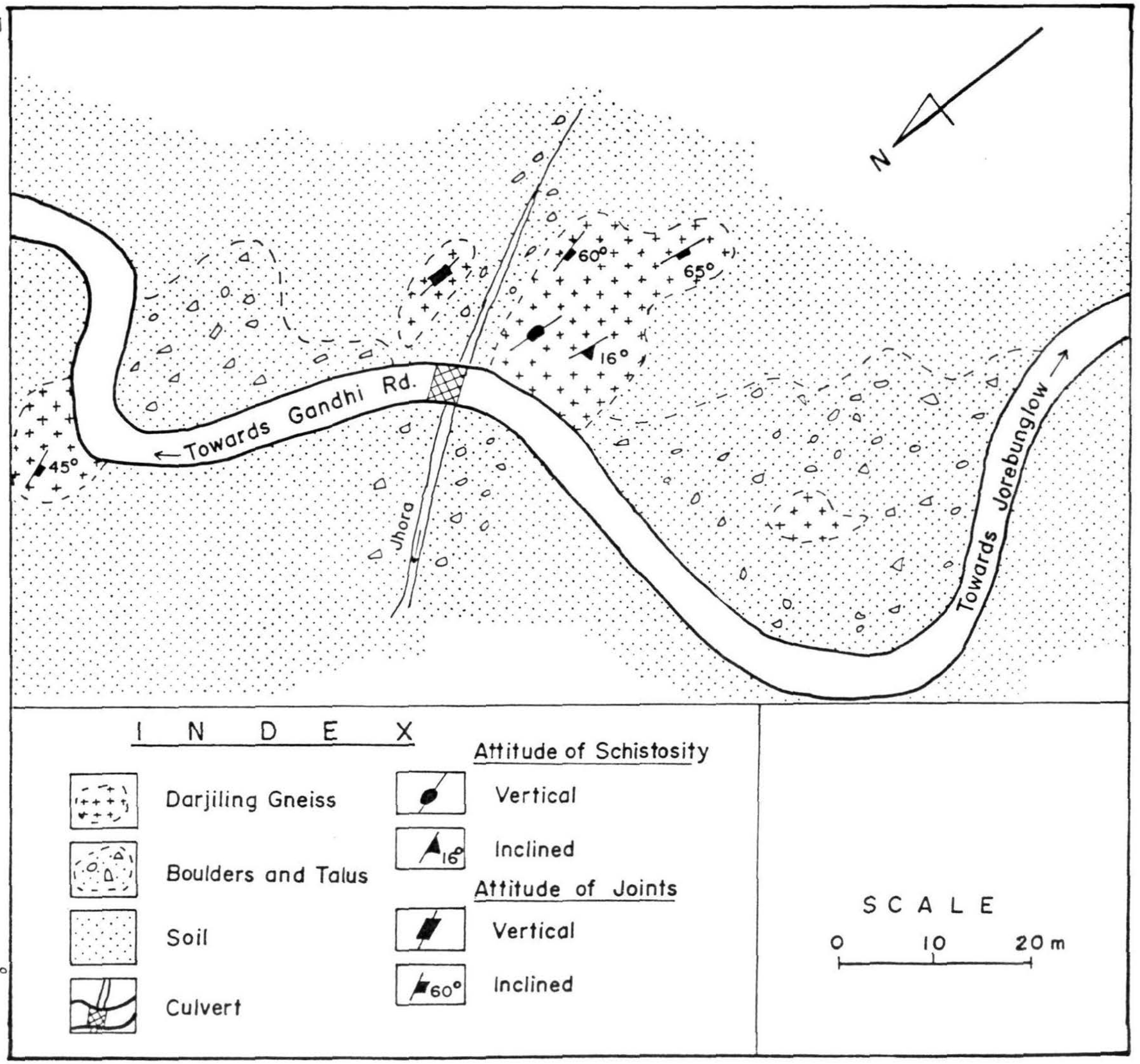


Fig — 4.8

Tonga Rd. and the old Military Rd., experienced a serious landslip, (Photo 4.13 & Fig.4.8).

a) Factors leading to slope instability

The New Rd. (Tonga Rd.) landslip has ooccurred following a period of heavy shower which therefore, appear to be the cause of the slip. But its action is more like the trigger in the gun, as it gives the last stroke when other factors have already brought the slope nearly to the point of failure. However, in the particular case, a rather common factor i.e. steepening of natural slope by the cutting of basal support for the construction of road, invites failure. The following are the important factors of slope instability (Fig.4.9).

i) Geological Factors

The region under study is composed of Darjiling gneiss varying from fresh to highly weathered rocks. The rocks are highly jointed both horizontally and vertically. Fresh rock has been noticed, south of the jhora. The main sets of joints are sub-horizontal, N-S and the inclined joints trend mainly N65°W-S65°E. The attitude of foliation is N25°E-S25°W and dip 16° towards west (Fig.4.8).

ii) Pedological Factors

In order to comprehend the nature of top soil as a factor of slope instability of the slipped area, the investigator has studied the soil and material condition under field observations. The region has thick cover of soil and talus materials. (1.5 to 1.75 metre). Materials are mostly course textured, sandy or gravelly and thus possess less cohesion. During the intensive field survey, the investigator has identified an interesting physical characteristics of the soil. Vulnerable conditions have developed at a depth of 40-45 cm. below the surface, where clay predominates with a good amount of organic matter, high water holding capacity and volume expansion.

iii) Changes in the vegetation cover

The apex of the slip under study has long been deforested and turned into settled terraces by local inhabitants. Such terraces are totally unscientific and are seldom laid along the contours with proper protection walls. Moreover, these terraces have often been cultivated with root crops and thereby further disturb the cohesiveness of soil and make it vulnerable to erosion. Thus, the slope under study, being devoid of proper vegetative mat, remain fully exposed to heavy and concentrated monsoon rain-stroms and are susceptible to both sheet and gully erosion (Basu & Sarkar, 1987).

iv) Effects of rainfall-run-off and Infiltration

In the slipped area, rain water percolates through the joints, cracks and pore- spaces of the soil materials and also through the joints of the bedrock. This increases the pore-water pressure and changes the consistency as well as the shear resistance of the soil, internal friction sets in, the soil ultimately loses its cohesion. Under such suitable circumstances, with the on set of monsoon, rill cutting as well as gully erosion starts and the slope becomes further denuded as the surface water flows through these channels.

Table 4.7

Morphology of Tonga Road (New Road) landslip

Pre-landslip conditions	Post-landslip conditions	Remarks
1. Rocks : moderate to highly jointed gneiss, N65°W-S65°E and foliated N25°E-S25°W and dip 16° towards west. 2. Altitudes : 2182-2208 metres 3. Slope : Convex, 35-41° 4. Rainfall : 236.5 mm 5. Natural Vegetation : grass with scattered shrubs and bushes. 6. Land-use : scattered houses and cultivated terraces 7. Soil colour : 5 Yr 3/1. 8. Soil is saturated with water.	1. Length of the scar: 12 m 2. Width of the scar: Max. 27 m Average 6 m 3. Depth of the scar: Max : 1.8 m Min : 0.3 m Average : 1.05 m 4. Shape : Recti-linear 5. Total area affected: 372 sq m 6. Total volume displaced : 380.6 m^3 7. Processes primarily responsible for slip: Removal of basal support by road cutting. 8. Modified slope: Concave; 40-65° 9. Type of slip: Debris slide	Displaced materials temporarily disrupted road communication. It has also endangered the settlements and terraced fields nearby. Immediate construction of a protected walls with adequate drainage are recommended.

*Compiled and processed in the above form by the investigator from the data collected from the field.

CONTOUR PLAN OF TONGA ROAD LANDSLIP

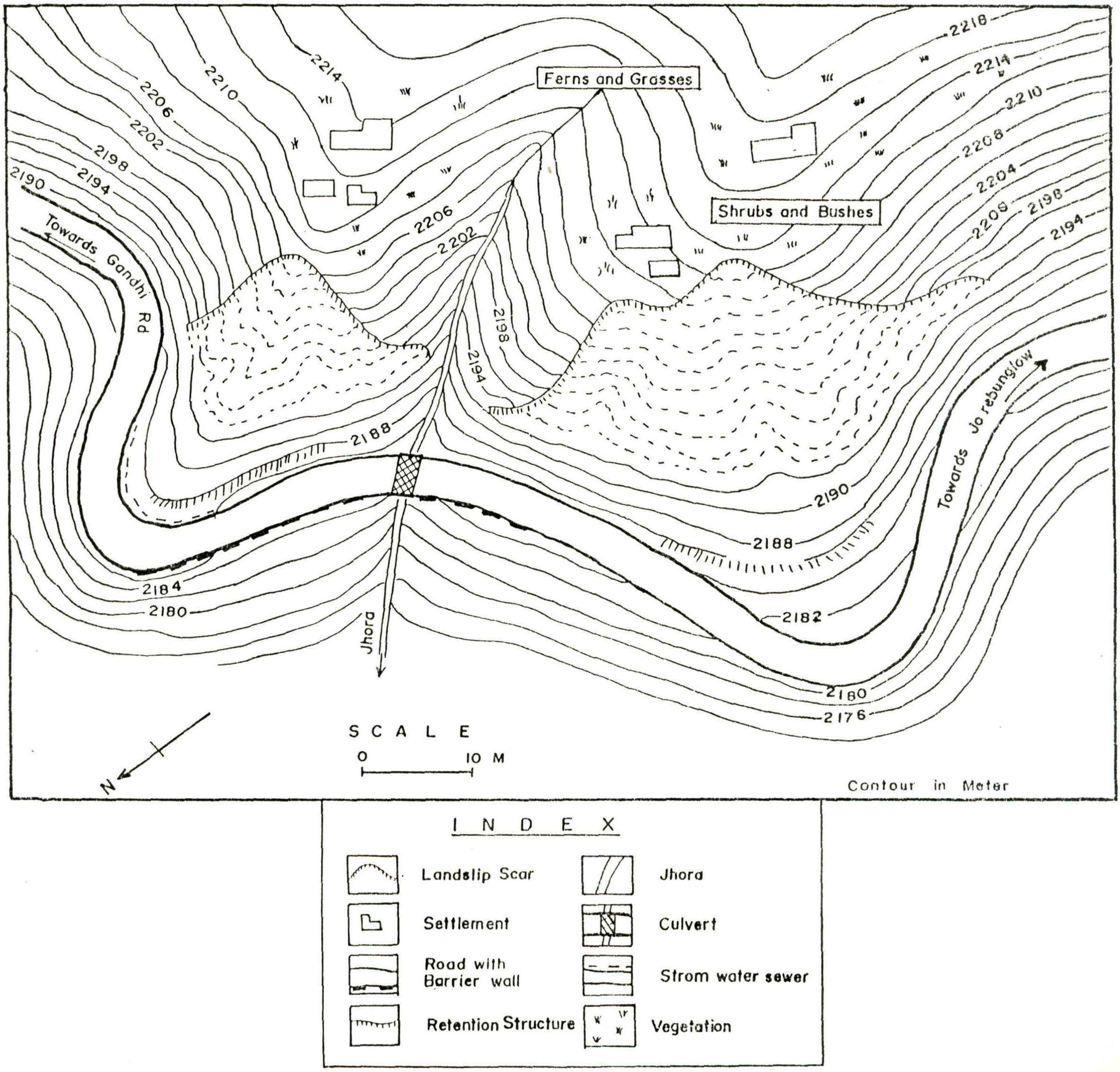


Fig-4.9

v) Effects of Human Interferences

Urban explosion invites massive traffic congestion and the existing roads of the study area have not been able to keep pace with the ever expanding vehicular traffic. Construction of New roads become inevitable. The road under study was constructed recently (1991-92) with modern geo-engineering knowhow. Yet, such a construction needs massive cut - and - fill of hill slopes. Road cuttings often invite steepning of hill-slope vis-a-vis removal of basal support. Such human interferences readily ruptures the slope stability to a large extent by removing the basal support and sets the stage ready for further erosion havocs.

b) Morphometric Analysis

A detail morphological account of the pre and post slip conditions of the area is given in Table 4.7 to follow the exact sequence of the disaster in order to arrive at a logical working of remedial measures.

c) Recommended Corrective measures

The first step in corrective efforts should be to construct retaining walls at the base of a slip with a good drainage system. The slopes above the walls should be so constructed as to allow a gentle gradient as far as possible. Afforestation is a must to prevent uncontrolled infiltration and run-off, as suitable sapling should be planted on these slopes to check an appreciable amount of soil erosion. The triggering problem that is unique in this landslip, however, will not be easily solved i.e. the New Rd. must be there, so the cutting of basal support will always remain dormant in this area. However, the unscientific terracing and housing at or near the crown of the slip should be controlled immediately to restrict the gully erosion.

G. PREVENTIVE MEASURES

The stabilization of landslips and landslip-prone areas must be executed according to a well thought-out plan, which lists individual measures according to their urgency. The following points should be considered before initiating difficult and expensive stabilization work :

a) The effects of a particular preventive measure changes with the engineering geological conditions of the site.

b) The choice of the techniques that are to be applied for prevention of the slope movement is also influenced by several aspects of economic character.

c) The local conditions of the site play a dominating role in assuring the stability of potential slip-prone area.

d) The importance of the project also influences the measures to be taken to tackle this problem.

It is important to distinguish between those physical characteristics of a site which make landslip possible and the actual cause i.e. the trigger mechanism. In the study area, it has been found that the "increase in pore-water" pressure or rise in "piezometric head", constitute the trigger mechanism for initiating a slip. Potentially most unstable hill slopes are also sensitive either to an increase in the load which they bear at the top or a decrease in the amount of support which they have at the toe. To recognise which of these causative factors, is in operation can in itself suggest the cure. Thus, the principles to be observed in suggesting preventive measures would naturally depend upon the causes that lead to the failure of a slope. The investigator has suggested the following preventive measures against slope failures in and around Darjiling Town :

i) Treatment of slope conformation, ii) The drainage of landslips, iii) Retaining walls and similar structures, iv) Stabilization of landslips by afforestation, v) Stabilization of landslips by piles and sheet-pile.

Of these the most important are the construction and maintenance of retaining walls and slope stabilisation by afforestation and these have been elaborated in the following lines.

iii) Retaining walls and similar structures :

Retaining walls are erected to bring greater stability to the unstable slopes and to check the existing landslips. Construction of retaining walls become necessary specially in slopes formed on clayey soils where it is difficult to ensure drainage due to the impermeability of the materials.

In Darjiling town, most of the houses and different road sections are protected by retaining walls. They are mostly built of dry rubble masonary. Some of these walls which are built of reinforced concrete have failed due to lack of adequate design. The retaining walls are found to be very weak in the congested busty areas i.e. Toongsoong, Bhutia busty, Kagjhora, Dhobi tala, Butcher busty and in Singamari areas, where landslips are common and these walls are not based on proper foundation. Such retaining walls instead of affording any protection, actually contribute to the failure of the slope due to the addition of extra weight. Another important cause of this failure is the seepage pressure. Thus, the retaining wall should have proper weep-holes for draining out the accumulated water without intervention. Proper and periodic maintenance should be made, so that such an outlet can never get clogged. The weep-holes in the masonary walls are often found to be chocked with fine materials infiltrating from the soil at the back of the walls and hence, the basic purpose becomes impared. Moreover the fragment of rocks used for the construction of these walls are of heterogeneous in nature with the removal of the cementing materials softer varities of rock get eroded quickly, and thereby creating gaps in between. Water percolating more fully through these gaps destabilise the whole structure above quickly. (Photo 14a)

Therefore, in future retaining walls should be built on improved design. Proper weep holes can be provided by embedding rows of 10 cm. diameter pipes through the masonary. The spacing of the rows and also the intervals between the holes should be about 1.5 to 2.0 mts. crushed stones should be placed in and around the intake end of each pipe to prevent blockage of the weep holes. Proper amount of quality cement should be used along with sand to plug the gaps in between rocks.

iv) Stabilization of landslip-prone areas by Afforestation :

Slope movements generally disturb the vegetation cover including grass cover. Afforestation of the distrubed slope is an important part of any corrective treatment and it should be carried out during the later stages of the work, invariably after at least some degree of stabilization of the slip has been achieved. The plantation should be proceeded by drainage along with the filling up the cracks of the affected area. Being an urbanised area, Darjiling town has a very limited scope for any large scale afforestation programme. However, the investigator has recommended the use of grasses, shrubs and bushes followed by trees for the gradual stabilization of vulnerable slopes. In this context the author has particularly recommended one local species of Fern locally known as "Welcome Fern" (Gleicheria Linearis) for highly vulnerable areas. During the intensive field study the investigator saw that the steep slopes along the northern face of Lebong Cart Rd. and along the Hill Cart Rd. towards Ghum lacking in slips are covered by the "Welcome Fern" (Gleicheria linearis). (Photo 4.14b)

H. RECOMMENDATIONS FOR ANY FURTHER URBAN EXPANSION IN DARJILING TOWN

One of the basic aim of this chapter is to demarcate the stable areas from the potentially unstable slopes within the town, so that the local government along with the citizens can restrict the construction of buildings and massive structure within the stable zone. This has been done on the basis of the identification of landslip-prone areas and the study of individual slips within the town. The distribution of slips all over the study area (Photo 4.8 & 4.11) indicate that there is no portion, except the top of the ridge that is stable, against slips so a strict enforcement of the above idea is not feasible but, it is possible to demarcate areas according to a compartive stability.

It has been found that the eastern slopes of Darjiling ridge and the spurs are steeper and the boulder cover on them extends nearly upto the crest. As the incidence of slips on these slopes are higher and their magnitude greatest, there would be more destruction to man-made structures. While, the soil-covered slopes on the other hand, show a comparatively less incidence of slips. The western slopes of the ridges and spurs are comparatively more stable than the eastern slopes (Photo 4.15 & 4.16). In the western slopes, however, the debris cover is fairly thick below the Hill Cart Rd. and the Victoria Rd., where gradient is also steeper. So the construction of buildings along these slopes should be stopped.

The construction of new urban structures should be restricted or preferably stopped in the following areas :

a) Slopes below the road between the Jalapahar Rd. and Tenzing Norgay Rd. and below the T.N. Rd.

b) Slopes below C.R. Das Rd. and Rangit Rd.

c) Slopes below east Birch Hill Rd. between C.R. Das Rd. and Hermitage.

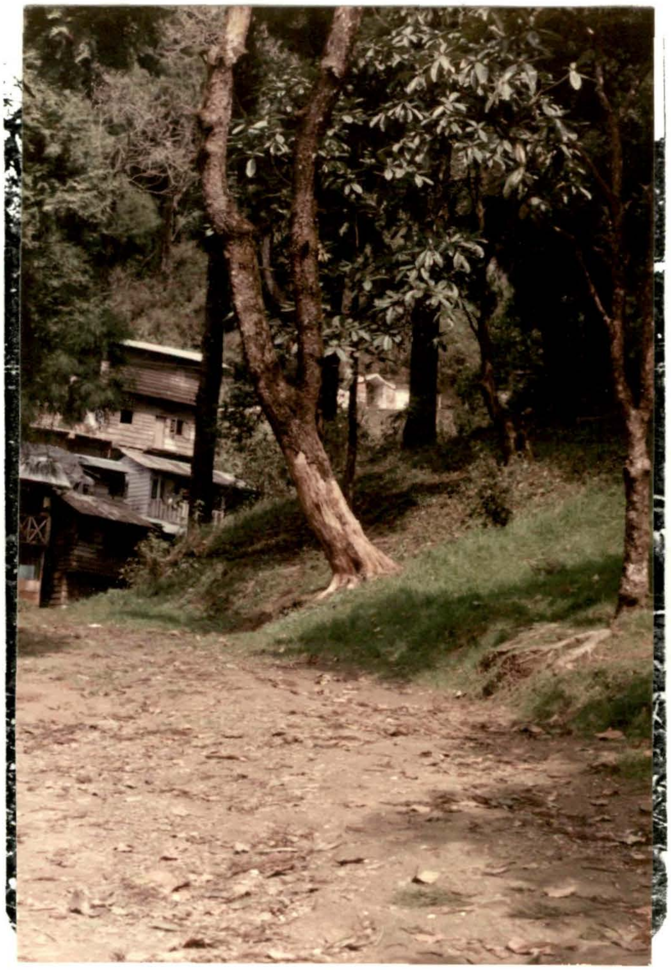
d) Slopes above and below the Birch Hill Rd. from Hermitage Rd. to Roy Villa.

e) Slopes below the Hill Cart Rd., Victoria Rd., above Lebong Cart Rd. and below Lebong Circular Rd.

f) Slopes along the Lochangar Rd.

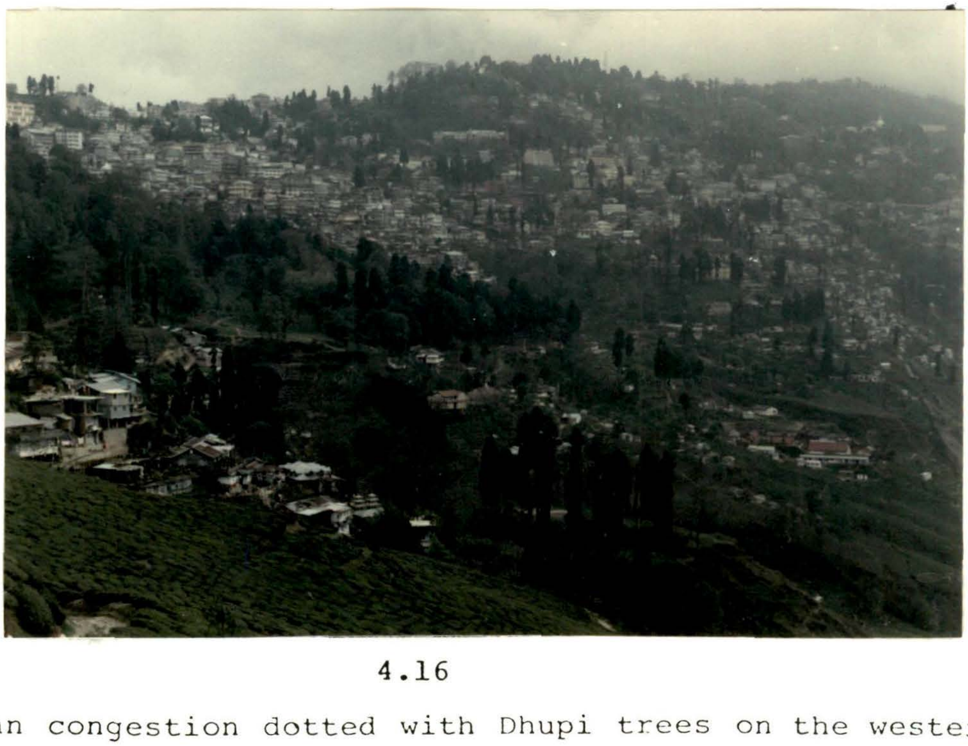
g) Slopes along R.N. Sinha Rd. and Uday Chand Rd.

The recommendations made here should be treated as provisional one, as there may be some stable patches found within the so-called unstable areas. Sometimes construction of a structure



4.15

Creeping slopes of the Botanical Garden with leaning trees.



4.16

Urban congestion dotted with Dhupi trees on the western spur of the Jalapahar - Birch Hill ridge.

within such zones may be absolutely necessary. Under such circumstances, they should be provided with proper revetment walls. Thick shrubs and undergrowth should be grown within these unstable areas.

The pipe line for the water-supply of the town are aligned along the eastern slope, just above the Jalapahar Rd. Slips have damaged and twisted the pipes at various places, causing temporary stoppage of water-supply. The G.S.I. scientists have surveyed this problem and recommended some preventive measures (Dutta, 1966). According to them, such damages to the pipes can be prevented by burying them underground. But, this would be costly and would not be possible for frequent inspection. The re-alignment of pipes along the western slope would be helpful. This again would be costly and it is doubtful whether such expenditure will be justified as the periodicity of such disastrous slips is infrequent. However, some protective measures should be provided to the pipe lines across the existing slip channels in order to protect them against the impact of falling materials ranging from stray boulders to slips affecting the walls of channels. Here the pipes should be supported on braces so that the channel is left free from the movement of the rolling debris.

According to Auden (1951) the narrow drains extending only a few feet down the hill side from Jalapahar-Katapahar may have helped in the seepage and thereby potential instability. He has recommended that 'pucca'* drains wide enough to pass the strom discharge should be taken down from the top to the bottom of the

*Cemented and plastered.

4.17

An old septic tank with eroded out-lets above the Victoria Rd.

4.18

People carrying illegally felled woods in Tiger Hill.

lower level of the town. The investigator has also found many un-plastered sewars in many parts of the town (Photo 4.17) and has recommended plastered sewars for the strom-water disposal system.

In the busty (slums) areas, especially Bhutia busty, Toongsoong, Alubari, Manpari busty, Butcher busty, Kagjhora etc., the greater incidences of slips is mainly due to bad drainage system through unplastered sewar, unscientific and badly managed terrace cultivation around the houses aggravate the soil-erosion also. Low, badly designed and poorly constructed revetment walls also assist the slips instead of providing protection against them. Hence, measures should be taken to ensure wider spacing of houses, with suitable revetment walls and proper drainage system.

I. CONCLUSIONS

In view of the ever increasing problem of landslips in Darjiling town, man must be made aware of the possible dangers that he is inviting, due to his careless dealing with nature. It is true that one has to make room for the growing population and in this persuit he has to utilise every piece of land available. But the precautions that have to be adopted should not be neglected. In the town, the revetments are not maintained properly, the weep-holes are chocked. The drains are dumped with garbage, restricting free drainage of water. More over the present landuse system should be properly evaluated. The construction of high rise buildings should be stopped immediately. The people should be provided with some alternate source of energy through construction of Mini-hydel projects utilising the springs which can be the only option to prevent them from cutting down more trees. But above all it is of utmost priority to develop mass awareness among both the local people and the tourists, so that they become aware of the possible dangers that they are inviting by interfering with the natural laws.

J. REFERENCES

Ananda Bazar Patrika of 4-7-93. p.3.

Bandopadhyay, M. (1980). Progress Report on slope stability of Tungsung Area, Darjiling Town, unpublished G.S.I. Report.

Basu, A.R. (1969-70). A Geotechnical note on investigation of certain stretches of border roads under project Swastik in Sikkim and Darjiling district, West Bengal, unpublished G.S.I. Report.

Basu, S.R. and Sarkar, S. (1984). Eco-system vis-a-vis landslides - A case study in Darjiling Himalayas, Proceedings of the National Conference on Impact of Development of Environment. Geog. Soc. of India, Calcutta pp. 45-53.

Basu, S.R. and Sarkar, S. (1985). Some considerations on recent landslides at Tindharia and their control; Indian Journal of Power and River Valley Development. 188-194.

Basu, S.R. (1986). "Darjiling Himalayas : A case study of the Effect of modernisation". The Eastern Himalayas : Environment and Economy. pp.89-95.

Basu, S.R. and Sarkar, S. (1987). Ecosystem vis-a-vis landslides - A case study in Darjiling Himalayas, Impact of Development on Environment, 2. 45-53.

Chatterjee, A. (1986). A Survey on the Occurrence of Landslide and their Impact on the economy of Darjiling district. R.L. Sarkar, Lama, M.P. (ed) The Eastern Himalayas. pp.74-87.

Dutta, K.K. (1966). Landslips in Darjiling and neighbouring hill-slopes in June, 1950, Buliten G.S.I. Series B, 15(1); 7-30.

Ghosh, A.M.M. (1950). Observation of the landslides of the 11th and 12th June, 1950, in the Darjiling Himalayas, unpublished G.S.I. Report.

Griesbach, G.L. (1899-1900). General Report, G.S.I.

Nautiyal, S.P. (1951). A geological report on the hill-slopes stability in and around Darjiling. W.B. unpublished Report G.S.I.

Nautiyal, S.P. (1966). On the stability of certain hill-slopes in and around Darjiling. W.B. Bulletin G.S.I. Series. 6(1), 31-48.

Paul, D.K. (1973). Report on Geotechnical Investigation of hill-slope stability and alignment of border road under project Swastik in Darjiling district W.B. and Sikkim, unpublished G.S.I. Report.

Roy, S. and Sensharma, S.B. (1967). Geological report on the stability of hill slopes in and around Darjiling town, Darjiling district, W.B. unpublished G.S.I. Report.

Roy, S. and Sensharma, S.B. (1986). "Application of Slope Analysis to the problem of Landslide investigation". Jour. of Engineering Geology. pp.12-19.

Sarkar, S. (1990). A Geo-environmental apprasial of the upper Mahananda Basin, Darjiling Himalaya, West Bengal, unpublished. Ph.D. thesis.

Sinha, B.N., Verma, R.S. and Paul, D.K. (1975). Landslides in Darjiling district (W.B.) and adjacent areas, Bulletin G.S.I. series B-36; 1-45.

Sondhi, V.P., Hazra, P.C., Dutta, K.K., Nautiyal, S.P., Dutta, S.M. and Jain, M.S. (1966). Landslides and hill-side stability in the Eastern Himalaya, Bulletin G.S.I. Series B-15, 1-117.

Starkel, L. (1972). "The role of Catestrophic Rainfall in Shaping the Relief of the Lower Himalayas (Darjiling Hill)" Geographia Polonica. 21. pp.105-113, 114-116, 119, 125-129, 137-138.

Verma, R.S. (1978). A note on the geotechnical investigation of the stability of hill slope along stretches of border roads in Sikkim and Darjiling district, W.B. unpublished G.S.I. report.